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Resilient Concrete Structures

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BOOK OF ABSTRACTS

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Resilient Concrete Structures

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Editors
Rick Henry
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fib Model Code 2020: Empowering Sustainable Concrete Solutions with Future-Oriented Standards

Dr Agnieszka Bigaj-van Vliet

Keynote Session 1, Auditorium, November 11, 2024, 9:30 AM - 11:00 AM

In the context of urgent sustainable development, codes of practice could play a crucial role in advancing sustainable solutions. Unique in its blend of academic excellence and practical rationality, the fib Model Code 2020 aims to drive innovation amidst rapid technological advancements. To serve as a catalyst for mainstreaming innovative practices, it provides comprehensive provisions for design, construction, operation, and circular usage in concrete engineering. The sustainability-oriented framework of the Model Code facilitates the integration of cutting-edge concepts and technologies - such as new material solutions, advanced structural models, data-informed assessment, and integrated life-cycle management - into sustainable practices for both new and existing structures. Through its forward-looking perspective, the fib Model Code 2020 accelerates the widespread adoption and acceptance of these advancements for enhancing the resilience and sustainability of concrete structures, establishing itself as a as key benchmark for code writers worldwide.

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Design, implementation and monitoring of TMD in Shanghai Center Tower under wind loading

Xilin Lu

Keynote Session 1, Auditorium, November 11, 2024, 9:30 AM - 11:00 AM

This presentation introduces a newly developed eddy-current Tuned Mass Damper (TMD) to reduce vibration response of building structures under wind loading and seismic event.

Firstly, the mechanism of the eddy-current TMD was investigated through experiment and theoretical analysis. Then free vibration test was carried out to study the dynamic properties of the eddy current TMD, such as damping value, dependence on the distance between the magnetic body and the copper plate, and relationship with frequency.

Secondly, shaking table model test with the eddy-current TMD attached was carried out to study the overall vibration reduction effect and the test results show (1) the EC TMD can effectively reduce the displacement response of primary system with a small weight M (1%-2%) by 40%, and the RMS values of acceleration response of the top floor were reduced up to 60%. (2) The EC TMD system is a simple and reliable damping system, which has high sensitivity, stable performance, good endurance and energy dissipation ability, and can be used for response control of tall buildings.

Finally, the eddy-current TMD was used in Shanghai Tower following a detailed study and a serious of field tests. Through optimization analysis the parameters of the eddy-current TMD were selected as follows. TMD mass: 1000 t, TMD floor: 125th, target frequency: 0.111 hz, tuning range: 95%-115%, length of suspend cable: 20.6 m.

1000 t TMD field test was done in the real building for tuning the basic frequency of the EC-TMD and checking the TMD free vibration characteristics. During the test, the mass block of EC-TMD was pushed to the initial displacement of 900 mm and rapidly released for free vibrations. Acceleration responses of both TMD and the 125th floor were measured along TMD moving direction.

During operation of the building, the response of the building under three Typhoon events were recorded and monitored. The results show that the EC-TMD is very effective to suppress the wind response and make the building in comfortable service condition.

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Future Directions in Seismic Design, Assessment, and Construction Practices: Insights from the February 2023 Türkiye Earthquake Sequence

Professor Alper İlki[1], Ali Osman Ates[2], Caglar Goksu[1], Kutay Orakcal[3], Koichi Kusunoki[4]
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Plenary Session 1, Auditorium, November 11, 2024, 11:30 AM - 12:30 PM

In February 2023, Türkiye experienced a series of earthquakes that had a profound impact on 11 provinces, affecting a population of over 14 million. These seismic events resulted in extensive devastation, particularly, affecting more than 90,000 reinforced concrete (RC) structures severely causing heavy damage or collapse. Subsequent reconnaissance investigations revealed that there were structural inadequacies similar to those observed in previous seismic events, including improper arrangement of structural systems, poor quality of construction materials and insufficient reinforcement detailing leading to insufficient stiffness, ductility and strength. Notably, besides these shortcomings, it was observed that several newer medium-rise buildings (8-12 stories) designed assumingly according to the recent seismic design code (and the recent seismic risk map) underwent heavy damages and collapses. In some cases, such new mid-rise buildings exhibited a complete overturning due to heavy damages of structural members at the first story, whereas in some other cases pancake-type collapses were observed, as was commonly seen after previous earthquakes in Türkiye. This study provides insights into seismic design, assessment, and construction practices, including considerations for new and medium-rise structures in the light of observations made in the aftermath of the Kahramanmaraş earthquakes. Furthermore, it was observed that the spectral accelerations calculated from measured strong ground motions were significantly higher than the elastic design spectral accelerations at some stations along certain ranges of periods. Therefore, the paper also initiates discussions on why many structures, despite being subjected to substantial demands for strength and ductility, did not collapse. The ratios of estimated seismic demands and structural capacities, and discussions on the observed performances of structures are presented.

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Recent achievements and future perspective in Japanese national model code for concrete structures in civil engineering field: introduction of JSCE standard specifications for concrete structures

Takumi Shimomura

Plenary Session 1, Auditorium, November 11, 2024, 11:30 AM - 12:30 PM

The Japan Society of Civil Engineers (JSCE) Standard Specifications for Concrete Structures are one of the Japanese national codes and standards for concrete structures in civil engineering field since 1931. In response to changes in social circumstances and technological advances, revisions have been made approximately every five years. The JSCE Standard Specifications have not only seen application in the design, construction, and maintenance of concrete structures but have also served as guidelines for research and technological development, even influencing education and human resource development. Considering international publicity, English summary edition has been published recently. History, characteristics, recent achievements, and future perspective of JSCE standard specifications are introduced.

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In-the-field Experiences and Research into the Development of Seismic Design Requirements of Concrete Structures in New Zealand: drivers, expectations, and outcomes.

Des Bull

Keynote & Plenary Session, Auditorium, November 12, 2024, 8:30 AM - 10:00 AM

The development of structural design requirements and later structural assessment guidance for reinforced concrete (RC) structures in New Zealand will be described. The preferential use of precast concrete in beams, columns and walls occurred during the 1980s and 1990s. The precast structures were detailed to emulate cast-in-place RC structures.

The positive performance of well-designed and detailed RC elements and systems was born out in the New Zealand earthquakes of the Canterbury Earthquake Sequence of 2010 and 2011 and the Kaikoura Earthquake of 2016. The structural strategies for reliable and predictable performance in earthquakes will be briefly discussed.

One aspect of concern in the seismic performance is the use of pretensioned, precast concrete floor units. These are typically topped with cast-in-place concrete. Concerns about the fragility or lack of robustness of precast floor units such as hollowcore units (without supplemental shear reinforcement) were confirmed after the Northridge Earthquake of 1994 (the collapse of the Meadows Apartments car parking structure). Research into the performance of hollowcore floors started in New Zealand in the mid-1990s. Numerous small subassemblies and large sub-assemblies (all full scale) were tested mainly at the University of Canterbury (UoC) in the first years and later at the University of Auckland (UoA). This University research led to several changes to the NZ Design Standard: NZS 3101:2006, and the further development of the guidelines for assessing the seismic performance of existing RC building incorporating hollowcore floors - MBIE, NZSEE, EQC, NZGS, and SESOC, 2018. "Technical Proposal to Revise the Engineering Assessment Guidelines - Part C5 Concrete Buildings" pp. 252. Wellington, New Zealand: Ministry of Business, Innovation, and Employment.

A recent and major collaborative research programme between UoC, UoA and BRANZ, funded by BRANZ, EQC, QuakeCoRE and CNZLS, called the "ReCast Floors - Seismic assessment and improvement of existing precast concrete floors" has significantly updated and extended earlier seismic assessment guidance on hollowcore floors, and now includes assessment of prestressed concrete rib and timber infills with concrete topping, concrete topped Tee and Double Tee precast units, and concrete topped prestressed concrete flat slabs. An outcome of the decades of research was, in effect, the removal of hollowcore units as an "design solution" as details for supporting the hollowcore were now no longer acceptable via the NZ Building Code.

In parallel to investigating issues with precast floors in conventional reinforced concrete structures, research into seismically resilient concrete structures was on going. Structures that could resist larger earthquakes and are reoccupied and functioning in the matter of days, if not hours. The development of very low damage RC structural systems will be highlighted, including very positive outcomes of shake table tests from a recent ILEE-QuakeCoRE New Zealand-University of Tongii collaboration.

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Preserving the Past, Securing the Future: The Seismic Retrofit of Te Matapihi - Wellington Central Library"

Mr Tony Holden[1], Ms Jess De Barr[2], Mr Adam Thornton[3]
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Keynote & Plenary Session, Auditorium, November 12, 2024, 8:30 AM - 10:00 AM

This paper details the seismic retrofit journey of Te Matapihi ke te Ao Nui - Wellington Central Library, an iconic facility which forms an integral part of Wellingtons Te Ngākau Civic Precinct.
In March 2019, Wellington City Council (WCC) closed Te Matapihi based on critical structural vulnerabilities identified that could significantly impact the building's life safety performance during a moderate earthquake. Following an extensive consultation process WCC committed to the refurbishment and seismic strengthening of Te Matapihi.

As a heritage-listed building the strengthening solution needed to be sympathetic to its architectural integrity, while providing a highly resilient, functional and future ready facility. The introduction of a retrofit base isolation system was fundamental in achieving this objective.

The structural design conducted by Aurecon employed advanced engineering techniques to inform the selection and implementation of a customised base isolation system. This system was tailored to Te Matapihi's unique structural and architectural features.

The main Contractor, LT McGuinness, has played a pivotal role in developing practical and buildable solutions. They have devised a safe and efficient construction methodology, addressing the many challenges and complex construction sequences, including the installation of base isolators, reinforcement of key structural elements, and the use of innovative fabrication techniques. Temporary works have been a significant issue during both the design and construction phases, to enable all columns to be temporarily separated from their foundations, and to maintain global stability. Temporary support structures, bracing systems, and strategic construction sequences developed by Dunning Thornton have maximised construction efficiency, minimised disruptions and prioritized safety.

This paper discusses the challenges encountered during construction, the devised solutions, and lessons learnt.

Te Matapihi represents a successful integrated multi-disciplinary team approach, focussed on the goal of delivering and preserving a cultural icon and national Taonga, fostering a sustainable and resilient future for Wellington's architectural heritage.

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Enhanced Seismic Resilience: A Pathway to the Wider Implementation of Dissipative Controlled Rocking in Bridges

Dr Brandon McHaffie[1], Dr Sabina Piras[1], Dr Royce Liu[1], Mr Peter Routledge[1], Dr Alessandro Palermo[2]
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Keynote & Plenary Session, Auditorium, November 12, 2024, 8:30 AM - 10:00 AM

Extensive research and development have been dedicated to Dissipative Controlled Rocking (DCR) Connections, derived from the PRESSS system, and their applica-tion to bridges. This research consistently demonstrates benefits in terms of resili-ence, robustness, recovery, and even indicates potential economic advantages under suitable circumstances. However, despite these demonstrated benefits, there hasn't been broader consideration or implementation of this technology. To facilitate the transition of DCR technology from the realm of research to practical implementation in New Zealand, a Low-Damage Design Guide is presently under development. Fo-cused on the innovative DCR technology, this comprehensive guideline consolidates years of research and presents a robust design framework, including guidance on numerical modeling, to facilitate its widespread adoption such as increased costs and constructability challenges.

This paper will draw from key developments within the guide, intending to address persistent challenges hindering the widespread adoption of this technology. Notably, the paper will articulate a new design philosophy applicable to low-damage bridge design. This philosophy aims to allow the optimisation of the DCR system, thereby unlocking the inherent benefits of incorporating DCR and other similar low damage systems. Furthermore, it provides guidance on design scenarios where using DCR connections could have significant benefit including similar construction costs com-pared to more conventional design strategies. Finally, previously encountered detail-ing challenges will be discussed, with solutions to address these challenges pro-posed.

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The future of design standards – has simplification become unaffordable?

Steve Denton

Keynote Session, November 13, 2024, 8:30 AM - 10:00 AM

Design standards play a fundamental role in the construction sector, impacting the activities of civil and structural engineers around the world. Against a backdrop of increasing length and complexity, over the years there have been many calls for design standards to be simplified. Using the evolution of the structural Eurocodes as an exemplar, which the author has led for the past decade as Chair of CEN/TC 250, the root causes for the changing character of design standards will be examined and the potential risks and consequences of a misdirected drive for simplification will be explored.

Recommendations to mitigate these risks and enable user-orientated standards to be developed will be presented drawing upon the CEN/TC 250 focus on enhancing ease of use, fib Model Code 2020 level of approximation approach and the future digital development and consumption of design standards.

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Models and Standards for Simulating the Earthquake Response of Flexure-Controlled Reinforced Concrete Walls for Design and Evaluation

Dr Laura Lowes

Keynote Session, November 13, 2024, 8:30 AM - 10:00 AM

Reinforced concrete walls are stiff, strong, easily configured to meet architectural constraints and structural requirements, and cost competitive. Additionally, slender walls exhibiting flexure-controlled response can be highly ductile and exhibit significant energy dissipation under cyclic loading. As a result, flexure-controlled walls are one of the most common lateral-load resisting systems found in new and existing buildings around the world. They are also one of the least standardized systems found in building construction, with many walls taking on unique cross-section and/or vertical configurations to accommodate specific architectural, structural, and mechanical requirements. Regardless of the complexity of the wall configuration and reinforcement layout, engineers are required to determine the stiffness and strength of the wall; additionally, in regions of high seismicity, engineers are often required to represent the deformation capacity, residual strength, and cyclic response of the wall to support the design of a new special structure or the evaluation of an existing structure. Thus, engineers require accurate, robust, and computationally efficient modeling tools that are easily integrated into design-office workflows as well as standards for conducting analyses to determine wall demands, capacities, and response histories.

The evaluation, calibration, and validation of models for use in simulating the earthquake response of flexure-controlled reinforced concrete walls to support building design and evaluation has been the focus of many research efforts for many years. This lecture presents the results of research conducted by the speaker and her collaborators as well as others addressing these topics with the objective of identifying the strengths, weakness, and range of applicability for models included in software platforms that are used commonly by practicing engineers and researchers. Given that assessment of collapse risk is often a primary goal of nonlinear earthquake response analysis, accurate simulation of the onset of strength loss is specifically included in this review. The lecture will conclude with a discussion of current US standards for nonlinear response modeling for evaluation of existing, and design of new, flexure-controlled concrete walls as well as ongoing American Concrete Institute (ACI) activities addressing these topics.

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Acceleration strategies to increase the early strength of concrete

Professor Horst-Michael Ludwig

Plenary Session 2, Auditorium, November 13, 2024, 3:30 PM - 4:30 PM

Accelerating concrete hardening can be desirable for various reasons. In the area of precast concrete, high early strengths lead to a more economical process sequence with effective use of the sometimes very expensive formwork materials. In ready-mixed concrete, rapid concrete hardening can also ensure faster construction progress. In addition, there are advantages in concreting at low temperatures and curing times can be shortened.

Traditionally, highly reactive cements of high strength classes are used in combination with high cement contents in the concrete to ensure high early strengths. Accelerating admixtures based on soluble calcium salts (calcium formate, calcium nitrate, calcium nitrite, etc.) are also often used. In precast plants, energy-intensive heat treatment is also used in some cases.

In the meantime, new approaches for accelerating concretes have been developed that increase the effectiveness of acceleration and improve the controllability of the acceleration processes. The approaches presented below are based on internal activation of the initial hardening process through the addition of C-S-H seeds on the one hand and external acceleration through power ultrasound on the other.

Calcium silicate hydrates (C-S-H) are the main reaction product between cement and water. They are largely responsible for the development of strength in the concrete structure. The formation of the C-S-H phases is based on a crystallisation process, which naturally begins with the formation of the first homogeneous or heterogeneous crystal seeds from the supersaturated solution. A normal concrete requires several hours to form the first C-S-H seeds. During this time, the concrete sets but does not yet harden. Only with the growth of the C-S-H seeds are gaps in the structure bridged and a measurable strength builds up. Accelerated strength development can be achieved if this initial time-consuming nucleation process can be skipped by the targeted addition of synthetic C-S-H seeds. In contrast to other hardening accelerators, which directly influence the composition of the pore solution and often endanger the corrosion protection of the steel reinforcement, this hardening acceleration is based on the rapid growth of new C-S-H phases on the surfaces of the added C-S-H seeds. With this acceleration system, the hardening process can be specifically accelerated in the first 24 hours of hardening (Figure 1).

Another option for accelerating the hardening of cementitious systems is the use of power ultrasound. Power ultrasound refers to ultrasound with frequencies between 20 and 100 kHz. Conventional areas of application are the cleaning of surfaces, the dispersion and homogenisation of suspensions and sonochemistry. The potential of power ultrasound is to influence the course of chemical reactions. The most important effect in this context is cavitation (formation and dissolution of cavities in liquids as a result of pressure fluctuations). It is assumed that the short-term high pressure and temperature changes that occur during cavitation influence nucleation and crystallisation (‘hot spot theory’). In cementitious systems, the induction period of the cement reaction can be shortened by power ultrasound and the nucleation of the C-S-H phases can be shifted to earlier times.

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Towards a green concrete future: a New Zealand perspective

Professor Allan Scott

Plenary Session 2, Auditorium, November 13, 2024, 3:30 PM - 4:30 PM

Sustainable reinforced concrete (RC) construction requires many components, including: structural design, material considerations and site practice. In this talk we will explore a number of options for achieving greater sustainability in RC structures with a focus on recent New Zealand research.

Oral and Special Session

Abstracts

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Alternatives to Portland cement – can we benefit both the environment and human development?

Professor John Provis

1A Special Session: Alternative binder systems and novel processing technologies, Auditorium, November 11, 2024, 1:30 PM - 3:30 PM

The very high environmental footprint of global cement production is well known and widely discussed. However, the availability of inexpensive, reliable and durable cement-based construction materials has underpinned the enormous advances in global development and human wellbeing that have been made during the past decades. So, we need to focus on improving how we produce and use cements and concretes, to provide the infrastructure needed for high quality and healthy life while also protecting the environment and ecosystems. Central to this discussion is the role of cements in generating wastes, but also in consuming wastes, and in safely treating wastes to remove potential contaminants from the biosphere. This presentation will touch on different aspects of cement materials science and engineering, particularly focusing on non-Portland based materials, spanning from fundamental materials characterisation to discussion of durability testing and efficient materials design. The central aim of the presentation is to highlight the contributions (ongoing and potential) that the diversification of our toolkit of cements can bring to the global transition to sustainable development and environmental protection.

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The future of cement - the next steps and visions for the future

Professor Horst-Michael Ludwig

1A Special Session: Alternative binder systems and novel processing technologies, Auditorium, November 11, 2024, 1:30 PM - 3:30 PM

For generations, Portland cements have formed the basis for the successful model of concrete, a building material that shapes our environment like no other and of which around 11 billion cubic metres were used last year. Cement production processes have been constantly optimised over the decades. The resulting Portland cement is powerful, efficient and, compared to other building materials, extremely inexpensive. So why should we change anything about cement production and the cement portfolio in the future?

One reason for the necessary cement transition is the considerable CO2 emission associated with the production of classic Portland cement (1 tonne of Portland cement means approx. 1 tonne of CO2. Combined with the huge consumption of cement, this means that cement production is responsible for around 8 % of anthropogenic CO2 emissions. The production of cement therefore releases around three times more CO2 than all global air traffic.

The cement industry has developed national and international strategies to achieve climate neutrality in cement by 2050 (Figure 1). The main instrument here will be carbon capture technology. In this process, CO2 is removed from the flue gases in the cement plant and subsequently liquefied. Carbon capture and storage (CCS) involves the safe storage of this CO2 - preferably in the seabed. Carbon capture and use (CCU) takes a different approach, in which the CO2 is used for further processes, such as the production of climate-friendly fuels (refuels) or the extraction of pozzolans from the carbonation of recycled materials.

Another key factor will be the further reduction of the content of clinker in cements. Classic Portland cement has already disappeared in many areas in Europe. In Europe, it has mostly been replaced by CEM II composite cements, in which clinker substitution of up to 35 wt.-% is possible, or in some cases by CEM III/A blast furnace cements with an average blast furnace slag content of up to 50 wt.-%. The future strategy of further reducing the content of clinker in mass cement is not only associated with challenges on the technical side (early strength, durability, corrosion protection of the metallic reinforcement, etc.), but also with open questions regarding the future availability of reactive clinker substitute materials. In addition to traditional materials such as granulated blast furnace slag and fly ash, whose usable quantities will decrease in the future, alternatives are needed. Calcined clays, in particular, but also natural pozzolans and modified steelworks slags are suitable here.

Work is also ongoing on new low-CO2 binder systems that are not based on classic Portland cement clinker. But many of these alternative binders do not have the potential to be used as a mass-produced building material. However, MgO-based binders could really be the big game changer here.

There is an incredible amount of magnesium silicates in the earth's crust and it is now possible to produce CO2-neutral or even CO2-negative binders from them.

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Alternate pathways to decarbonize cement & concrete industry

Dr Vineet Shah[1], Dr Milap Dhakal[1], Dr Allan Scott[2]
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1A Special Session: Alternative binder systems and novel processing technologies, Auditorium, November 11, 2024, 1:30 PM - 3:30 PM

Reactive MgO-based binders offer a promising alternative to conventional Portland cement-based binders, potentially resulting in a lower carbon footprint. The combination of reactive MgO and silica (M-S-H binder) has garnered significant interest due to its performance characteristics as a binder, contributing to overall mechanical and durability properties in the long term. However, the application of M-S-H binder is limited by its slower strength development in the early stages. This study explores the effects of adding different alkali anions on the early hydration characteristics of the M-S-H binder. The results obtained indicate the possibility of enhancing the development of hydration products and improving the early age characteristics of the M-S-H binder.

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Transforming Gold Mine Tailings into Sustainable Concrete

Mr Kushal Ghosh[1], Mr Balasubramanian Elankumaran[1], Ms Ashmita Kumar[1], Dr Kim de Graaf[1], Dr Krishanu Roy[1]
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1A Special Session: Alternative binder systems and novel processing technologies, Auditorium, November 11, 2024, 1:30 PM - 3:30 PM

Mine tailings are typically stored as bunds or dams, designed as large geotechnical structures and requiring large areas of land, ongoing inspection and testing of tails water to ensure minimal environmental damage. Over the past year, our team has been studying the potential use of gold mine tailings from the OceanaGold Waihi mine as a supplementary cementitious material. The mine tailings have been considered as substitutes for cement and sand, and also utilized as a raw material in geopolymer production.

Initially, the mine tailings exhibited low reactivity, prompting a thorough investigation to enhance their reactivity. Techniques such as grinding and calcining were explored in this regard. Our research also delved into the mechanical properties of the concrete derived from mine tailings as a full or partial SCM, such as compressive strength and stress-strain behavior. To complete the material characterisation, extensive durability tests were conducted over an extended period, subjecting the materials to acidic conditions and high temperatures.

Various material characterization techniques were used to analyse the concrete samples, including scanning electron microscopy (SEM), energy-dispersive X-ray analysis (EDS), X-ray diffraction (XRD), Fourier transform infrared spectroscopy, atomic absorption spectroscopy, and thermogravimetric analysis (TGA). In addition rheological studies were performed to assess the 3D printability of the mine tailing mixtures.

This paper highlights key findings from our project, with a focus on variations in compressive strength, rheological properties, and microstructural features of specimens based on mine tailings.

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The potential for utilising locally available kaolinitic clays in low-carbon MgO-based binder systems

Mr Banujan Balaskandan[1], Prof Allan Scott[1], Dr Giuseppe Loporcaro[1]
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1A Special Session: Alternative binder systems and novel processing technologies, Auditorium, November 11, 2024, 1:30 PM - 3:30 PM

While concrete remains the most popular construction material, there are some serious environmental concerns that the construction industry needs to address. Portland cement has a high carbon footprint and as a result, there has been a growing interest in finding alternative binder systems and/or supplementary cementitious materials to replace Portland cement. Several cementitious materials have previously been identified as partial replacements for Portland cement in concrete. However, these partial replacements only reduce CO2 emissions, not eliminate them completely. The goal for 2050 is to achieve a carbon-zero future and therefore, researchers are focusing on developing very low-carbon cementitious binder systems. MgO-based systems appear to be a promising alternative to Portland cement concrete as they have the potential to be carbon-free binders.

The available literature describes various types of MgO-based cements, including reactive magnesia cements, magnesium phosphate cements, magnesium silicate hydrate (M-S-H) cements, magnesium oxychloride (Sorel) cements, and magnesium oxysulfate cements. Recent studies have demonstrated the beneficial effects of incorporating aluminosilicates (metakaolin) into reactive magnesia (MgO) cement. However, the limited availability of metakaolin, its expensive nature, and the excessive water demand are the major obstacles to the practical use of metakaolin in MgO-based binders. This study primarily focuses on combining locally available calcined kaolinitic clays with light-burnt magnesia to develop a M-S-H-based binder system. Isothermal calorimetry tests revealed that the reactivity of the clay was significantly lower than metakaolin but still acceptable as a potential binder. A commercially available polycarboxylate-ether-based superplasticiser was used in this study to enhance the workability and slump retention of the binder system. The calcined clay required significantly less superplasticiser to produce a workable mortar mix compared to metakaolin. Mortar mixes with a 28-day compressive strength well in excess of 25 MPa were achieved with the binder. In conclusion, this study demonstrates the potentials of utilising moderate level calcined kaolinitic clay in MgO-based binders, and offers insights into its compatibility, reactivity, and overall performance.

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Development of geopolymer systems using thermally treated bauxite tailings and rice husk ash

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1A Special Session: Alternative binder systems and novel processing technologies, Auditorium, November 11, 2024, 1:30 PM - 3:30 PM

Mining as the primary sector industry in Australia, which plays vital role in contributing the local economy. However, the associated environmental issue such as the generation of mine waste such as tailings has been raised. Although, the utilization of industrial by product in construction materials has gained a lot attention. Tailings is still underestimated in the cement replacement due to the wide range of types and lack of understanding their chemical characteristics.

A newly developed geopolymer binder through combined calcined bauxite tailings and rice husk ash has been investigated in this study. Several characterization methods were utilized to investigate this the newly developed binder and compare with fly ash. The mineralogical phase transition was investigated by X-ray diffraction. The hydration product formation was characterized by SEM-EDS. In addition, to compare the reactivity of representative SCM such as fly ash, their potential properties working SCM has been investigated through R3 isothermal calorimetry test and mortar compressive strength test.

In the SEM-EDS mapping results, a uniform distribution of the Al and Si element in the product is evident, with a Si/Al ratio of approximately 2.5 and a Na/Al ratio of roughly 0.5. On the other hand, in both R3 isothermal calorimetry test and mortar strength test both indicate that the calcined bauxite tailings mixed incorporation of rice husk ash present excellent reactivity which is prior to fly ash. Furthermore, the mixture exhibits impressive mortar strength, ranging from 36.8 to 39.6 MPa at 28 days, suggesting the viability of this newly developed blend (CBT and RHA) as a potential alternative binder.

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Development of Geopolymer Mortar Incorporating Waste Clay Brick Powder

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1A Special Session: Alternative binder systems and novel processing technologies, Auditorium, November 11, 2024, 1:30 PM - 3:30 PM

The utilization of various waste materials and industrial by-products in the production of geopolymer binders has gained global popularity. Nevertheless, the availability of these materials is diminishing as the demand for eco-friendly cementitious binders continues to rise and the conventional steel making, and power generation processes are gradually phasing out. Waste clay bricks, a significant by-product of urban redevelopment, are recognized as a prominent contributor to the growing waste stream. This research aimed to investigate the integration of this waste material in the production of geopolymer binders. After creating a fine powder from discarded clay brick pallets, different percentages of this material (10%, 20%, 30%, and 40%) were used to substitute fly ash in the formulation of fly ash-GGBFS-based geopolymer mortar under ambient and heat curing conditions. The study examined fresh and hardened properties of the ternary blended geopolymer mortar samples by conducting workability and compressive strength tests. Moreover, microstructural properties were explored using scanning electron microscopy to acquire a more profound insight into the reaction products and their dispersion within the substance. A decrease in the workability of fresh mortar was noted as the proportion of WCBP increased. In ambient and heat-curing conditions, the mortar sample containing 40% WCBP exhibited the highest compressive strength at 28 days. Microstructural analysis of the specimen with a high WCBP content revealed a denser structure. This development can be attributed to the beneficial impact of WCBP, which enhances reactivity, resulting in a firm geopolymer gel and improved mechanical strength in the fly ash-GGBFS-based geopolymer mortar.

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Outline of field investigation results by the Turkey-Japan joint reconnaissance team

Yo Hibino, Yusuke Maida, Seitaro Tajiri, Professor Koichi Kusunoki, Professor Alper İlki

1B Special Session: Lessons from the 2023 Pazarcik-Elbistan (Turkey) Earthquake Sequence, Dobson 1, November 11, 2024, 1:30 PM - 3:30 PM

Due to the preliminary information on the devastating damage in the affected area due to the 2023 Turkey-Syria Earthquakes, AIJ (Architectural Institute of Japan) decided to dispatch a reconnaissance team. AIJ also discussed with JSCE (Japan Society of Civil Engineering) and JGS (Japan Geotechnical Society) and decided to organize a joint team. Japanese Government also decided to provide Grants-in-Aid for Scientific Research to conduct a comprehensive investigation of the 2023 southern Turkey earthquakes and their damage, and they also joined the team. The team consisted of 27 members from Japan and 22 members from Turkey. It was the largest international investigation team for AIJ. The target items to be investigated were Reinforced concrete, Steel, Wall-type, Masonry, Hospital, Base-isolated, Geotechnical, Strong motion, and code system. The target areas were Gaziantep, Nurdağı, Bahce, Osmaniye, İskenderun, Kırıkhan, Antakya, Cigli, Gölbaşı, Kahramanmaraş, İslahiye, Adıyaman, Malatya, Sekeroba, Erzin, Dortyol, and Adana.

The building damage around the strong motion observation stations was investigated to confirm if the building damage coincided with the level of measured accelerations. The damage to R/C buildings and steel buildings was investigated, and it was found that the minimum spacing between re-bars at the lap splice joint should be defined. Many buildings were inclined due to uneven settlement in Gölbaşı, where the soil condition was poor. The pile foundation is recommended to the buildings on soft soil. The detailed investigation, which is the investigation to collect the dimensions of members, span lengths and heights, and material properties so that the buildings were able to be modeled in a computer. The code compliance system in the affected area and recovery plan were also investigated. We should investigate the effect of a series of strong earthquakes.

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Seismic performance and damage level evaluated with Japanese standards of RC buildings damaged by the 2023 Turkey Earthquake

Professor Seitaro Tajiri

1B Special Session: Lessons from the 2023 Pazarcik-Elbistan (Turkey) Earthquake Sequence, Dobson 1, November 11, 2024, 1:30 PM - 3:30 PM

The Architectural Institute of Japan formed an investigation team to survey the damage to buildings damaged by the February 2023 Turkey earthquakes. The investigation team was dispatched to the affected area from March 28 to April 4, 2023, and conducted field surveys jointly with a Turkish expert group. As part of this investigation, the authors conducted detailed surveys of damaged reinforced concrete buildings. The survey area covers five provinces where extensive building damage was confirmed: Gaziantep, Hatay, Kahramanmaras, Adiyaman, and Malatya. The buildings surveyed were those that are useful for comparative analysis, and ones that allowed for relative ease of an on-site inspection. As a result, a total of 25 buildings were investigated, many of which were constructed after 2000, and the damage level ranged from slightly to severely damaged. In each building, the arrangement, dimensions, and damage grades of columns and walls on the floors that suffered the most damage were recorded, and their damage level was evaluated based on the Japanese post-earthquake damage assessment guidelines.

In this paper, an overview of the results of this survey is reported. Based on the survey results, we report the results of an analysis of the structural features and seismic performance of the surveyed Turkish buildings compared to typical Japanese buildings. Japanese seismic performance evaluation method and damage evaluation method assume buildings with typical Japanese buildings' dimensions. Comparing Turkish buildings with Japanese buildings, there are significant differences in the dimensions and arrangement of columns and walls. Therefore, based on the Japanese evaluation method, corrections were made that took into account the characteristics of buildings in Turkey, and the seismic performance and damage level of the affected buildings were evaluated. We also present the results of an analysis of the relationship between seismic performance and damage level evaluated using the corrected method.

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Collapse of Reinforced Concrete Buildings - Implications from the 2023 Turkey Earthquakes

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1B Special Session: Lessons from the 2023 Pazarcik-Elbistan (Turkey) Earthquake Sequence, Dobson 1, November 11, 2024, 1:30 PM - 3:30 PM

Overall structural performance of reinforced concrete buildings will be presented considering correlations with ground motions recorded during the February 6, 2023 Turkey earthquakes. Contribution of critical gravity and lateral structural systems and elements (including floor slabs, beams, beam-column joints, columns, shear walls and foundations) will be discussed first. Although the seismic response contribution of less critical components (e.g., infill walls) will be briefly summarized, the focus will be on why too many buildings collapsed and why so many people were killed as a result. The emphasis, then, will be mainly on column behavior and how shear walls helped.

Although building collapse is a system behavior, in vast majority of cases, collapse was triggered by failure of one or more columns. Then, the question is why the columns failed, especially in the lower stories. Column reinforcement details, lap splices, axial load levels, flexure-axial-shear interaction, and shear failures will be discussed. The overarching goal of this presentation is to translate the field observations and data into improved design practices and to demonstrate the importance of detailing in high seismic regions. This presentation will use examples of damage at the system and element level and relate to the building code requirements.

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Analyzing Ground Motion Data for Building Damage Potential

Professor Ayhan Irfanoglu

1B Special Session: Lessons from the 2023 Pazarcik-Elbistan (Turkey) Earthquake Sequence, Dobson 1, November 11, 2024, 1:30 PM - 3:30 PM

2023 February Kahramanmaras earthquakes demonstrated our increasing ability to obtain strong ground motion records almost immediately following earthquakes. Rapid analysis of these records to estimate their potential to cause damage in buildings, when combined with information about nearby building stock, can inform and improve emergency response decisions. A selection of ground motions recorded in/near urban areas in the 2023 February earthquakes disaster zone will be used to illustrate a simple way to evaluate ground motions quickly for their potential to cause damage in different types of buildings

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The Lack of Robustness of Buildings in Turkey and New Zealand

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1B Special Session: Lessons from the 2023 Pazarcik-Elbistan (Turkey) Earthquake Sequence, Dobson 1, November 11, 2024, 1:30 PM - 3:30 PM

Data collected by ACI Committee 133 from Antakya to Malatya -Turkey- are compared with data from 14 urban areas affected by earthquakes elsewhere through the World. The data are also compared with data obtained from drawings of buildings in Christchurch and Wellington. The comparisons suggest that the majority of buildings in both Turkey and New Zealand lack the robustness required to survive intense ground motion without severe structural damage.

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Non-interacting masonry infills as a solution for improving the seismic behavior of infilled RC frames: Experimental results

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1B Special Session: Lessons from the 2023 Pazarcik-Elbistan (Turkey) Earthquake Sequence, Dobson 1, November 11, 2024, 1:30 PM - 3:30 PM

Masonry infills serve as a prevalent solution for both interior and exterior partitions within reinforced concrete (RC) frame structures. However, recent earthquake events (especially earthquake series in Turkey, February 2023) have revealed signif-icant, uncontrolled damage to masonry infills, primarily attributed to their interaction with RC frames. This high seismic vulnerability poses substantial economic losses and a considerable threat to human safety. Recognizing the imperative need for en-hanced seismic performance, this paper explores an innovative approach aimed at mitigating damage to RC structures with masonry infills. The proposed solution cen-ters on the principle of decoupling (non-interacting) masonry infills from the sur-rounding RC elements. This decoupling is achieved by inserting recycled rubber strips between the masonry infills and the RC frame. The implemented decoupling system effectively delays the activation of masonry infills under in-plane seismic loads and offers crucial support during out-of-plane seismic events. In order to in-vestigate the effectiveness of the decoupling system, quasi-static cyclic tests were performed on full scale specimens. The paper presents a comprehensive examina-tion of experimental results, drawing comparisons between traditionally infilled RC frames and those employing the novel decoupling system. The study takes into con-sideration infills with and without openings. The findings demonstrate a markedly enhanced seismic performance of masonry infills with the innovative decoupling system.

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Expected Cost of the Improved Seismic Resilience Based on the Data from 2023 Kahramanmaraş Earthquakes

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1B Special Session: Lessons from the 2023 Pazarcik-Elbistan (Turkey) Earthquake Sequence, Dobson 1, November 11, 2024, 1:30 PM - 3:30 PM

The 2023 Kahramanmaras Earthquakes underscored the importance of prioritizing robustness in seismic design. Despite evidence from the 1970s highlighting the lower fatality and property loss risks associated with robust structures, seismic design preferences have largely favored flexible moment frames or their derivatives. This preference is often driven by the allure of lower initial costs associated with less robust options. However, repeated seismic events have demonstrated the imprudence of this approach.

This study aims to investigate the economic viability of selected design approaches by shifting the focus from initial costs to life-cycle costs. Utilizing data from the Hassan Index as a reference, the study attempts to estimate the change in initial costs and probable damage ratios for a more accurate decision base. Given that urban areas bear the brunt of earthquake damage due to the concentration of infrastructure and human activity, the study will also consider the resilience and sustainability requirements for modern cities. Through this analysis, the study seeks to provide insights into the economic implications of seismic design decisions, focusing on long-term sustainability and urban resilience.

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Assessment of reinforced concrete structures: Exploring the Reliability of NDT/SHM

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1C Special Session: NDT/SHM as basis for the condition assessment for reinforced concrete structures, Dobson 2 & 3, November 11, 2024, 1:30 PM - 3:30 PM

Non-Destructive Testing (NDT) and Structural Health Monitoring (SHM) stand as integral components in the lifelong management of existing concrete structures, playing a pivotal role in extending their service life and advancing sustainable infrastructure. The reassessment of these structures necessitates a nuanced understanding of the capabilities of NDT/SHM. However, in the realm of civil engineering, the reliability assessment of NDT/SHM remains in the research stage.

This research scrutinizes various indicators, such as the Value of Information (VoI), Probability of Detection (POD), Probability of Identification / Characterization (POI/C), and Probability of Localization (POL), evaluating their maturity and efficacy in delineating the benefits and capabilities of NDT and SHM. The overarching goal in reliability assessment lies in estimating the Probability of Failure (POF) for structures or components, contingent upon a profound comprehension of the criticality of specific defects identified through NDT/SHM.

The primary aim is to compile and deliberate upon the state-of-the-art in these assessment tools. The knowledge derived from such assessments assumes a critical role in facilitating informed decision-making in structural management. This comprehensive exploration not only contributes valuable insights to the field but also provides a roadmap for effectively harnessing NDT and SHM in the sustainable management of concrete infrastructure.

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Unmasking Structural Health: A Bold Exploration into the Uncharted Realms of Reliability Assessment in SHM

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1C Special Session: NDT/SHM as basis for the condition assessment for reinforced concrete structures, Dobson 2 & 3, November 11, 2024, 1:30 PM - 3:30 PM

The transition from periodic maintenance to condition based maintenance in safety-critical sectors is only possible by means of structural health monitoring (SHM) methods. While the incorporation of SHM sensors into Civil Engineering structures is a costly endeavor, the immediate benefits remain somewhat elusive. Despite widespread implementation of SHM methods across various industries, realizing their full potential necessitates a profound understanding of the reliability inherent in these systems. Such understanding is paramount for an unbiased evaluation of the monitoring system.
In this contribution, we will provide an overview of potential approaches to identify and quantify the advantages of SHM. The transfer of models from Non-destructive Testing is not easily applicable due to the substantial variability and complexity of structures. Therefore, advanced reliability approaches become crucial. From a standardization perspective, there is currently a gap. Consequently, in the ongoing study, we are striving to develop SHM-based Probability of Detection (POD) models specifically tailored for the vibration-based monitoring of civil engineering bridges. Additionally, this research seeks to instigate a discussion on how to adapt standards to establish a reliable key performance indicator for SHM in the field.

The talk provides a comprehensive introduction to the reliability assessment as well as the advanced approaches needed for and applied to SHM. It sheds light on the reasons why prevailing approaches fall short and proposes innovative solutions to bridge the existing gaps in understanding and standardization.

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Proof-of-Concept of a Bayesian Updating Approach for Corrosion Degrees on the Basis of Crack Measurements

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1C Special Session: NDT/SHM as basis for the condition assessment for reinforced concrete structures, Dobson 2 & 3, November 11, 2024, 1:30 PM - 3:30 PM

A common problem with existing reinforced concrete (RC) structures is the occurrence of early signs of deterioration, sometimes even leading to collapse before reaching their design service life. The alarming issue of reinforcement corrosion and related concrete deterioration leads to significant reductions in structural safety and very high repair costs. Consequently, determining the corrosion degree of structural RC elements is a crucial step in the damage assessment process.

The condition assessment of RC structures is often based on visual inspections, accompanied by tapping and crack mapping. Crack width measurements hence serve as an im-portant damage parameter. Nevertheless, a quantitative approach to use these measurements in order to estimate the corrosion degree accounting for all relevant uncertainties is still missing. In this contribution crack width measurements are used to update the corrosion degree and the associated uncertainties by means of Bayesian updating. The posterior distribution of the corrosion degree is computed adopting Markov Chain Mon-te Carlo sampling and existing (semi-)empirical models, taking due consideration of the model and measurement errors. Finally, also spatial variability of the corrosion degree is accounted for by means of random field modelling. The experimental data for this re-search are obtained from an accelerated corrosion test program on RC specimens, in which beams are corroded uniformly by using an accelerated corrosion setup with an impressed current and a 5% NaCl solution.

The posterior distribution of the corrosion degree enables a better estimation of the RC element's failure probability and remaining service life, contributing to a comprehensive understanding of its structural health.

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Integrated sustainability and quality assurance concepts for subway constructions based on inspection and monitoring

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1C Special Session: NDT/SHM as basis for the condition assessment for reinforced concrete structures, Dobson 2 & 3, November 11, 2024, 1:30 PM - 3:30 PM

With the help of modern digital methods and sensor technologies, new solutions for a more economical and sustainable operation of structures can be realized. Sensors can indicate incipient damage so that countermeasures can be taken early and with little effort. This makes (visual) maintenance much more efficient, resulting in less disruption (fewer closures, less downtime) and lower costs, and extends it to non-visible areas. At the same time, monitoring the effects on the structure (e.g., loads, vibrations, chlorides) makes it possible to calculate the remaining service life, which is an essential auxiliary parameter for planning. Sensor data can help to find the cause of unexpected impacts, thus increasing service life and serviceability.

Inspection and monitoring concepts as presented are based on a digital building model, as is already required today by many clients for infrastructure buildings and named Building Information Model (BIM). Sensors, already embedded or installed during construction, help to update such a digital model as a so-called Digital Twin. Since the model is available in digital form, it can be called anytime from any location, and the system generates automatically received warning messages. It enables the operator to retrieve current information on the condition and to initiate appropriate measures on time.

An overall concept for "permanent and adaptive structural monitoring in the sense of quality assurance (QA) for sustainable infrastructure structures" requires explicitly adapting the techniques to the concrete construction project. The essential elements of such a QA system will be outlined covering the entire construction process. Examples will be given for subway structures.

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Detection of damages in prestressed concrete structures using distributed fiber optic sensors

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1C Special Session: NDT/SHM as basis for the condition assessment for reinforced concrete structures, Dobson 2 & 3, November 11, 2024, 1:30 PM - 3:30 PM

Prestressed concrete structures are used, particularly as large span girders, in infrastructure or buildings from almost 100 years. During last decades dynamic growth of these structures can be observed worldwide. On the other hand significant amount of prestressed structures are now quite old and their technical condition is worsening. Prestressed concrete structures are considered as durable, provided that they are properly erected. Execution errors can lead to structural damages that may emerge even years after use. Moreover, identifying of local damages in prestressed structures is difficult and very labor-intensive with currently used methods due to the location of prestressing tendons usually inside the concrete section. Therefore, currently new monitoring and diagnostic methods are developing all over the world. One of promising method for damage detecting as well as monitoring of global structural behavior is distributed fiber optic sensing (DFOS). It allows for continuous measurements over the entire structural length, which enables identification of local phenomena, such as cracks of other abnormalities. DFOS can be applied to both new and existing structures owing to their construction. The paper presents research conducted on pairs of prestressed concrete beams, in which one served as a reference and the second was damaged in specified locations. The damages included: loss of part of the cross-section, chemically accelerated corrosion of strands, void in the ducts. The main aim of the research was to check the possibility of local damage identifications using distributed fiber optic sensors. DFOS sensors were embedded inside the concrete cross-section (solution dedicated to new structures) in pre-made near-surface grooves at side surfaces of the beams (solution dedicated to existing structures), as well as inside the ducts and even prestressing strands. During the tests they were used to measure strains, stresses, cracks and displacements and based on these measurements to identify locations of damages. The DFOS measurements were also compared with reference measurements made with conventional spot techniques, achieving very good compliance. The research proved that a well-designed DFOS-based system, encompassing suitable measurement methodologies, optical sensor configurations, installation techniques, and post-processing algorithms, is the relevant tool for the diagnostics of post-tensioned concrete structures.

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Evaluation of air coupled impact-echo for the non destructive monitoring of concrete structures

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1C Special Session: NDT/SHM as basis for the condition assessment for reinforced concrete structures, Dobson 2 & 3, November 11, 2024, 1:30 PM - 3:30 PM

Non-destructive testing (NDT) technologies are a key asset for monitoring insidious changes in civil engineering structures, regardless of whether these originate from environmental conditions or intrinsic material degradation phenomena. NDT can help address modern challenges related to resilience, safety insurance and sustainability of concrete structures. Impact Echo and ultrasound testing for instance can measure concrete thickness as well as detect features (such as tendon duct) and defects (such as delamination and honeycombing). Yet, the application of NDT remains sporadic for most concrete structures, particularly in the case of NDT methods that can assess embedded defects. One reason for this sporadic usage is the time-consuming and laborious nature of the manual process involved in the acquisition of NDT data. Most commercial devices that can perform sound-based NDT, such as ultrasound and impact-echo systems, are manually operated and require the lifting and repositioning of the probe with every measurement. The probes used in these devices require dry coupling with the material's surface for the waveforms to be acquired. In the case of impact-echo, the sound waves are generated using a mechanical impactor, such as a hammer or an automated solenoid impactor.

For twenty years, progress in impact-echo testing involved the development of air-coupled devices which could accelerate and simplify the data acquisition process. This innovation relies on acquiring in the air the planar wavefront that emanates from the vibration of the concrete structure caused by the propagation of the S1 zero group velocity Lamb mode, which is characteristic of the impact-echo application. The use of an array of MEMS microphones has been proven to be a promising solution, capturing impact-echo signals while reducing interference from background noise. This research explores the recent developments in air-coupled IE technology and provides a comparison between different array systems for the development of a portable and functional air-coupled impact echo device.

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Detecting Non-Visible Tendon Breaks – A New Approach Using Coda Wave Interferometry

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1C Special Session: NDT/SHM as basis for the condition assessment for reinforced concrete structures, Dobson 2 & 3, November 11, 2024, 1:30 PM - 3:30 PM

Pre-stressed concrete bridges represent the majority of the world's bridge stock. Pre-stressing induces compression in cross-sections and yields slender and durable structures. Tendon failure due to fatigue or corrosion poses high risk on their durability. In both pre-tensioned and post-tensioned structures, tendons are bonded into the concrete, making visual inspection impossible. While the cross-section remains compressed, damage to the tendons can occur silently without indication by cracks on the concrete surface, emphasizing the need for early detection methods.

A new approach for detecting non-visible tendon breaks is presented. It involves the Coda Wave Interferometry to evaluate ultrasonic measurements. Ultrasonic sensors embedded in the concrete create a robust monitoring system capable of detecting subtle changes in the structure. In addition to changes in temperature and moisture, ultrasonic signals are sensible to stress-variations in the concrete, making Coda Wave Interferometry a promising technique for detecting the altered stresses caused by non-visible tendon breaks early.

To demonstrate the feasibility of detecting tendon breaks using Coda Wave Interferometry, two beams were fabricated at Ruhr University Bochum, Germany, one post-tensioned and a pre-tensioned one to cover all practical needs. External drilling induced the breaks in the bonded tendons, while several embedded ultrasonic sensors recorded signal changes. The tendon strains of both beams were measured simultaneously using fiber optic sensors for reference.
In both cases, the tendon breaks come along with distinct changes in the ultrasonic results, even though there is no evidence of damage on the concrete surface. Moreover, the localization of the breaks is successful. Results from fiber optic sensors validate the ultrasonic findings, confirming the quality of the obtained data and providing insights into the re-anchoring behaviour during tendon failure.

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Intelligent wall-climbing robot with stereo camera for real-time and high-accuracy concrete crack inspection

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1C Special Session: NDT/SHM as basis for the condition assessment for reinforced concrete structures, Dobson 2 & 3, November 11, 2024, 1:30 PM - 3:30 PM

The existing concrete crack detection methods, including manual instrument-based detection and Unmanned Aerial Vehicle (UAV) vision-based detection, still have limitations in terms of accuracy, efficiency, and operational safety. To address these challenges, this paper proposes a self-developed intelligent wall-climbing robot for crack inspection specialized in high-altitude and remote concrete structures. The key features of the robot include an automatic swing arm with a mounted stereo camera and an edge computing CPU deployed with 3D crack recognition and quantification algorithm using deep learning. Wall-climbing test on the façade of a 6-floor building and crack detection were conducted. The results show that the robot appears remarkable wall-climbing performance with a moving speed of 15 m/min, a detection radius of 3 m, and a working endurance of 140 m.

Additionally, the robot exhibits the outstanding ability of real-time and high-accuracy concrete crack inspection with a detection speed of 15 FPS and a crack size accuracy of 95%.

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Lightweight Hollow Core Carbon Reinforced Slab System

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1D New and innovative structural designs, Dobson 4, November 11, 2024, 1:30 PM - 3:30 PM

The construction of conventional steel-reinforced concrete slabs is a significant contributor to CO2 emissions, primarily due to the substantial cement material requirement. To address this environmental concern and optimize the structural behavior of slab elements, the use of carbon reinforcement presents an alternative that reduces material consumption. However, achieving sufficient stiffness in long slab elements with thinner profiles remains a challenge. In response, a novel approach is adopted, involving the development of hollow core slab elements reinforced with Netzgitterträger (NetzGT) elements. The NetzGT represents a specialized carbon reinforcement characterized by high-strength rovings, and serves as a multifunctional reinforcement in tension and shear zones. The trapezoidal geometry of the NetzGT reinforcement features a net-shaped prefabricated textile comprising diagonally offset rovings with overlapping edge strands. This innovative non-metallic reinforcement not only allows for material savings but also provides enhanced load-bearing capacity and durability due to its corrosion-resistant properties.

Comprehensive testing has been conducted on these hollow core beams reinforced with NetzGT reinforcement, revealing high bending strength and structural performance. This research signifies a step towards environmentally conscious construction of slab elements by not only minimizing material resources and CO2 emissions but also demonstrating the superior mechanical properties of carbon reinforcement in creating sustainable and resilient structural elements.

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Implementation of Functionally Graded Concrete (FGC) in New Zealand: Proof of Concept Tests

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1D New and innovative structural designs, Dobson 4, November 11, 2024, 1:30 PM - 3:30 PM

The use of Functionally Graded Concrete (FGC) where the properties (e.g. density) are varied throughout the member can result in efficient structural components that minimise material use and thus reduce embodied carbon. Investigations into implementing FCG as a building component have been conducted internationally, specifically at the Institute for Lightweight Structures and Conceptual Design (ILEK) of the University of Stuttgart. This project investigated the potential implementation of FGC in New Zealand, focusing on residential applications where the added insulation benefits could be utilised. Proof of concept trials were conducted on FGC wall component using local materials and construction methods. A total of 7 FGC wall panels were constructed with layers of different concrete mixes to replicate typical ‘sandwich panel’ construction. The mixes included a standard weight structural concrete and a lightweight concrete that used local pumice aggregates. Variations in the delay being placing layers was investigated to assess the degree of mixing between the layers to create more gradual changes in density throughout the panel thickness. Core samples were extracted from the constructed panels to quantify the degree of mixing of layers and to measure the density of slices through the panel thickness. The trials have proven the viability of FGC components and form the basis of further research and development.

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Crack development in non-metallic textile-reinforced concrete members under cyclic loading with regard to serviceability

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1D New and innovative structural designs, Dobson 4, November 11, 2024, 1:30 PM - 3:30 PM

Non-metallic reinforcement not only facilitates a substitution of conventional reinforcing steel, but also leads to slender members with a reduced concrete cover or an increase in structural capacity, significantly increasing the sustainability of concrete buildings. The ability of non-metallic reinforcement in advancing the ultimate limit state for concrete members directs attention to serviceability criteria, such as crack width limitation, which become decisive for design. These criteria need to be accounted for by adequate models, especially regarding the bond behaviour and tension stiffening. To characterise the bond behaviour and the crack development under cyclic loading, experimental investigations were conducted on different carbon grids. The selected load level represented crack widths at the serviceability limit state. The crack opening and bond behaviour were detected using fibre-optic measurements on the textile grids and the concrete surface as well as digital image correlation to determine the crack widths and opening during the load cycles. The obtained strain developments of the reinforcement and concrete were used to determine the bond stress evolution with the corresponding transfer lengths. This allows for a determination of the bond strength and tension stiffening in relation to the crack width, both of which are required in design codes for a practical and progressive design in terms of crack width control. The obtained values are used for a crack width prediction using the principal approaches presented in design codes.

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Assessment on Concrete Structure Environmental Performance Potential (CSEPP) of Ultra High Performance Concrete Composite Bridges

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1D New and innovative structural designs, Dobson 4, November 11, 2024, 1:30 PM - 3:30 PM

Ultra-high-performance concrete (UHPC) is a sustainable construction material recog-nised for its exceptional mechanical strength, durability, and its ability to provide long spans, especially in segmental precast construction. In Malaysia and India, the use of long-span UHPC bridge girders have rapidly increased in bridge construction and is par-ticularly beneficial for urban areas where the need for piers within the highly congested and obstructed areas can be eliminated; or for river crossings where the need for piers within the waterway can be eliminated. This paper provides two examples of the envi-ronmental impact calculation (EIC) of the (i) 106-metre-long navigation span UHPC composite bridge versus the structural steel I-beam composite bridge; and (ii) the 80-metre-long UHPC composite railway bridge versus conventional box girder concrete bridge. In both bridges, precast/prestressed UHPC U-girders with a depth of 4m were used, and they come with 200 mm thick cast-in situ conventional normal strength con-crete deck. In the first example, the UHPC design shows an immediate embodied energy (EE), embodied carbon (EC), and 100-year global warming potential (GWP100yr) reduction of 63.2%, 56.7% and 57.2%, respectively. In the second example, a sustainability assessment comparing it with a conventional box girder bridge. The UHPC design shows an immediate embodied energy (EE), embodied carbon (EC), and 100-year global warming potential (GWP100yr) reduction of 10.2%, 11.4% and 11.5%, respectively. The UHPC bridges exhibit significantly better sustainability metrics when compared to steel structures, whereas some savings are still achievable when compared to conventional concrete structures.

Keywords: long span, segmental, embodied energy, embodied carbon, global warming potential

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CO_2 savings through individual void formers in concrete slabs

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1D New and innovative structural designs, Dobson 4, November 11, 2024, 1:30 PM - 3:30 PM

The building sector needs to reduce its CO_2 emissions. A simple—so to speak, ascetic—method is to use only as much material as is really necessary. In particular, flat slabs, which account for up to 50% of the total mass of the overall load-bearing structure of buildings, offer a lucrative lever for material savings. The use of just one type of void formers can already save more than 20% of the concrete in comparison to conventional flat slabs. However, wide areas of such slabs are thereby still not fully utilized and thus offer the opportunity for even greater concrete savings.

This paper presents a method for placing void formers of individual shapes and sizes in slabs according to the local stress. The method's centerpiece is non-penalized topology optimization. It specifies the local density, which is equated to the remaining concrete volume after the void formers are placed. Redistribution effects of internal forces due to varying stiffness are inherently taken into account. The shapes of the void former are generalized by superellipsoids and can be cuboidal, spherical, or ellipsoidal. Load capacity is verified by minimum compression zone heights (bending) and against the reduced resistance of not shear-reinforced slabs (shear). Corresponding placement of individual void formers saves more than 40% of concrete. Examples are given to illustrate the practical application. They demonstrate the void former distribution for different combinations of bending moments and shear forces, highlight the limitations of the method, and outline future developments.

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Experimental study on the flexural behavior of steel-tubed reinforced ultra-high strength concrete columns

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1D New and innovative structural designs, Dobson 4, November 11, 2024, 1:30 PM - 3:30 PM

Ultra-high-strength concrete (UHSC; f'c≧120 MPa) columns are used for the lower stories of super-high-rise buildings in Japan. Even though UHSC columns can carry large axial loads, the cover concrete is prone to explosive failure under earthquakes. The UHSC columns are encased with steel tubes (steel-tubed reinforced UHSC columns; STR-UHSC columns) to prevent this failure. Previous studies revealed that STR-UHSC columns exhibit excellent seismic performance compared to UHSC columns without a steel tube. However, the flexural behavior of STR-UHSC columns has not been thoroughly investigated, and little test data are available on the relationship between the deformation capacity and the amount of transverse reinforcement. In this study, bending tests were performed on seven STR-UHSC columns with f'c = 145 – 165 MPa to study their flexural behavior. The main test variables were the amount of transverse reinforcement and the presence of a steel tube. The steel tubes improved the flexural capacity and ductility of the columns. The amount of transverse reinforcement significantly affected the ductility. An equation was proposed to describe the relationship between the drift capacity and the amount and strength of the transverse reinforcement and steel tube.

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Study on mechanical properties of a new joint with concrete-filled steel tube keys between shear walls and coupling beams

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1D New and innovative structural designs, Dobson 4, November 11, 2024, 1:30 PM - 3:30 PM

Shear wall structures are extensively employed in high-rise structures due to their high lateral stiffness. This paper proposes a new joint with concrete-filled steel tube keys between shear wall members and coupling beams to improve the construction efficiency of shear wall structures. The new joint is made by welding the embedded steel plate to the concrete-filled steel tube. To study the mechanical properties of the proposed joints, a finite element model was developed by ABAQUS. Then, the developed finite element model was verified by relevant tests and further used to compare the mechanical properties of the proposed and conventional joints. The results show that the proposed joint has better load-bearing and energy dissipation capacities. In addition, the influence of factors, such as the length, width, and thickness of the steel tube, on the mechanical properties of the proposed joint was analyzed in this paper. The results show that the increase in steel tube length, width, and thickness can improve the bearing capacity and ductility of the proposed joint. The thickness of the steel tube has a significant effect on the joint. When the thickness of the steel tube increases from 4 mm to 10 mm, the load-bearing capacity of the joint increases by 51.9%.

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Rethinking the seismic design of RC buildings for improved post-earthquake reparability

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1D New and innovative structural designs, Dobson 4, November 11, 2024, 1:30 PM - 3:30 PM

The 2010-2011 Canterbury earthquakes and the 2016 Kaikoura earthquake highlighted issues with the reparability of reinforced concrete (RC) structures in New Zealand. A traditional seismic design approach for RC structures is to encourage weak-beam strong-column mechanisms to form. However, the damage observed to floors and beams is very costly and time-consuming to repair. In response to such observations, the industry has been developing a testing a range of new technologies and approaches to improve the post-earthquake reparability of buildings. This paper provides an overview of different strategies for improved post-earthquake reparability of RC buildings. Subsequently, a novel spreader wall system is described that allows a distributed weak-column strong-beam mechanism to form, protecting floors and beams from damage but also preventing the formation of soft-storey mechanisms. The performance of the system is illustrated using the results of non-linear time-history analyses.

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Seismic Evaluation of Building Inventories using AI, HAZUS, and Shakecast.

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2A Special Session: Nonlinear modeling, seismic assessment, and rehabilitation of reinforced concrete structures (part 1), Auditorium, November 11, 2024, 4:00 PM - 6:00 PM

Degenkolb Engineers has conducted seismic evaluations on a diverse range of buildings in California, USA, following the ASCE/SEI 41 consensus standard, 'Seismic Evaluation and Retrofit of Existing Buildings,' over the past several decades. A comprehensive database encompassing the evaluation results of approximately 2,700 buildings has been compiled. This database served as the foundation for training Artificial Intelligence (AI) using the Random Forest and Support Vector Machine (SVM) Machine Learning (ML) models. The AI has been utilized with the HAZUS Advanced Engineering Building Module distributed by the Federal Emergency Management Agency (FEMA) and Shakecast developed by the United States Geological Survey (USGS) to evaluate seismic risk, expected damage, and Life Safety performance of the buildings in response to earthquake hazards as mandated by the standard and various earthquake scenarios.

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Evaluation of performance metrics for seismic assessment of RC Frames

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2A Special Session: Nonlinear modeling, seismic assessment, and rehabilitation of reinforced concrete structures (part 1), Auditorium, November 11, 2024, 4:00 PM - 6:00 PM

Seismic assessment methodologies rely on comparisons between building capacity and demand metrics to determine if structures can achieve defined levels of performance. For example, linear and nonlinear comprehensive evaluation methods in the ASCE 41 standard establish comparisons between element force and deformation demands, while the collapse assessment methodology in FEMA P2018 evaluates deformation demand at critical elements defined in terms of the maximum drift ratio. While the greatest emphasis on improving assessment methodologies is placed on refining modeling parameters and analysis procedures, the choice of evaluation metrics has significant effect on the outcome of seismic assessments.

The objective of this research is to evaluate different demand metrics obtained from a parametric study of reinforced concrete frames to compare their accuracy and dispersion. Global and local demand metrics were calculated for 63 different reinforced concrete frames with different qualities of detailing and subjected to four different intensities of shaking. Frame models were created following the provisions in the ASCE 41 and ACI 369.1 codes, and evaluated using linear and nonlinear analysis procedures using the far fault earthquake set defined in FEMA P695. It was found that performance metrics used in ASCE 41 linear procedures become increasingly skewed as deformation demand increases because non-ductile structures are more vulnerable to collapse. A comparison between linear and nonlinear demand metrics showed that linear procedures are not suited to be used as indicators of damage location because the distribution of deformations over the structure can be significantly different than calculated with nonlinear models.

It was also found that dispersion of seismic demand metrics increased with decreasing quality of detailing and increasing earthquake intensity. Both accuracy and precision of demand metrics were found to be better for global metrics than for component metrics, which indicates that estimating damage in individual components is significantly more challenging than obtaining a broad estimate of damage based on global demand metrics.

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Evaluation of ASCE/SEI 41 procedures for assessing the seismic vulnerability of an earthquake-damaged reinforced concrete wall building

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2A Special Session: Nonlinear modeling, seismic assessment, and rehabilitation of reinforced concrete structures (part 1), Auditorium, November 11, 2024, 4:00 PM - 6:00 PM

Seismic performance evaluation of existing buildings is becoming increasingly prevalent in structural engineering practice due to aging infrastructure, the growing understanding of earthquake hazards, and emerging policies for societal resiliency. In US practice, ASCE/SEI 41 standardizes procedures for such assessments, including methods for linear and nonlinear analysis of reinforced concrete buildings. The current ASCE/SEI 41 approach for analysis and performance evaluation is component and action based, which reflects decades of experimental research on individual component and subassemblage inelastic behavior. Since real buildings are complex systems comprised of many different components (including nonstructural features) and generally subjected to seismic loading that is difficult to reproduce in a laboratory setting, the ability of ASCE/SEI 41 procedures to accurately identify seismic vulnerability is uncertain.

To evaluate the ASCE/SEI 41 nonlinear analysis procedures, the Pyne Gould Corporation Building, which collapsed in the 2011 Christchurch Earthquake, is used as a case study in the Applied Technology Council project entitled “Performance-Based Seismic Engineering: Benchmarking of Existing Building Evaluation Methodologies” (ATC-134). This five-story reinforced concrete wall building is modeled in OpenSees using a combination of fiber-based elements and component backbone curves derived from ASCE/SEI 41-17 and analyzed with recorded ground motions judged to best represent shaking at the site in the 2010 Darfield and 2011 Christchurch Earthquakes. The results show that the ASCE/SEI 41-17 nonlinear analysis procedure correctly indicates the vulnerability but not the mechanism of collapse in the 2011 Christchurch Earthquake. Comparisons to outcomes from a companion study benchmarking linear analysis procedures and recommendations for improvements in future evaluation standards are provided.

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Repair of heavily damaged walls by replacement of concrete and reinforcing steel

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2A Special Session: Nonlinear modeling, seismic assessment, and rehabilitation of reinforced concrete structures (part 1), Auditorium, November 11, 2024, 4:00 PM - 6:00 PM

The assessment of earthquake-damaged buildings is a critical aspect for post-earthquake functional recovery. Currently, New Zealand has no official guidelines for the evaluation of the residual capacity of earthquake-damaged buildings and the effectiveness of repair techniques to restore original seismic performance. This project will contribute to the development of NZ guidelines for the post-earthquake assessment of RC buildings by conducting an experimental program on large-scale RC walls designed according to the current New Zealand Concrete Structures Standard NZS 3101:2006 A3. Two identical walls previously tested beyond reaching lateral failure were repaired and retested to evaluate the effectiveness of the repair techniques to restore original seismic performance. The damage before repairs was consistent with well-detailed flexure dominant walls, including concrete crushing and buckling of the reinforcing bars. Both walls were repaired by replacing the concrete and the reinforcing bars in the plastic hinge region but with different locations of the welded connections between the new reinforcing bars and the existing ones. While one wall kept its original foundation and reinforcement, the other had a new foundation constructed to avoid discontinuities at the critical section. Both repaired walls performed similarly during testing compared to the reference wall regarding damage progression, stiffness, strength, and displacement capacity. However, differences in the local behaviour of the repaired walls were observed. Despite these differences, the welded reinforcement connections did not fail throughout the tests, confirming that properly designed welded connections for G500E reinforcement can resist earthquake demands at the critical region of the wall.

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Experimental Assessment of Large-Scale Anchored FRP-Strengthened RC Shear Controlled Walls Subjected to Cyclic Loads

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2A Special Session: Nonlinear modeling, seismic assessment, and rehabilitation of reinforced concrete structures (part 1), Auditorium, November 11, 2024, 4:00 PM - 6:00 PM

Strengthening of existing reinforced concrete structures using externally bonded fiber reinforced polymer (FRP) composites has gained significant interest over the last few decades. Currently, guidance is limited on the design of seismic retrofit systems for reinforced concrete (RC) structural walls with FRP in retrofit standards such as ACI 369.1 and ASCE 41. ACI PRC-440.2R-23 provides general evaluation and component acceptance criteria and classifies all applications with FRP strengthening as force-controlled actions. Previous testing on shear strengthening of RC walls with FRP has usually been limited to thin walls due to testing laboratory limitations. Also, limited tests have been performed on one-sided strengthening of RC walls with FRP or with the use of FRP embed anchors, which have been shown to improve the performance of bonded FRP systems. Design methodologies for seismic strengthening of walls with anchored FRP strips are inconsistent throughout the industry. An experimental research study was conducted to investigate the one-sided application of carbon FRP (CFRP) composites for strengthening of full-scale RC walls with FRP anchors. RC wall specimens with varying thicknesses (6” and 12”) and varying steel reinforcement ratios were strengthened with CFRP composites and tested under reverse cyclic loading. Various FRP anchor configurations were considered for this study. A full-field three dimensional (3D) digital image correlation system was used to investigate the bond behavior and debonding mechanisms of anchored CFRP composites. The experimental findings will help better understand the behavior of FRP-strengthened RC walls and provide better design parameters for both linear and nonlinear analyses that can be used to shape the future design of FRP strengthening systems.

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Calibration of ACI 369.1-22 model using the nonlinear three-dimensional simulation of instrumented RC structure.

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2A Special Session: Nonlinear modeling, seismic assessment, and rehabilitation of reinforced concrete structures (part 1), Auditorium, November 11, 2024, 4:00 PM - 6:00 PM

This study shows a comparison between displacement, accelerations, and floor rotations recorded in a seven-story non-ductile reinforced concrete building located in Van Nuys, California and values calculated using 2D and 3D numerical models created according to the provisions in ASCE 41 and ACI 369.1. The case study building was instrumented during several strong earthquakes and the building behavior was recorded. The study focuses on the response of the building during the 1994 Northridge Earthquake, which caused severe damage to the building, bringing it near collapse. The Northridge Earthquake strong motion set includes acceleration records at the ground, second, third, sixth, and roof levels, so the comparison of measured and calculated displacement, acceleration, and floor rotation histories were performed at various locations over the height of the building.

The main objective of the study was to compare the response calculated with 2D models, a 3D model with uniform base excitation and different mass eccentricities, and a 3D model with multiple support excitation based on the two strong motion records obtained at the floor level. Although the computational effort and modeling complexity are greater for 3D than 2D models, the former have the added advantage of including the torsional response induced by mass eccentricity and nonsymmetric damage to the lateral load resisting system, resulting in better model estimation. Having a record set that included multiple recordings at the base allowed comparisons to illustrate the relative contributions of wave-passage and mass and stiffness eccentricity to the torsional response of the numerical 3D model. Furthermore, the effect of modeling mass distribution in a building floor on capturing the torsional response of the model is evaluated. The accuracy of models estimates was assessed objectively through comparisons in terms of acceleration, displacement, and floor rotation histories quantified using the Frequency Domain Error (FDE) index. The analyses showed that 3D with multiple support excitation provided the most accurate results, and that effects of wave passage were a significant.

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Sustainable Resilience for 3D Concrete Printed Homes in New Zealand: a three years research government funding overview

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2B Special Session: Structural Engineering of 3D concrete printed elements: status and future challenges, Dobson 1, November 11, 2024, 4:00 PM - 6:00 PM

3D Concrete Printing (3DCP) in construction is a novel technology that has the potential to disrupt the current construction industry as well as bring numerous benefits. These include reduced construction time, waste minimisation, higher accuracy, fewer CO2 emissions, geometrical freedom, and site safety improvements. Research in 3DCP materials and structures has been investigated for more than a decade. However, the implementation of this technology in New Zealand is still limited due to the seismicity of the country, the availability and the cost of the raw material, some mechanical characteristics of the 3DCP material such as anisotropy and durability, and unknowns regarding reinforcement solutions for structural elements.

The Ministry of Business, Innovation and Employment has funded the “Low-carbon and seismically resilient solutions for 3D concrete printed home”, a project aimed at investigating the feasibility of 3DCP in New Zealand. The project aims to develop low-carbon novel 3DCP materials as well as to develop and test steel-reinforced 3DCP structural elements for seismic-cyclic loading.

This article presents the results and plans of the ongoing research at the University of Canterbury as well as some case studies of 3DCP homes in New Zealand. At a material level, two novel binders have been developed using local and waste materials: limestone, calcined clay, zeolite, wastepaper sludge and mussel shell powder. Results in terms of fresh and mechanical properties including durability are presented. At a structural level, the plans for experimental tests of vertical 3DCP adopting post-tensioning bars and conventional reinforcement will be overviewed. The paper concludes by discussing two case studies of residential 3DCP homes built in New Zealand's low-seismic areas.

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A structural engineering perspective on extrusion-based 3D concrete printing: from green to solid state

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2B Special Session: Structural Engineering of 3D concrete printed elements: status and future challenges, Dobson 1, November 11, 2024, 4:00 PM - 6:00 PM

3D printed concrete is well known to demonstrate anisotropic mechanical properties due to weak bonding between the successively deposited concrete layers. A recent study noted a 45.6% averaged maximum reduction in mechanical strength together with a 53.8% coefficient of variation. The weak bonding is synonymous with cold joints in conventional construction, which can be attributed to i) fast material hydration due to the use of accelerating admixtures for increased buildability and ii) filament surface water evaporation due to the lack of formwork. From a structural engineering perspective, it is required to consider this orthotropic behaviour in analyses. Anisotropic continuum macro-modelling and multi-surface interface micro-modelling strategies have successfully been employed in literature to accurately capture failure mechanisms. It has furthermore been demonstrated that the Eurocode 2 design equations hold for printed concrete's structural design, specifically in bending, if the poor shear performance of printed elements with weak interlayers is improved. This is possible through i) novel shear-contributing reinforcement strategies such as nailing, helical screws and rivet reinforcement and ii) by improving the bond strength between layers. The latter has been successfully achieved through i) topologically interlocking layers as a mechanical mechanism and ii) steaming of layer surfaces to replace evaporated water. Although impressive results have been obtained from these interlayer interventions, both in mechanical and durability performance, it remains critical that the fresh state (also called constructability performance) be accounted for. Here, it is in the engineer's best interest to print vertically as fast as possible in order to reduce the time required to print one layer, whilst also preventing in-print structural collapse. Analytical optimisation models have been successfully employed to this end. This contribution delves into these structural engineering aspects to highlight their importance as part of the structural analysis and design process of 3D printed concrete elements.

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Current Developments in the Application of Extrusion-based 3D Concrete Printing

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2B Special Session: Structural Engineering of 3D concrete printed elements: status and future challenges, Dobson 1, November 11, 2024, 4:00 PM - 6:00 PM

Automation technology for construction applications is gaining significant attention, contributing to economical and sustainable construction practices. Extrusion-based 3D concrete printing (3DCP) is one of the widely adopted automation processes allowing to built intricate geometries with a freeform construction method. However, despite its potential, the large-scale application of extrusion-based 3DCP still poses significant challenges in developing high-strength, sustainable printable concrete mixes and feasible reinforcement methods. This study discusses the current developments in sustainable printable concrete mixes, assessing their pumpability performance and exploring the in-process reinforcement methods for 3DCP structures. Recent advances in alkali-activated printable mixes using fly ash and slag instead of cement have paved the way for high-strength sustainable printable mixes. Moreover, employing vibration-induced active rheology control during pumping enhanced the lubrication layer properties, thereby improving the pumping efficiency by reducing the pumping pressure and mitigating the clogging issues along the pipeline. Apart from the advancements in printable mixes, the in-process reinforcement method utilising textile reinforcement and recycled plastic fibres has shown promise in improving the mechanical properties of 3DCP structures. Incorporating plastic fibres significantly improved the flexural and compressive strength of 3DCP elements, along with improving thermal resistance. This paves the way for building energy-efficient and aesthetically pleasing structures. Moreover, incorporating high-strength flexible textile reinforcements (like AR-glass, carbon and basalt) improves the flexural and tensile capacity of 3DCP structures and facilitates the construction of slender structures, thus reducing the overall carbon footprint. These advancements in sustainable concrete mixes and reinforcement methods expand potential of 3DCP for large-scale construction, offering opportunities for efficient and aesthetically pleasing structures.

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Seismic Performance of Large-Scale 3D Printed Concrete Panels: An Experimental and Analytical Study

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2B Special Session: Structural Engineering of 3D concrete printed elements: status and future challenges, Dobson 1, November 11, 2024, 4:00 PM - 6:00 PM

The advent of 3D Concrete Printing (3DCP) technology has opened new possibilities in the construction industry, especially in the optimization of structural design and sustainability. This study is deals with the seismic implications of using large-scale 3D printed concrete panels, focusing on their unique manufacturing characteristics and potential advantages over traditional construction methods. Through an experimental framework, we examine the behavior of these panels under cyclic in-plane loading and axial forces, simulating seismic effects to assess their structural resilience and performance. Accompanying the experimental investigation is an analytical interpretation that includes a Finite Element Method (FEM) approach for accurately modeling the interfaces between layers, a critical aspect unique to 3DCP. Furthermore, we compare the seismic response of 3D printed panels with existing structural codes to highlight discrepancies and areas of alignment. The findings reveal insightful aspects of 3D printed concrete's behavior under seismic loading, emphasizing the technology's potential and current limitations. Despite demonstrating promising attributes, the study identifies specific constraints related to the material properties and printing techniques that need addressing to fully exploit 3DCP in seismic-prone areas.

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Analytical investigation on the structural performance of RC column with 3D-printed concrete permanent formwork

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2B Special Session: Structural Engineering of 3D concrete printed elements: status and future challenges, Dobson 1, November 11, 2024, 4:00 PM - 6:00 PM

Mechanical anisotropy of 3D printed concrete (3DPC) has been often considered harmful; however, its detrimental effect is not so serious or even negligible in some applications, such as permanent formwork made of 3DPC. Recently, several previous studies have demonstrated that 3DPC permanent formwork for reinforced concrete (RC) column construction can rather enhance the structural performance due to higher confinement effects from the permanent formwork. However, no comprehensive research has yet been conducted on effects of influential factors, including material properties, interlayer bonding properties, dimensions of 3DPC, bonding properties between 3DPC and inner core RC, and loading conditions. This research aims to evaluate effects of various factors on the structural performance of the RC column with 3DPC permanent formwork by using finite element method (FEM)-based nonlinear structural analysis. Specifically, the behaviors of 3DPC-RC columns under either uniaxial compression or reversed cyclic loading, which were reported in previous experimental studies, were investigated. Properly considering the material properties, structural dimensions, boundary and loading conditions of the columns, the FEM analysis could reproduce the force-displacement curves observed in experiment. The enhanced load-bearing capacity due to confinement effects could also be reproduced. The simulated failure modes also agreed with those in experiment. Subsequently, a parametric study using the FEM analysis was conducted varying material properties and bonding properties of 3DPC. The analysis results implied that the interlayer bonding properties have relatively small effects on the structural performance, especially in the case of the reversed cyclic loading. This is probably because the overall behavior is governed by the inner core RC and the effects of the thin permanent formwork are relatively limited. Therefore, 3DPC permanent formwork for RC column construction is a promising application in which detrimental effects of weak interlayers of 3DPC can be negligible and the overall structural performance can be even enhanced.

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The Contribution of 3D Printed Lost Formworks to the Compressive Capacity of Structural Columns

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2B Special Session: Structural Engineering of 3D concrete printed elements: status and future challenges, Dobson 1, November 11, 2024, 4:00 PM - 6:00 PM

Large-scale cement-based Additive Manufacturing (AM), also known as 3D Concrete Printing (3DCP), is a promising technique aimed at innovating the construction industry. Although proto-type 3DCP homes have been built around the world, the structural performance of large-scale printed elements is not fully understood yet. 3D-printed structures, in particular columns, have already been utilised as lost formworks. However, there is a significant lack of knowledge regarding the structural contribution as well as the confining effect of printed formwork.

The goal of this research is to investigate experimentally the behaviour under pure compression of columns with 3D printed shells. Limestone-calcined-clay-cement (LC3)-based mortar is used for the printed shell. A concrete mix is utilised for the inner core of the specimens. Traditional cast concrete columns are also tested (using the same concrete mix) and used as a benchmark. A total of 9 specimens are tested at the age of 28 days, 3 cast columns, 3 printed columns and 3 printed columns with extra interlayer stirrups (placed every 5 layers). Traditional reinforcement is used in all cases. The printed filament width of the shell is 27±2 mm, and a concrete cover of 30 mm is selected for all the specimens.

Due to the lack of guidance on dimensioning and detailing the 3DCP elements, columns have been designed according to the Seismic Design Guide for Low-rise Confined Masonry (CM) buildings. The interlayer stirrups are proposed as an economical solution to enhance the confinement effect of the printed shells. Therefore, the early spalling of the printed shells mentioned in the literature may be delayed and the shell could contribute to the load-bearing capacity of the column. This paper presents the experimental research plan for testing 3D printed columns.

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A Rapid Reinforcement Technique using FRP and Steel Wire Mesh in 3D Printed ECC Beams

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2B Special Session: Structural Engineering of 3D concrete printed elements: status and future challenges, Dobson 1, November 11, 2024, 4:00 PM - 6:00 PM

3D concrete printing is a potential technology for increasing automation and introducing digital fabrication in the construction industry. Engineered Cementitious Composites (ECC), due to its strain-hardening and multiple cracking capability, have been proven as excellent materials for the construction of unreinforced structures and have emerged as a promising material for 3D printing. However, the difficulty on reinforcing integration and limited flexural strength of unreinforced ECC structures obstruct 3DP-ECC materials to shift towards a large-scale construction technology paradigm. This study innovated a method for rapid arrangement of fiber reinforced polymer (FRP) meshes and steel wire meshes at the interlayer interface of 3DP-ECC beams in the synchronous printing process. The effect of mesh specification, ECCs with different strain capacity on the mechanical behavior of reinforced 3DP-ECC beams were investigated by tests. Experimental results demonstrated that contrast to FRP mesh, steel wire meshes could deform collaboratively better with ECC. The load bearing capacity of 3DP-ECC beams reinforced with FRP meshes and steel wire meshes were 1.22~2.01 times and 1.98~3.17 times that of the unreinforced beam, respectively. Furthermore, a series of parameter analyses were conducted by numerical simulation, including printing interface strength, mesh material properties, toughening measures, etc. The technique accommodated the automatic characteristics of additive manufacturing processes and satisfied the requirements of mechanical properties for construction applications. The study validated the feasibility and effectiveness of FRP mesh and steel wire mesh to reinforce 3D printed ECC beams.

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Is 3D Printed Concrete a Game Changer?!

Wafaey Swelim

2B Special Session: Structural Engineering of 3D concrete printed elements: status and future challenges, Dobson 1, November 11, 2024, 4:00 PM - 6:00 PM

As New Zealand grows, we face a housing shortage and a need to be kinder to our planet. 3D concrete printing steps in as a game-changer. 3DCP tech speeds up construction, cuts down on emissions, and saves money—huge wins in a world where skilled workers are scarce and affordable housing is in high demand.

Thanks to additive manufacturing, 3D concrete printing can create complex and unique shapes that traditional methods can't. This freedom in design opens up new possibilities for architects and engineers to get creative with their projects. Plus, because it uses materials more efficiently and automates the building process, it helps make construction more eco-friendly, fitting right in with global sustainability goals.

QOROX wall systems have been tested and appraised in NZ and we have printed, houses, commercial buildings, traffic islands, coral reefs and even skatepark features.

From houses and offices to flood defences, infrastructure, and bridges, the uses of 3D concrete printing are vast. With quicker construction times, potential cost savings, and the ability to build low-maintenance, energy-efficient structures, this cutting-edge technology is set to transform the construction world and tackle the big challenges faced by communities everywhere."

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Natural pozzolans in Germany

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2C Special Session: Using natural resources as a cement replacement for a lower carbon concrete, Dobson 2 & 3, November 11, 2024, 4:00 PM - 6:00 PM

The use of natural pozzolans has a long tradition in Germany: the pozzolanic properties of local volcanic ashes were recognised as early as the 17th century. Two main natural materials are used as natural pozzolans. The volcanic ash from the Laach Lake region is the result of numerous volcanic eruptions, the last of which occurred 13,000 years ago. The material is now known as Rhenish trass and is used as a supplementary cementitious material. On the other hand, suevite is used as a SCM. Suevite is an impact material formed by a meteorite impact about 14 million years ago and is similar to volcanic ash. In principle, the pozzolans found in Germany have many similarities with the volcanic ashes known worldwide. This article gives an overview of the use of these natural pozzolans in Germany. The chemical and mineralogical compostion of both Rhenish trass and suevite are characterised and their differences are described. Reactivity is also shown using the Chapellle and the R^3 test.

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Pilot Study on Natural Pozzolans as Cement Replacements for Low-Carbon Concrete

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2C Special Session: Using natural resources as a cement replacement for a lower carbon concrete, Dobson 2 & 3, November 11, 2024, 4:00 PM - 6:00 PM

Concrete is a prominent construction material around the world, and demand is increasing due to urbanization and population growth. This study aimed to investigate the performance of concrete with locally sourced pumice and tephra from New Zealand as partial cement replacements. The sum of SiO2, Al2O3 and Fe2O3 oxides in pumice and tephra was higher than 70%, achieving the ASTM C618 criteria for use as a natural poz1zolan. Pumice and tephra were ground to particles smaller than 75 microns and replaced the cement up to 30% in concrete. The average target compressive strength was 20 MPa at the 28 days of curing. Slump, temperature, pH and density were measured as fresh concrete properties, and compressive strength and flexural strength were observed as hardened concrete properties. Life cycle assessment was conducted as per the BS EN 15804+A1(2013) to evaluate the environmental impact of concrete mixes based on three concrete batching plants. The 10% replacement level could achieve the design require1ments, and the reduction of global warming potential (GWP) is closely aligned with the percentages of cement replacement, up to 30%.

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Low-Carbon Concrete with New Zealand Pozzolans

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2C Special Session: Using natural resources as a cement replacement for a lower carbon concrete, Dobson 2 & 3, November 11, 2024, 4:00 PM - 6:00 PM

Supported by Hoe ki angitū, the NZ Transport Agency Waka Kotahi Innovation Fund, this project focused on minimising cement usage in concrete by harnessing New Zealand’s natural pozzolans through Neocrete’s innovative technology – the Activator.

Neocrete's Activator serves as a catalyst, stimulating and expediting pozzolanic reactions within concrete. This process yields superior concrete properties compared to conventional concrete, while significantly reducing cement and thus embodied carbon.

The project's objective was to gradually substitute cement in concrete with pozzolans, aiming for similar hardened and plastic properties as standard 25 and 40 MPa grade concrete.

Extensive testing in Neocrete and Higgins Concrete laboratories in New Zealand were in line with NZS3104:2021 Specification for Concrete production and relevant concrete testing practices as per NZS 3112:1986 Methods of Test for Concrete. Evaluations encompassed fresh concrete properties, compressive strength, and additional special durability tests, performed by independent laboratories in Australia.

The test results demonstrated that concrete with up to 40% replacement of cement with natural pozzolans and the Activator at 3-4.5% (of cementitious material), achieved similar or higher compressive strength at every age of strength setting, including overnight strength.

Similar workability and slump retention levels were achieved with pozzolanic concrete at up to 40% cement replacement levels and the Activator at 3-4.5%, however the pozzolanic concrete required a higher original slump than control.

Improved durability and water-permeability characteristics were achieved with concrete at up to 40% cement replacement levels at the Activator at 3%-4.5%.

The project has demonstrated that concrete with up to 40% cement reduction can safely be used for NZ roading infrastructure, without significant changes to existing concrete practices and timelines, when using New Zealand based natural pozzolans activated with Neocrete Activator.

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Classification and Quantification of Pore Structure of Hempcrete

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2C Special Session: Using natural resources as a cement replacement for a lower carbon concrete, Dobson 2 & 3, November 11, 2024, 4:00 PM - 6:00 PM

Hemp (i.e., Cannabis sativa L.) was used as paper or rope, but its usage declined due to the discovery of cotton and negative views on the drug. However, it started to be used in agriculture and construction, mainly in France and Belgium. Hemp particle (i.e., hemp shiv) is currently used as one of the promising bio-based aggregates along with cereal straws, wood aggregates, bast fibers, and palm tree fibers).

It is well known that hempcrete can be used as sound-proof or thermal insulated cementitious materials due to the large porosity of hemp. However, the correlation of the sound and thermal performances of hempcrete with the 3D porous structure of hempcrete has not been well understood. This is mainly due to the complex 3D structure of pores in hempcrete. It should be noted that hempcrete is composed of three types of porosities such as (1) intra-porosity in hempcrete (i.e., air void), (2) inter-porosity in the binder, and (3) inter-porosity in raw hemp. In this study, three different types of porosities were quantified using different characterization techniques (micro X-ray computed tomography and mercury intrusion porosimetry) to comprehensively understand the pore structures of hempcrete.

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Development of wood-geopolymer composites for masonry units: Effect of alkaline solution ratio and wood type

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2C Special Session: Using natural resources as a cement replacement for a lower carbon concrete, Dobson 2 & 3, November 11, 2024, 4:00 PM - 6:00 PM

The construction industry significantly impacts the environment through greenhouse gas emissions, high energy demand, extensive consumption of natural resources, and waste generation. Various studies have delved into repurposing industrial by-products as alternatives to traditional construction materials. One area that holds promise in this regard is waste wood recycling. End-of-service timber can be repurposed into innovative construction materials such as masonry units. Their high availability, desirable heat and sound insulation properties, and lightweight nature make them ideal for masonry block production. Given masonry blocks' moderate mechanical strength requirements, achieving the necessary structural integrity is well within reach. Using a sustainable binder, such as a geopolymer, could further enhance the overall sustainability of these materials, allowing for rapid development of strength, improved durability, and heightened protection against fire and weathering effects.

Accordingly, this study explored the feasibility of producing wood-geopolymer composites (WGC) suitable for the production of masonry units. Through rigorous experimentation, the development of a mix-design with controlled workability to produce masonry units utilizing WGC was explored. The research also investigated the viability of employing the standard block-making method for WGC blocks. In this context, a 2×6 partial factorial-based experimental design was used to study the effect of sodium silicate to sodium hydroxide ratio (3 levels) and different wood types (2 levels) on the workability and strength of WGC. The results yielded encouraging prospects for manufacturing wood-geopolymer masonry units (WGMUs), affirming the viability of seamlessly integrating the production of masonry units using established block-making processes.

Keywords: Sustainable construction material, bio-sourced material, workability, wood-geopolymer composite, mix design, lightweight composites, masonry units.

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Strength and Permeability of Concrete using Lithium Slag as a Supplementary Cementitious Materials

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2C Special Session: Using natural resources as a cement replacement for a lower carbon concrete, Dobson 2 & 3, November 11, 2024, 4:00 PM - 6:00 PM

This paper will present the results of an experimental study that examined the impact of lithium slag (LS) on the durability properties of concrete. The lithium refinery residue known as LS is an industrial by-product obtained after the extraction of lithium from spodumene ore. As the demand for lithium in modern technology is increasing day by day, the emission of LS is also increasing abruptly having adverse effects on the environment. However, it has been discovered that LS contains a considerable amount of active silicon dioxide and aluminium oxide, therefore, can be used as a potential supplementary cementitious material (SCM) in concrete. In this study, the durability of concrete is evaluated by partially replacing cement with LS. To assess this, 20-40% cement was replaced by LS and the results are compared with those of the control mix. To evaluate the effect of LS on the properties of concrete, workability, compressive strength, and volume of permeable void (VPV) are conducted at 28 days of curing. Results show that with a constant water-to-binder ratio, slump decreased by 16% and compressive strength increased by 7% when compared to those of the control mixtures. and the volume of permeable voids decreased by 30% due to the incorporation of 20% LS.

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High-Temperature Fracture Behaviour Of One-part Geopolymer Incorporating Lead Smelter Slag and Steel Fibre: Digital Image Correlation (DIC) Analysis

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2C Special Session: Using natural resources as a cement replacement for a lower carbon concrete, Dobson 2 & 3, November 11, 2024, 4:00 PM - 6:00 PM

Driven by the transition toward net-zero emissions, the evolution of low-carbon materials holds a significance for the future sustainability. Alkali-activated materials (AAMs), derived from waste materials, offer a promising alternative to conventional materials like Portland cement, reducing reliance on high-carbon footprint resources. Also, AAMs exhibit enhanced thermo-mechanical properties, rendering them especially suitable for high-temperature applications. The incorporation of lead smelter slag (LSS), a byproduct of metallurgical processes, along with the addition of steel fibers (SF), represents a promising avenue for enhancing the high-temperature stability and performance of AAMs. This study aims to characterise fracture behaviour of ambient-cured one-part AAMs incorporating LSS and SF before and after exposing to high temperatures, using digital image correlation (DIC) method. Three mixes are designed, including the control mix (G), the G-LSS mix with 100% LSS as sand replacement and the G-LSS/SF mix with the addition of 1.5% SF. The one-part AAM paste constituents contain the mixture of precursor (40% fly ash + 50% slag + 10% copper powder), solid sodium metasilicate (10 wt.% of precursor) and graphene oxide (0.1 wt.% of precursor). The three-point bending test coupling with DIC technique is conducted to compare the crack patterns and strength/toughness of samples before and after exposing to elevated temperatures (450oC). The outcome of this study can provide not only the understanding on effects of LSS and SF on temperature-induced crack resistance of one-part AAMs, but also the sustainable ambient-cured one-part AAM mixtures incorporating metallurgy waste for high temperature applications such as thermal energy storage.

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Prestressed Members Subjected to Prestressing Analysis Using Stress Release Technique

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2D Structural health monitoring, Dobson 4, November 11, 2024, 4:00 PM - 6:00 PM

Application of prestressed concrete structures in civil engineering practice enabled to design of structures with longer spans or more subtly cross-sections. The essence of these structures is the prestressing force. Therefore, the knowledge of its actual value is crucial for proper structural analysis. Recently, we have witnessed numer-ous failures of prestressed concrete bridges in the world as a result of an unexpected decrease in the level of prestressing. Consequently, researchers are trying to find methods for prestressing force monitoring. Currently, available methods include, e.g., stress-release techniques (Saw-cut method, Drilling method), Magnetoelastic methods, Structural response methods (Crack initiation, Crack reopening) and so on. This paper presents a summarization of numerical and experimental analyses of the prestressing of members subjected to the Saw-cut method. Saw-cuts of various pa-rameters are applied to specimens and subsequently normal stress release is record-ed by linear foil strain gauges and FBG sensors. A presented analysis was performed to verify the method in various conditions (compressive stress and tensile stress re-lease) and saw-cut parameters (depth, axial distance, type of sawing). The measure-ments have been performed in both laboratory conditions and in situ on existing prestressed concrete bridges. Finally, the experiments showed good agreement with the assumptions described by the parametric study. Performed measurements sug-gest that it is advisory to use gradual application of saw-cut, for example, in 10 mm increments. Moreover, the future of this technique is in using modern and more pre-cise FBG sensors.

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Experimental investigation using an innovative wireless sensor technique to measure concrete strains in situ and in real time

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2D Structural health monitoring, Dobson 4, November 11, 2024, 4:00 PM - 6:00 PM

During their life, Reinforced Concrete (RC) structures are naturally subjected to degradation, exceptional events or anthropocentric events, such as change of intended use and increase of loads applied on its structural elements. All these events affect the conditions of structures which may lead to the accumulation of damage. Therefore, in order to prevent accidents, or even disasters, Structural Health Monitoring (SHM) is essential to monitor the conditions of structures and allow to act preventively with maintenance or reinforcing solutions. To monitor the internal stress-strain state of structural elements, sensors, such as electrical strain gauges or fibre optics, are commonly employed.

Within the framework of the i-MON project, an innovative wireless and fully passive sensor capable of measuring deformations inside a Reinforced Concrete (RC) element is being developed. Such device is based on the Surface Acoustic Wave (SAW) technology. In this work, a preliminary investigation about the quality of the measurements obtained with this sensor is presented by comparing these measurements with those of resistive strain gauges mounted on steel rebars. To do so, the measurements are performed at the top of the central region of a 2-meter long beam tested under 4-point bending test. The test consists of three load cycles in which the maximum concrete compressive strain, recorded by the electrical strain gauges (ESG), was progressively increased up to a value of about close to 1000 µm/m which represents a typical SLS-level (serviceability limit state). The results show a good match between the measurements of the sensor and the electrical strain gauges. In particular, a direct correspondence between the variation of frequency, measured by the sensor, and the variation of strain, measured by the electrical strain gauges, was observed. These results are very promising and confirm the interest of the SAW-based solution for future applications on real structures.

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openLAB – A large-scale demonstrator for advancing digital twin developments of bridges

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2D Structural health monitoring, Dobson 4, November 11, 2024, 4:00 PM - 6:00 PM

In future, digital twins will be used for the predictive maintenance of civil infrastructure. The real-time capabilities of digital twins are typically achieved through metrological monitoring of real objects, the “physical twins”. The monitoring process usually generates large amounts of data, the full value of which can only be exploited if the monitoring data is automatically evaluated and assessed. If anomalies are detected in the monitoring data, it is mandatory to reliably distinguish between sensor faults and structural damage. In the worst case, damage is identified as a sensor fault, entailing incorrect condition assessment of the structures being monitored.

Due to a lack of real data, in which structural damage is reflected (e.g., on bridges), existing evaluation methods are not sufficiently validated. This is where the IDA-KI research project comes in. A 45 m long, three-span research bridge, the “openLAB”, has been built and equipped with an extensive monitoring system. Parts of the measurement technology, such as distributed fiber optic sensors, have been installed before pouring the concrete. In the first year after completion, the undamaged reference condition of the bridge is measured under climate and simulated traffic impact. Subsequently, load tests up to the state of severe damage are carried out to create a database containing specific signal characteristics for sensor faults and structural damage.

This contribution outlines the project idea behind IDA-KI, and first results of the preliminary tests and measurements on the research bridge are presented. The openLAB, which will also be made accessible to international research groups, is presented with its structural features and the monitoring system installed on the research bridge. As will be shown in the full paper, methods for automated data analysis and sensor fault detection based on the monitoring data are proposed and validated through first tests.

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Exploring Bridge Structural Response similarities: Data-Driven SHM Through MEMS Clinometer Clustering over a Network of 25+ Reinforced Concrete Bridges

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2D Structural health monitoring, Dobson 4, November 11, 2024, 4:00 PM - 6:00 PM

Structural Health Monitoring (SHM) employs a combination of mechanism analysis, monitoring technology, and data analytics to identify, classify, and assess the significance of structural conditions such as sudden or cumulative damages. In recent years, the spread of IoT continuous SHM systems has enhanced the control of the functionality and operational integrity of bridges supporting an informed proactive maintenance, management, and decision-making processes associated with bridges. With the growing availability of big data across a network of similarly monitored structures, there is an increased interest and possibility of conducting a more in-depth analysis to identify commonalities or differences between homogeneous structural schemes and typologies. This interest arises from the dual need to optimize the utilization of monitoring systems over a widespread network and to address the challenge that in-service bridges often lack data from damage scenarios, with existing methods struggling to achieve real-time detection. In this context, unsupervised learning has gained popularity, as this approach can operate without the need for damaged samples and can be used in conjunction with transfer learning to extend considerations regarding the structural behavior within structural families. However, this assumption requires a rigorous validation process based on a large number of acquired data. This paper focuses on the analysis of the static response of over 25 reinforced concrete and prestressed bridges/viaducts built in Italy, sharing similarities in static schemes and construction methods. The analysis involves clustering statistical features, previously synthetized using Principal Component Analysis (PCA), to represent the long-term static structural response. MEMS biaxial sensors, installed in analogous positions on the bridges structural components for at least 1 year of continuous monitoring, are employed. The research draws on data from more than 3500 MEMS clinometer sensors installed on 28 bridges within the monitoring network of Sacertis Ingegneria, a leading company in structural monitoring with over 150 continuously monitored structures. Various clustering algorithms have been applied to identify analogies between similar structures, materials, spans, construction age, static schemes, and structural components (piers, deck, abutments). The extensive dataset analyzed serves as a valuable database for a thorough validation of the assumption of transfer learning within structural families.

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Maximizing Predictive Maintenance Efficiency across Extensive Infrastructure Networks: Optimized Approaches Integrating Model-driven and Data-driven Solutions in Practical Applications

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2D Structural health monitoring, Dobson 4, November 11, 2024, 4:00 PM - 6:00 PM

Bridges are key infrastructures constructed with the long-term goal of addressing the socioeconomic needs of multiple generations, designed with a lifespan of 100 years or more. Despite this longevity, the service demands required to bridges are subject to evolution throughout their lifespan. The cumulative effects of degradation over the years, natural and human-induced hazards, aging or increase in traffic loads, poses escalating risks for bridge infrastructures. Within this context, the crucial aspects of an asset management plan include the structural assessment of existing structures, prioritizing structural interventions, and optimizing maintenance schedules. To facilitate accurate diagnostics, guide cost-effective safety assessments, and inform decisions on repairs and renovations, timely and precise information from Structural Health Monitoring (SHM) proves indispensable. The deployment of SHM systems across extensive infrastructure networks enables administrators to evaluate the ongoing safety levels of managed bridges. However, the implementation of a widespread monitoring system on a large scale often involves costs that may not align with available resources, posing to Road Operators and Engineers the challenging requirement to optimize the utilization of monitoring systems over the network. The design of SHM systems, both in terms of sensors type and positioning, can be optimized, ranging from a diffuse to a local approach. The diagnostics approach may vary between different structures, as well as within different spans of the same bridge, based on the monitoring requirements or the state of conservation, mixing more refined Model Driven (MD) analysis with Data Driven (DD) approaches. Model Driven diagnostics approaches are supported by detailed non-linear FEM models updated based on the structural ongoing response and provide a deep knowledge of the asset fostering damage identification goals. Conversely, Data Driven approaches encompass anomaly detection techniques to promptly identify deviations from the standard bridge behavior in those structures that are not subject to safety deficiencies. This paper delves into the optimized approaches applied by Sacertis Ingegneria integrating Model-Driven and Data-Driven solutions in practical applications over a network of more than 150 bridges under continuous monitoring using MEMS sensors. Case studies will be presented to detail the monitoring strategy, focusing on the mixed approach MD-DD over modular bridges with multiple similar spans. The monitoring mixed strategy will be explained following both a civil engineering focus, as well as using unsupervised machine learning algorithms such as feature-based transfer learning that can support the long-term damage detection process based on a classification of similar structural components.

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Vibration-Based Damage Detection in a Reinforced Concrete Plane Member Using a Small Exciter

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2D Structural health monitoring, Dobson 4, November 11, 2024, 4:00 PM - 6:00 PM

To assess damage in reinforced concrete (RC) structures following a significant earthquake, the changes in the structure's vibration characteristics can be examined via a specific method. This research involves a combination of static loading tests and forced vibration tests to evaluate the fundamental vibration characteristics of an RC member affected by seismic damage. The test specimen was an RC plane mem-ber devoid of shear reinforcing bars. In the static loading test, vertical loading and unloading, corresponding to the out-of-plane direction, were applied repeatedly. During the unloading intervals of the loading test, forced vibration tests were con-ducted using a small exciter on the test specimen. The first and second natural fre-quencies were estimated from the transfer function characteristics, which were based on the acceleration data from the exciter and the test specimen. These natural mode shapes were correlated using a finite element model. A typical change ob-served in the vibration characteristics due to static loading was a decrease in the nat-ural frequency. Additionally, an increase in the number of resonance peaks in the higher frequency region was demonstrated, suggesting that local vibration modes of the RC member might emerge due to the development of a shear crack.

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Health Monitoring During Construction of Century Pavilion in 10th China Flower Expo

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2D Structural health monitoring, Dobson 4, November 11, 2024, 4:00 PM - 6:00 PM

Century Pavilion in 10th China Flower Expo is an exhibition hall during 10th China Flower Expo and will be a permanent venues for future programs, which is a prestressed concrete thin-shell structure of ultra-large span free-form surface. The health monitoring during construction of Century Pavilion in 10th China Flower Expo was carried out. Strain-temperature sensors, inclinometers, machine vision measuring instruments, preset center hole pressure sensors were used to monitor the status of the structure in real time. Midas/Gen is used for finite element simulation calculation of the construction process of the structure, which provides a basis for data control and analysis in the construction process. It is found that the subsidence of the structure roof is less than the calculated value, and the whole structure is safe. The structure is sensitive to temperature change, and the daily strain fluctuates greatly (about 30℃) when exposed to direct sunlight, which became better (in 20℃) after covering with soil. Structural health monitoring during construction provided measured data of the main structure of the exhibition hall in working state, which verified the safety of the structure in construction stage and ensured the orderly and efficient construction of the structure. The method, data and analysis of this health monitoring project can be reference for future engineering practice and research.

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Advancements in Digital Twin Development for Bridges in Germany

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2D Structural health monitoring, Dobson 4, November 11, 2024, 4:00 PM - 6:00 PM

The conception and development of digital twins (DT) are increasingly under investigation within the domain of civil engineering. They manifest considerable potential across diverse stages of construction, encompassing design, construction, operation, and maintenance. This paper focuses on the development and advances in digital twins for bridges in Germany. Firstly, the application and development of DTs in bridge engineering are introduced. Subsequently, the implementations of related methods and technologies, including 3D measurements, Building Information Modelling (BIM), structural health monitoring (SHM), non-destructive testing (NDT), etc., are elaborated upon. As an essential component of DT, the management methods like common data environment (CDE) and linked data, for different data are explained. Afterwards, various pilot projects in Germany such as SmartBridge Hamburg, the DT of Fils Viaduct, and the Nibelungen Bridge Worms are demonstrated in detail. In the end, some conclusions and outlooks are provided.

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Effects of Loading History on the Behavior of Reinforced Concrete Columns

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3A Special Session: Nonlinear modeling, seismic assessment, and rehabilitation of reinforced concrete structures (part 2), Auditorium, November 12, 2024, 10:30 AM - 12:00 PM

Experimental studies have indicated that the lateral and axial behaviors of concrete columns under seismic excitation can be highly dependent on loading history, particularly at high-damage states. However, most experiments on concrete columns have used fully reversed cyclic loading protocols, with only limited tests in the literature exploring the effects of loading history. Due to the lack of experimental data, continuum finite element models were constructed to cover a relatively wide range of column parameters and failure modes, with primary objective of quantifying the effects of loading history on both lateral and axial degradation of concrete columns. Eighteen column models representing experimentally tested columns were subjected to varying lateral loading protocols, including different axial load levels. A total of 116 simulations were conducted to axial failure. The effects of the lateral loading protocols on strength and deformation capacities of concrete columns were quantified. Relations for estimating reductions in drift capacities due to increased lateral cycling are proposed for both initiation of lateral strength degradation and initiation of axial degradation.

Keywords: Finite element, Reinforced concrete, Columns, Loading effects

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Calibration of Different Analytical Models for Concrete Coupling Beams and Walls Against Experimental Data for Performance Based Design

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3A Special Session: Nonlinear modeling, seismic assessment, and rehabilitation of reinforced concrete structures (part 2), Auditorium, November 12, 2024, 10:30 AM - 12:00 PM

Special reinforced concrete shear walls (with or without coupling beams) are efficient earthquake- and wind-resistant systems for mid- and high-rise buildings. These systems have been predominantly used for tall buildings in the United States and the world where a Performance Based Seismic Design (PBSD) approach is utilized. Localized ductility in the walls and coupling beams are the primary fuses to limit force demands on capacity protected elements and actions, such as foundation and wall shear, providing reliable and stable energy dissipation mechanisms. For PBSD, reference guidelines (i.e., LATBSDC; TBI) provide the basic framework without analytical implementation details. Currently, there are various structural software applications available for modelling the required nonlinear behaviour. However, there is a lack of a unified approach across software applications to define element properties for nonlinear response. In this study, analytical nonlinear models are implemented using Perform3D, ETABS, and OpenSees and calibrated against experimental data. Examples of the calibration for coupling beams include diagonally reinforced, conventionally reinforced, fiber reinforced, and encased steel shapes. For walls, a calibration for a rectangular and coupled wall system is presented. The calibration approach for these components is applicable to large deformation PBSD and low amplitude Performance Based Wind Design (PBWD).

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Updated modeling parameters and acceptance criteria for concrete structural walls

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3A Special Session: Nonlinear modeling, seismic assessment, and rehabilitation of reinforced concrete structures (part 2), Auditorium, November 12, 2024, 10:30 AM - 12:00 PM

Most of the provisions for concrete structural walls in ASCE/SEI 41-17 were developed in the late 1990s based on limited experimental data and judgement for FEMA-273 (1997a) and FEMA-274 (1997b). The only exception being the modeling parameters and acceptance criteria of shear-controlled walls, which were updated for ASCE/SEI 41-06 Supplement 1. As a result, the wall provisions tend to be, in many cases, inaccurate and conservative, and thus can produce uneconomical retrofit schemes. This study involves utilizing available experimental data from a large wall test database (more than 1,100 wall tests) and new information on performance of structural walls to perform a comprehensive review of all structural wall provisions and develop modeling parameters and acceptance criteria for walls (conforming and non-conforming flexure-controlled walls, diagonal shear-controlled walls, shear-friction-controlled walls) that will produce improved seismic assessments of wall buildings. Assessment outcomes between provisions of ASCE/SEI 41-17 and the proposed provisions showed that the current provisions in ASCE/SEI 41-17 are in many cases overly conservative for many structures.

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Resurrection of a 13-story earthquake damaged tower building, 66 Oxford Terrace, Christchurch

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3A Special Session: Nonlinear modeling, seismic assessment, and rehabilitation of reinforced concrete structures (part 2), Auditorium, November 12, 2024, 10:30 AM - 12:00 PM

66 Oxford Terrace in Christchurch was a project involving an alternative method of seismic strengthening to the earthquake damaged 13-storey tower building. It can be evidenced from the damage incurred that the building responded differently to the Canterbury Earthquake Sequences (2010 and 2011), than intended from the original design (2003) and was subsequently assessed as earthquake prone with a rating of less than 34% of New Building Standard (NBS).

Seismic strengthening was undertaken using Tectonus friction damping devices. These devices had not been used on a reinforced concrete building before, let alone a building which is 13 stories high. As this building was the first of its kind to incorporate seismic strengthening using this technology, there was significant technological uncertainty around the design and constructability to integrate the Tectonus devices into the building, to achieve 100% NBS, along with the extensive temporary works and project sequencing to construct.

The project objectives involved:

- Saving the building as this was a greener outcome than demolition.
- Achieve a minimum 100% NBS.
- Transfer from the original rigid shear wall design to a rocking solution utilising 'Tectonus' devices.

The Tectonus solution whilst complex provided an elegant strengthening solution to the building because it:

- Reduced overall extent of the retrofit, due to reduction in the requirement of further strengthening of the reinforced concrete wall elements above level 4 of the existing building.
- The ability of the Tectonus system to provide a rocking plane which will provide a low-damage solution in the event of a seismic event, allowing building to be re-occupied safely post event.
- The reduction in the load demands created by the Tectonus and rocking wall system causes a reduction in the foundation loads (uplift), which in turn reduces the amount of strengthening work needed for the foundation.

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Experimental study on the FRP ties used in precast diaphragm strengthening subjected to incompatible rotation of the floor support beam

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3A Special Session: Nonlinear modeling, seismic assessment, and rehabilitation of reinforced concrete structures (part 2), Auditorium, November 12, 2024, 10:30 AM - 12:00 PM

Hollow core unit floors, a type of precast floor, were used extensively in New Zealand construction, but they have insufficient capacity to transfer high seismic force demand to the lateral load-resisting elements and provide adequate diaphragm performance. Fibre-reinforced polymer (FRP) ties emerged as a preferred solution for concrete floors to retrofit and provide diaphragm functionality, typically using strut and tie methods. However, these precast floors are subjected to notable deformation incompatibility with the ductile frames, which are not considered in the strut and tie methods as these are planar. A prominent type of incompatible deformation is the rotation of the support beam with respect to the precast unit, leading to a substantial discontinuity crack at the interface between the beam and the precast unit. This phenomenon not only damages the floor connection but can also affect the performance of FRP ties during seismic events. Three hollow core unit specimens with a dimension of 4000×1200×280 mm were strengthened with FRP ties and three different FRP anchor layouts and subjected to cyclic rotational deformations to assess the effectiveness of the FRP ties in such a condition. The results indicate that three distinctive mechanisms of predebonding (elastic), progressive debonding and anchor engagement can provide the deformation capacity against incompatible deformation demand. The results highlight that the substantial deformation capacity of ties depends on the adequately designed anchors.

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Seismic retrofit of non-ductile reinforced concrete frame buildings

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3A Special Session: Nonlinear modeling, seismic assessment, and rehabilitation of reinforced concrete structures (part 2), Auditorium, November 12, 2024, 10:30 AM - 12:00 PM

Non-ductile reinforced concrete frame buildings built prior to the enactment of modern seismic codes are often seismically deficient in terms of strength, stiffness and ductility. An effective seismic risk mitigation strategy for such buildings involves seismic retrofits either at the elements level, in terms of improving strength and deformability of individual members, or at the system level for increasing lateral strength, stiffness and energy dissipation capacity while promoting drift and hence damage control. Three seismic retrofit techniques were recently developed at the University of Ottawa, consisting of i) the use of high-strength packaging strips as externally placed column transverse reinforcement for shear strength and flexural ductility enhancements, ii) use of a special BRB system for improved lateral bracing, and iii) the use of progressively engaging prestressing strands as diagonal tension braces. Combined experimental and analytical research was conducted in each research project. The column retrofit technique was developed by testing large-scale circular, square and rectangular columns under reversed cyclic loading, demonstrating the significant shear strength capacity improvement and concrete confinement enhancement with the use of high-strength steel strips. The special BRB used for lateral bracing of nonductile frames was developed such that the ductile internal core bar could function without a gap that is typically required in conventional BRB systems to allow for axial shortening in compression, resulting in improved performance. The diagonal strands used as tension braces for frames were specially designed to engage in seismic resistance only when a predetermined level of lateral drift is attained, without prematurely stiffening the building so that the increase in seismic force demand associated with reduced structural period would not occur until the bracing action is needed. The latter two projects were conducted by using ½ scale reinforced concrete frames under reversed cyclic loading. The results indicate improved seismic performance in all cases.

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Government Action

Mr Nick Leggett

3B Special Session: Decarbonisation of the Built Environment, Dobson 1, November 12, 2024, 10:30 AM - 12:00 PM

This presentation focuses on the New Zealand Government's considerable challenge in addressing a significant national infrastructure deficit while mitigating the impacts of climate change. Treasury's 2022 Investment Statement puts the deficit figure at $210 billion. The New Zealand Infrastructure Commission (Te Waihanga) has stated the nation would need to spend $31 billion on infrastructure each year, for the next 30 years, if we are to build our way out of current and future infrastructure challenges.

Government has made long-term commitments to international and domestic emission targets to ensure a smooth transition to a low-emissions future. Under the Paris Agreement, New Zealand's first Nationally Determined Contribution is to reduce net greenhouse gas (GHG) emissions to 50% below gross 2005 levels by 2030. In 2019, the Government introduced the Climate Change Response (Zero Carbon) Amendment Act which set a target for net-zero greenhouse gas emissions by 2050 (other than for biogenic methane).

Concrete New Zealand's Decarbonisation Roadmap to 2050 recognises that the Government plays a critical role in the journey to achieving net-zero carbon concrete in New Zealand by 2050 and makes 'A Call for Government Action'. The NZ cement and concrete industry has decarbonised by 11% between 2005 and 2020 while simultaneously growing its production by the same amount. The industry can make substantial further progress on decarbonisation by 2030, while delivering a built environment that is resilient and resistant to the rigors of climate change.

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Infrastructure Sustainability Rating Scheme

Dr Kerry Griffiths

3B Special Session: Decarbonisation of the Built Environment, Dobson 1, November 12, 2024, 10:30 AM - 12:00 PM

This presentation explores the pivotal role of the Infrastructure Sustainability (IS) Rating Scheme in advancing the decarbonisation agenda within the construction industry. Comprising the IS Planning, IS Design, and As-Built ratings, the scheme provides a comprehensive framework to quantify economic, social, and environmental opportunities and benefits from the project's inception to its operational phase. The IS Planning rating streamlines benefit delivery by identifying opportunities early, fostering the strongest sustainability outcomes, and allowing flexible application at individual, community, or regional levels.

Transitioning into the design and construction phases, the IS Design and As-Built rating ensures continued focus on economic, social, and environmental aspects, recognising project team achievements and applicable to every infrastructure asset class. The IS Rating Scheme, as the exclusive comprehensive rating system for Australia and New Zealand, evaluates the full asset lifecycle, demonstrating its universal relevance and sustainability impact. With Waka Kotahi's adoption of the Infrastructure Sustainability Council as its rating scheme provider, this presentation provides insights into the practical applications, benefits, and successes of the IS Rating Scheme, offering guidance for stakeholders committed to fostering a sustainable and decarbonised future in construction.

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Low-carbon Cement and Concrete

Mr Chris Johnstone

3B Special Session: Decarbonisation of the Built Environment, Dobson 1, November 12, 2024, 10:30 AM - 12:00 PM

This presentation explains why Holcim has opened a new low-carbon cement replacement facility at the Ports of Auckland in 2023. This facility was the culmination of several years planning to introduce reliable and consistent low-carbon cements and cement replacements into the NZ concrete market. The facility includes supplementary cementitious materials import capability, a grinding plant, and cement blending infrastructure.

Holcim can now provide project-specific, on-demand Environmental Product Declarations (EPDs) to back-up new products. This capability represents a significant step in Holcim's sustainability journey as it provides customers with verified data for use in their own process to determine the carbon footprint of their concrete. Holcim received EPD Process Certification in 2023 having satisfied a rigorous, third-party evaluation of its Life Cycle Assessment (LCA) Calculator. The verified carbon model's development was conducted by internationally recognised experts and was verified in accordance with the relevant ISO standards and guidelines of the International EPD Program and EPD Australasia.

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Large Concrete Products Manufacturing Case Study

Dr Jackson MacFarlane

3B Special Session: Decarbonisation of the Built Environment, Dobson 1, November 12, 2024, 10:30 AM - 12:00 PM

First hand experience from a large user of cement and supplementary cementitious materials (SCMs). This company will outline their reasons for using SCMs to lower the embodied carbon of their products, outline the manufacturing requirements including design and process control considerations, and discuss how they introduced these products to the market and discuss the pull from the market as well as the challenges they faced.

This company will highlight the benefits they see from adopting this strategic direction, and the risks from not moving in this direction.

Concrete New Zealand's Decarbonisation Roadmap to 2050 recognises that the Government plays a critical role in the journey to achieving net-zero carbon concrete in New Zealand by 2050 and makes 'A Call for Government Action'. The NZ cement and concrete industry has decarbonised by 11% between 2005 and 2020 while simultaneously growing its production by the same amount. The industry can make substantial further progress on decarbonisation by 2030, while delivering a built environment that is resilient and resistant to the rigors of climate change.

Infrastructure Sustainability Rating Scheme
This presentation explores the pivotal role of the Infrastructure Sustainability (IS) Rating Scheme in advancing the decarbonisation agenda within the construction industry. Comprising the IS Planning, IS Design, and As-Built ratings, the scheme provides a comprehensive framework to quantify economic, social, and environmental opportunities and benefits from the project's inception to its operational phase.

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Recent progress on seismic strengthening of concrete diaphragms with FRP ties

Dr Enrique Del Rey Castillo[1]
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3C Special Session: Seismic strengthening of concrete diaphragms, Dobson 2 & 3, November 12, 2024, 10:30 AM - 12:00 PM

Concrete floor diaphragms of existing buildings are often inadequate to resist tension forces developed as the diaphragm spans between the lateral load resisting elements. A common strengthening method to provide additional tension capacity is through Fibre Reinforced Polymer (FRP) ties. However existing research is not applicable because it was conducted on thin and short FRP ties which are dissimilar to those typically required for diaphragm strengthening applications. This paper summarises the progress to date on an extensive research programme, including experimental carried out to date. More specifically, the completed research has yielded the following outcomes:

1. A design model to predict the debond strain (design strain) of long and thick ties to improve the tension capacity of existing diaphragms,
2. A bond-slip model that offers deep insight into the debonding mechanisms that govern the behaviour of FRP ties,
3. Diaphragm panel testing in shear and flexural, demonstrating the proof of concept for in-plane strengthening of concrete diaphragms using the deep beam analogy,
4. Precast unit testing that corroborates the capacity of the FRP ties to survive the large three-dimensional deformations resulting from the relative rotation of the floor with respect to the supporting beam, and
5. Preliminary results on computer modelling of simple buildings (as-built and strengthened), showing the influence of a large number of parameters such as building stiffness and ductility on the global behaviour.

A brief summary of the upcoming work is included, mainly focusing on more precast testing considering both rotational and tension demands and computer modelling of more complex buildings.

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Implications of ongoing research for design of FRP seismic strengthening of diaphragms in New Zealand

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3C Special Session: Seismic strengthening of concrete diaphragms, Dobson 2 & 3, November 12, 2024, 10:30 AM - 12:00 PM

This paper discusses findings from an ongoing research project into the seismic strengthening of concrete floor diaphragms using Fiber Reinforced Polymer (FRP). The research project includes researchers from New Zealand and the USA and is intended to inform FRP diaphragm strengthening design in both countries. This paper specifically discusses the implications of the research for design in a New Zealand context including the general suitability of FRP for diaphragm strengthening in New Zealand structures with a focus on the deformation tolerance of FRP systems when installed on precast flooring systems. Additionally, the low debonding strain of externally bonded FRP is discussed along with the necessary detailing requirements to ensure adequate diaphragm performance for structures with varying levels of ductility.

Preliminary findings from various diaphragm tests and their implications on strengthening design for typical New Zealand structures are discussed, including the types of structure that are likely to be suitable for diaphragm strengthening with FRP, and key considerations for the design and detailing of FRP diaphragm strengthening systems. The research is ongoing, and if required the paper will include discussion of any important research queries that are still being evaluated, and any suggestions for future testing. This study aims to inform the design of FRP diaphragm strengthening systems for New Zealand structures, contributing to the field of structural engineering.

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Multi-layer anchored and unanchored CFRP Shear Strengthening of Reinforced Concrete Diaphragms

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3C Special Session: Seismic strengthening of concrete diaphragms, Dobson 2 & 3, November 12, 2024, 10:30 AM - 12:00 PM

Externally bonded fiber reinforced polymer (FRP) sheets offer a cost-effective and minimally invasive option for seismic retrofitting of non-ductile concrete buildings, providing a viable alternative to traditional strengthening methods. However, a significant gap remains in design guidance and research for effectively applying FRP to address shear deficiencies in existing concrete diaphragms. This paper investigates the effectiveness of multi-layer anchored and unanchored carbon fiber reinforced polymer (CFRP) retrofits in improving the shear strength of deficient reinforced concrete diaphragms. Large-scale reverse cyclic tests were conducted on two 4” thick low concrete strength specimens, each retrofitted with full-coverage of Simpson Strong-Tie CSS V-WRAP C220HM CFRP sheets applied parallel to the direction of applied shear. However, only one specimen included end anchorage, while the other did not. The retrofit aim was to achieve a nominal strength ($V_n=V_c+V_s+V_f$) at or above the maximum shear reinforcement limit of $8\sqrt{f_c'}\, b_w d$ required by the ACI 318-19 building code, while maintaining an FRP-to-steel ratio of $V_f/V_s \geq 2.0$. The CFRP retrofits markedly improved the strength of the diaphragms, achieving significantly higher strength as compared to an equivalent unretrofitted control specimen using finite element analysis. The specimen strengthened with FRP anchors experienced significantly less degradation than the specimen without FRP anchors, particularly in the post-peak region of loading, suggesting the importance of adequate detailing of FRP anchors for seismic applications. The effectiveness of CFRP strengthening and benefits of providing supplemental mechanical anchorage to FRP were evaluated in terms of their impact on the strength, stiffness, failure mode, energy dissipation, and post-peak response of the diaphragms. Additionally, FRP strains at peak load, derived from back-calculation analyses and strain gauge measurements, were compared with the effective design strains calculated using the FRP debonding expressions from ACI 440.2R-23. The findings inform recommendations for design practitioners, which is significantly lacking.

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Evaluation and retrofit design practices for concrete diaphragms in the U.S., using FRP as a seismic strengthening solution.

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3C Special Session: Seismic strengthening of concrete diaphragms, Dobson 2 & 3, November 12, 2024, 10:30 AM - 12:00 PM

This presentation focuses on the evaluation and retrofit design practices for concrete diaphragms in the U.S., using FRP as a seismic strengthening solution. Although there are extensive component modeling load-deformation characteristics and acceptance criteria prescribed for various concrete components in U.S. standards like ASCE/SEI 41, such provisions for concrete diaphragms generally point to walls and other similar component idealizations. As a consequence, practicing engineers must resort to alternative design methods for assessing retrofit design decisions where real building diaphragms rarely resemble the idealized wall counterpart. Furthermore, after evaluation shows that retrofit is required, similar extrapolations are required for FRP strengthening schemes, using the beam-analogy and debonding strains prescribed in ACI 440.2-R and other documents. Although many of such methods are not standardized in design codes at this time, this presentation will aim to provide insight on several of the leading design methods currently practiced in the United States for concrete diaphragm strengthening.

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Collapse of a reinforced concrete building with insufficient diaphragm and discussion on diaphragm strengthening for avoiding such failures

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3C Special Session: Seismic strengthening of concrete diaphragms, Dobson 2 & 3, November 12, 2024, 10:30 AM - 12:00 PM

Structural integrity is one of the key issues during design of a proper lateral force resisting system for building structures (i.e. against seismic actions). Therefore, proper design and construction of rigid diaphragms is extremely critical if “rigid diaphragm” assumption is made during structural analyses. Seismic events show that insufficient rigid diaphragms, failing to transfer seismic forces properly to vertical structural members as foreseen during design, are among reasons of collapse of buildings. In this paper, observations on a 15-story reinforced concrete (RC) building that lost its integrity and totally collapsed due to insufficient diaphragm action during 2023 Türkiye Earthquakes, are presented. Furthermore, several approaches for strengthening of the diaphragm that could have avoided total collapse of the building are discussed.

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Chloride diffusivity and life cycle analysis of typical low-carbon cementitious materials

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3D Special Session: Performance Evolution and Control of Concrete Structures, Dobson 4, November 12, 2024, 10:30 AM - 12:00 PM

Concrete prepared with low-carbon cement should have good durability to ensure the performance of the structure during service, thereby reducing resource consumption and maintenance costs throughout the life cycle. Aiming at green low-carbon concrete with potential application in the future, such as composite cementitious materials and alkali-activated slag materials, concrete mix with good workability, mechanical properties and low-carbon emission is studied. The typical low-carbon cementitious materials, includ-ing sulphoaluminate cement (SAC), limestone calcined clay cement (LC3) and alkali-activated slag (AAS) were used. Based on experimental analysis, multiple sets of on-crete mix proportions were designed to analyze its mechanical properties. Combined with mechanical properties and workability, the optimal mix proportion of three types of low-carbon cementitious materials were determined. The typical low-carbon concrete mix was then selected to carry out the chloride salt diffusion test of concrete. The re-sistance to chloride transport of the low-carbon concrete was compared with that of port-land cement concrete with the same strength level. The carbon emissions divided by the time when steel bars start to corrode are analyzed, indicating the importance of durabil-ity of low-carbon construction materials.

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Statistic investigation on sulfate ions distribution in concrete by a mesoscale model

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3D Special Session: Performance Evolution and Control of Concrete Structures, Dobson 4, November 12, 2024, 10:30 AM - 12:00 PM

Sulfate attack is one of the main reasons responsible for the performance deterioration of concrete. Accurate prediction of the temporal and spatial distribution of sulfate ions in concrete is the basis for revealing the mechanical performance evolution of concrete caused by sulfate attack. In order to investigate the random characteristics of sulfate ions transport in concrete caused by the random distribution of coarse aggregates, a two-dimensional mesoscopic numerical model is introduced, in which the concrete is regarded as a three-phase composite including mortar, coarse aggregates, and the interfacial transition zone (ITZ) between them. Several important issues in this model, such as explicitly incorporating the ITZ in the mesoscale model, were discussed. The influence of ITZ on the diffusion of sulfate ions was then thoroughly discussed. Through a fitting and hypothesis test on the concentration distribution histogram of sulfate ions, a reliable probability density distribution function of sulfate ions concentration was proposed. Finally, the influence of several key parameters (e.g. coarse aggregate content, shape, and angularity) related to the mesoscopic structure of the concrete on the degree of spatial variability of the sulfate ions was comprehensively evaluated. The findings of this study can bring insight into the design and prediction of the durability of concrete structures subjected to sulfate attack.

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Effect of coarse aggregate on compressive mechanical properties of irradiated concrete

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3D Special Session: Performance Evolution and Control of Concrete Structures, Dobson 4, November 12, 2024, 10:30 AM - 12:00 PM

It is widely acknowledged that the radiation-induced volumetric expansion (RIVE) of aggregates is the primary mechanism responsible for the degradation of mechanical properties of concrete under neutron irradiation, while the effect of coarse aggregate on the mechanical properties of irradiated concrete remains to be further elucidated. In this study, the random aggregate model for irradiated concrete was established by the finite element method, and the free volume expansion and subsequent uniaxial compression loading of concrete specimens were simulated under experimental conditions involving non-uniform neutron fluence and temperature fields. Afterward, the simulation of cube-shaped concrete specimens under uniform neutron fluence and temperature fields was conducted. The numerical results show that under uniform neutron fluence and temperature fields, the relationship of elastic modulus and compressive strength with the aggregate linear expansion is consistent for irradiated concretes with different coarse aggregate contents. The concrete linear expansion is linearly related to aggregate linear expansion, and the slope of the linear relationship increases with the increase of coarse aggregate content. Besides, the evolution patterns of linear expansion, elastic modulus, and compressive strength with neutron fluence for irradiated concretes with different maximum particle sizes of coarse aggregates are identical.

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A novel crack detection equipment for existing concrete structures and its validation testing

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3D Special Session: Performance Evolution and Control of Concrete Structures, Dobson 4, November 12, 2024, 10:30 AM - 12:00 PM

The application of computer vision technology in crack identification is becoming increasingly mature and has gradually become the main method of crack detection. However, digital cameras are still the image data collection equipment, and it is difficult to obtain the location information and true geometric dimensions of cracks. This paper proposes a new equipment with numerous sensors that can collect pictures and inertial unit data during the acquisition process, enabling fast and convenient data acquisition. By combining visual-inertial SLAM with crack identification technology, accurate and efficient crack measurement and location can be performed based on the acquired data. The effectiveness of the proposed method is demonstrated through field testing, and the equipment has high potential in detection and localization of surface damage or defect.

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New Opportunities for Single-Photon Sensing in Civil Engineering

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3D Special Session: Performance Evolution and Control of Concrete Structures, Dobson 4, November 12, 2024, 10:30 AM - 12:00 PM

As buildings experience performance degradation over time, issues such as structural deformation, material ageing and reduced durability pose serious threats to safety. Traditional sensing methods have limitations in accuracy and adaptability, highlighting the need for new technologies. This paper explores the application of single-photon sensing technology in civil engineering, focusing on its basic principles, development history and preliminary investigations. Compared to traditional methods, single-photon sensing technology offers ultra-sensitive detection capabilities and sub-picosecond time resolution, making it particularly suitable for long-distance measurements under extreme conditions. Our preliminary research suggests that by integrating filtering and machine learning techniques, effective target detection can be achieved in low signal-to-noise environments. In the future, single-photon sensing is expected to be integrated with other sensors to create complementary intelligent sensing systems, driving innovation and development in civil engineering technologies.

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Impact resistance performance of freeze-thaw damaged RC columns under different axial compression ratios

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3D Special Session: Performance Evolution and Control of Concrete Structures, Dobson 4, November 12, 2024, 10:30 AM - 12:00 PM

Abstract: Freeze-thaw and drop hammer impact tests were carried out on eight reinforced concrete (RC) columns, considering the effects of freeze-thaw cycles (0, 100, 150, 200) and axial compression ratio (0.14, 0.28). The impact resistance of the freeze-thaw damaged RC columns was investigated in terms of failure modes, crack propagation, impact force-time history, and mid-span deflection-time history. Test results indicated that when the freeze-thaw cycles exceed 150, the impact failure mode of the RC columns changes from flexural failure to brittle shear failure. A higher axial compression ratio exacerbates the development of inclined cracks during the impact process. The impact force plateau value and duration of RC columns decrease with an increase in freeze-thaw cycles. A higher axial compression ratio leads to a larger impact force plateau value and a shorter impact force duration. The mid-span deflection of RC columns augments with an increase in freeze-thaw cycles. For RC columns with a higher axial compression ratio under shear failure mode, the mid-span deflection experiences a sudden increase when the freeze-thaw cycles exceed 150. Considering the effects of freeze-thaw damage and axial compression ratio, a double-degree-of-freedom impact response calculation model for RC columns was established and validated.

Keywords: Freeze-thaw damage; RC columns; Impact resistance performance; Axial compression ratio

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Re-simplified calculation methods for bending bearing capacities of corroded RC beams

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3D Special Session: Performance Evolution and Control of Concrete Structures, Dobson 4, November 12, 2024, 10:30 AM - 12:00 PM

Corrosion of steel reinforcements can decrease the bending bearing capacities of RC beams through degrading the mechanical properties of steel reinforcements. Three-phase model for tensile properties of corroded steel bars was proposed. Hence, four different failure modes and three balanced failures could be identified for corroded RC beams under bending. The concepts of balanced corrosion degrees have been proposed corresponding to three balanced failures. Accordingly, the four failure mode-based calculation method was proposed for predicting the bending bearing capacities of corroded RC beams, which, albeit could be worked out by hand, needs some redundant calculations. To re-simplify the calculations, the three-phase model was further simplified as the two-phase model for tensile properties of corroded steel bars. Hence, two balanced failure and three failure modes could be identified. The three failure mode-based calculation method was proposed to assess the bending bearing capacities of corroded RC beams. Comparisons were made among three failure mode-based method, four failure mode-based method and experimental dataset, which demonstrated the validity of the proposed re-simplified calculation method. The re-simplified calculation method could help rapid assessments of bending bearing capacities of existing corroded RC beams in practice.

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Estimation of the risk of rupture by corrosion of external prestressing tendons injected with cement grout

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3E Corrosion and impact on structural performance, Bealey 4 & 5, November 12, 2024, 10:30 AM - 12:00 PM

In prestressed concrete box girder bridges, the rupture by corrosion of an external tendon injected with cement grout in contact with the wires or strands raises the question of maintaining the load carrying capacity of the structure and the safety of the agents who intervene inside the box girder. The major risk is a sudden breakage and whipping of a tendon. This whipping can endanger the lives of people near the tendon and cause damages to other tendons, the ejection of anchor heads, and the destruction of sensitive equipment or networks.

The recommendations developed in this paper for assessing the risks are based on an extensive feedback obtained on structures and on tests characterizing the redistribution of stresses due to partially cut strands during tests carried out by Gustave Eiffel University, Ecole des Ponts ParisTech and Cerema, under the funding of the Association of French Highway Companies. A synthesis of the main test results is presented, including a discussion on the re-anchoring length of the strands in an healthy grout.

A theoretical calculation is then presented to determine at what level of degradation (in number or proportion of broken wires), a tendon reaches a “conventional risk of rupture”. The developments carried out within this calculation make it possible to determine the reduction of the tendon force which results from the breakage of wires, the overtension of the wires in the damaged area, and the tension diminution of the wires in the healthy area.

Finally, a decision flowchart is proposed to manage the risks; it is mainly based on an evaluation of the number of broken wires and corroded wires with respect to a critical number of broken wires for a conventional risk of tendon rupture.

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Experimental and analytical study on the bending capacities of RC beams under non-uniform corrosion

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3E Corrosion and impact on structural performance, Bealey 4 & 5, November 12, 2024, 10:30 AM - 12:00 PM

Corrosion of steel reinforcement embedded in concrete is a dominant factor in the deterioration of reinforced concrete (RC) structures. The accelerated corrosion process was conducted using an accelerated electrochemical method in two phases: initially, localized corrosion was induced over lengths of 20 mm and 120 mm at the mid-span and the shear span, respectively; subsequently, corrosion was implemented across at the entire span. The localized corrosion was expected to be the maximum among the non-uniform corrosion. The spatial variability factor R', defined as the ratio of the maximum corrosion rate to the average corrosion rate, was set at 2.0. A four-point bending test was conducted on one sound RC beam and four corroded RC beams. All five specimens had a similar failure pattern, characterized by steel yielding and compressive failure of concrete. The trends observed in both the experimental and simulation results were consistent and the findings are shown in the following: (1) The reduction in bending capacity due to corrosion is more significant at mid-span than at the shear span; (2) the length of corrosion has a greater impact on capacity when it occurs at mid-span, whereas the effect of corrosion length on capacity is less pronounced when corrosion occurs at the shear span; (3) the effectiveness of using average corrosion to represent a non-uniform corrosion distribution in FEM (finite element method) analysis depends on the location and length of the maximum corrosion.

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Quantifying the influence of chloride-induced corrosion on the bending moment capacity of a prestressed girder considering different exposure scenarios

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3E Corrosion and impact on structural performance, Bealey 4 & 5, November 12, 2024, 10:30 AM - 12:00 PM

Chloride-induced corrosion is one of the main causes of deterioration of concrete structures, decreasing the structural reliability over time. For prestressed concrete elements, this has a significant influence as corrosion-induced loss in the prestressing reinforcement might reduce the safety level of the element considerably. In this work, the effect of chloride-induced corrosion on the safety level of a real-life prestressed girder is investigated. The corrosion process is predicted by modelling the diffusion of chlorides into the element using 2D finite-element analyses. Based on the diffusion analysis, the onset of corrosion of each prestressing strand is determined and the area of the strand is reduced according to a certain corrosion rate, leading to a decreasing safety level over time.

The safety level is quantified within a probabilistic framework, considering uncertainties in both the initiation period (onset of corrosion) of the different prestressing strands and the corrosion rate. Various scenarios are examined, considering different origins of the chloride ingress. This study allows identifying which exposure scenario might lead to the most severe deterioration and assess the structural redundancy available in the prestressed girder.

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Effects of Severe Chloride-Induced Corrosion with Spalling on the Structural Performance of RC Structures in Marine Environments: An Experimental Study

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3E Corrosion and impact on structural performance, Bealey 4 & 5, November 12, 2024, 10:30 AM - 12:00 PM

The chloride-induced corrosion of reinforcing bars is a major problem for reinforced concrete structures. Structures that are damaged by corrosion progressively lose their structural performance and reliability. In particular, the degradation of bond performance between rebar and concrete due to corrosion is one of the primary mechanisms in the loss of structural capacity. While numerous tests have already been conducted to investigate the bond performance of corroded rebars, little to no studies have been done on specimens with spalled bottom cover and high mass loss, which is often found in structures subjected to harsh marine environments. In this study, severely corroded structural members were simulated by casting small concrete beams without bottom cover, which were then corroded severely using the impressed current method. Several parameters were considered such as the depth of spalling, corrosion level of rebars, and the spacing of stirrups. Then, loading tests were conducted on the specimens. It was found that as long as there was contact between the concrete and the rebar, some residual bond remained.

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Corrosion effects on the prestressing force of post-tensioned cables due to lack of mortar injection

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3E Corrosion and impact on structural performance, Bealey 4 & 5, November 12, 2024, 10:30 AM - 12:00 PM

The contribution focuses on the analytical formulation of the effect of localized corrosion on a post-tensioned concrete bridge in which cables were made adherent by cast-in-situ mortar injections. The corrosion is considered homogeneously distributed over a finite portion of the structure characterized by a lack of mortar injection. The dissertation proves that the reduction of the prestressing cross-section area due to corrosion generates losses in the prestressing force and a stress redistribution inside the undamaged cables. These aspects are numerically quantified by considering several percentages of corroded area for the case study of an existing prestressed concrete bridge, providing information for design and monitoring purposes.

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Corrosion effects on the bending moment-curvature diagram of post-tensioned concrete beams

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3E Corrosion and impact on structural performance, Bealey 4 & 5, November 12, 2024, 10:30 AM - 12:00 PM

High-strength steel strands used in post-tensioned Reinforced Concrete (RC) elements are prone to corrosion leading to reduced strength and ductility. A new resistance model for corroded strands has been proposed, enabling the development of reduction curves for ultimate strength and displacement, that take into account both the longitudinal and transversal corrosion geometry along the strand and steel material properties. The present paper investigates the effects of corroded strands on the moment-curvature diagram of post-tensioned RC elements. This is evaluated through an equivalent constitutive stress-strain relationship for the steel material resulting from the reduced strength and displacement curves.

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Performance of Concrete Bridges in Cyclone Induced Floods in Queensland Australia

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4A Special Session: Concrete bridge performance in flood/cyclones, Auditorium, November 12, 2024, 1:00 PM - 3:00 PM

Cyclone and associated flooding are common in Far North Queensland in Australia, and sometimes less frequently in Central and Southern. Queensland. The majority of highway bridges in QLD are concrete, or have a significant portion of the construction from concrete due to its relatively long maintenance free life. However due to the relatively extreme nature of flooding as a result of cyclones some concrete bridges do get damaged sometimes to the extent where they are no longer serviceable. Most of the time, this damage to concrete bridges in Queensland is due to scour around abutments and/or piers.

This paper will profile our experience with flood damage, and provide some examples and case studies of concrete bridges that have been damaged due to cyclone induced flooding over the last ten years in Queensland, and outline some repair techniques and strategies, along with some improvements we have made to design and construction of new bridges to hopefully make concrete bridge more resilient to flood damage in the future.

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Performance of the New Zealand’s bridge stock during Cyclone Gabrielle

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4A Special Session: Concrete bridge performance in flood/cyclones, Auditorium, November 12, 2024, 1:00 PM - 3:00 PM

Cyclone Gabrielle caused widespread damage to the 1,500 bridges across Hawke’s Bay and Tairāwhiti with thirty washed away and hundreds more damaged. The scale of damage is unprecedented. The rebuild and repair of the affected bridge stock is estimated in the hundreds of millions of dollars. We have assembled a comprehensive database of all the bridges in the region. Data captured includes the level of damage each bridge experienced, estimated water level, flow velocity and presence of debris during the cyclone at each bridge site, and relevant structural data of each bridge. We believe the database of 1,500 bridges represents a significant insight into the likely performance of the existing bridge stock throughout Aotearoa New Zealand, and will supplement existing scour screening guideline.

Based on analysis of this dataset the following key risk factors which increase probability of poor performance during a major flood event were identified (TBC as research ongoing):

- Undersized foundations (such as shallow spread footings, small diameter piles, short pile lengths)
- Short spans (<15m)
- Insufficient positive fixity between superstructure and substructure (such as the typical hold down bolt and dowel bar details common to the 1960-1980’s)
- Insufficient hydraulic area

Review of the Bridge Manual flood loading requirements have shown a dramatic increase over the last 80 years. However further consideration of pulse loading and large objects is warranted.

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Enhancing Bridge Resilience: Lessons Learned from Cyclone Gabrielle's Impact on New Zealand's North Island

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4A Special Session: Concrete bridge performance in flood/cyclones, Auditorium, November 12, 2024, 1:00 PM - 3:00 PM

In February 2023, Cyclone Gabrielle had a devastating impact on the East Coast of New Zealand's North Island. This paper aims to present a comprehensive analysis of the impact Cyclone Gabrielle had on older bridges, particularly those with inadequate detailing. It sheds light on the evolving design requirements that contribute to enhanced resilience in the face of extreme flood events.

This paper discusses the trajectory of design requirements, exploring how they have adapted to accommodate the complexities of today's natural hazards. By drawing on lessons learned from Cyclone Gabrielle, this paper identifies how our current design criteria calls for resiliency and proposes additional measures necessary to fortify structures against the multifaceted threats posed by extreme flood events.

Moreover, this paper provides an overview of key design features adopted in the reconstruction efforts, emphasising a commitment to "build back better" and fortify structures against future cyclones and flooding events.

The lessons learned from this reconstruction effort can inform future infrastructure projects, setting a benchmark for resilient bridge design in cyclone-prone regions.

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Challenges and adaptations of Auckland Bridges recovery

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4A Special Session: Concrete bridge performance in flood/cyclones, Auditorium, November 12, 2024, 1:00 PM - 3:00 PM

Auckland Transport (AT) stands at the intersection of responsibility and opportunity, entrusted with the care of transport structures that connect our communities together. Among these, over 1200 bridges span the Auckland region, each bearing a unique story—varies in age, materials, and purpose.

In the context of encountering diverse situations, AT has consistently avoided rigid rules. Instead, we should appreciate the adaptability of context, understanding that a bridge's significance goes beyond mere practicality. These structures, resilient yet vulnerable, face threats both human-made and nature.

In January 2023, Auckland experienced the impact of Ex-Cyclone Gabrielle—an unforeseen event that rigorously tested our asset management system. The challenges were unprecedented. Structural damage, financial strain, risk assessment, community resilience, environmental consequences, and logistical complexities became our shared reality. The following up recovery actions have been carried out aiming to confront these challenges.

The recovery process has accumulated some invaluable experience through implying AT operation principles. These principles emphasize financial responsibility, prudent management of assets and liabilities, ensuring long-term viability, and efficient utilization of revenue. Most importantly, this process has encouraged us to delve deeper when confronting major natural disasters. For instance, what level of service is appropriate when restoring a damaged bridge. These insights are detailed in the paper.

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New Zealand rail bridge flood damage and recovery - case study of Rangitata River bridge MSL57

Liam Coleman

4A Special Session: Concrete bridge performance in flood/cyclones, Auditorium, November 12, 2024, 1:00 PM - 3:00 PM

MSL 57 – Rangtata is a 610m long bridge on the rail line between Christchurch and Dunedin. The bridge has 34 spans and was built in the 1930's. On the 12 April 2024 following a flood event pier 8 was completely washed away leaving the adjacent 20m spans suspended in mid air with no support. The presentation will give a brief overview of KiwiRail and its bridge assets and other scour damage events that have occurred on similar bridges. The presentation will cover the temporary repair which allowed the reopening of the line to trains 10 days after the event and the permanent design which was built and commissioned 2 months after the initial pier wash out.

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Innovative Bridge Deck-to-Pier Connections for Improved Tsunami Resilience

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4A Special Session: Concrete bridge performance in flood/cyclones, Auditorium, November 12, 2024, 1:00 PM - 3:00 PM

Recent tsunami events, including the 2004 Indian Ocean and 2011 East Japan events, have highlighted the vulnerability of bridges to tsunami loading and how reliant coastal communities are on the functionality of these structures. Bridge design does not typically consider the large uplift forces that tsunami waves apply to the superstructure, and reconnaissance conducted following these events found that these uplift forces contributed to the widespread failure of bridges.

This research proposes a novel bridge deck-to-pier connection that accommodates the tsunami uplift demands. The proposed connection consists of a mechanical bar designed to yield and elongate to increase the vertical displacement capacity of the superstructure and minimise damage to the super- and substructure. Utilising this connection has the potential to minimise post-event repairs, which are likely limited to bar replacement and minor concrete repairs, thereby minimising bridge downtime following a tsunami.

Experimental testing was conducted on a 1/3 scale pier cap and bridge deck to verify the design philosophy and theoretical predictions used to design this connection. Three bar materials were investigated for their feasibility based on their material properties and suitability for coastal environments: mild carbon steel, stainless steel and glass fibre reinforced polymer. To accurately capture the connection and system response, a novel large-scale experimental testing set-up was developed, which simulated both vertical and horizontal tsunami loads and considered both the initial and return wave loading. The experimental testing verified the design philosophy and concluded that this proposed connection could effectively dissipate tsunami wave energy and minimise the damage induced on other critical bridge components.

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Low damage seismic isolation of the Parahaki Bridge

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4B Resilient and low-damage seismic design, Dobson 1, November 12, 2024, 1:00 PM - 3:00 PM

State Highway 3 Te Ahu a Turanga Manawatu Tararua Highway Project (Manawatu Gorge Bypass) features a new 295m long balanced cantilever concrete box girder bridge across the Manawatu River. The bridge, to be known as Parahaki Bridge, is currently under construction and is a four span structure with main spans of 88m. The project is being delivered using an Alliance model consisting of Waka Kotahi, constructors Fulton Hogan and HEB and design consultants Aurecon, WSP, RoadLab and Gaia.

The new bridge is situated in an area of high seismicity and near the major fault system running through New Zealand. Minimum Requirements for the project dictated use of a site specific seismic hazard study for derivation of seismic loading which resulted in demands between 20 to 50% higher than code based values. In preliminary concept design, conventional elastic and ductile design approaches were assessed to not be viable due to high seismicity. Base isolation of the structure using lead rubber bearings was determined to be a feasible option that would provide a low maintenance and low damage solution. Base isolation of the bridge required six 1410mm and 1360mm diameter bearings with a 390mm diameter lead core at each abutment and pier respectively. Design requirements for base isolation are outside the scope of the New Zealand Bridge Manual and therefore a project specific design criteria was developed using guidance from AASHTO. Lead rubber bearings were designed to achieve a fully isolated structure up to the collapse avoidance limit state. At this limit state, the bearing displacements were estimated using nonlinear time history analysis to be a maximum of 955mm or 250% rubber strain.

This paper will outline the design criteria developed for the project, analysis of lead rubber bearings using nonlinear time history analysis and specification of the bearings for protype and production testing.

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Integral seismic performance of self-centering concrete wall structures incorporating innovative low-damage infill walls

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4B Resilient and low-damage seismic design, Dobson 1, November 12, 2024, 1:00 PM - 3:00 PM

The past study on self-centering concrete walls have demonstrated its excellent seismic performance and advantages over traditional reinforced concrete shear wall structures, especially on control of damage and residual deformation under severe seismic events. However, relatively large displacement demand for self-centering walls may potentially cause severe damage to the infill walls within the same structure, the latter of which is generally deformation sensitive. In order to achieve the integral seismic resilience for self-centering wall structures, control of damage and large displacement compatibility in conjunction with the main structure are two critical concerns for developing novel infill walls that could be used in a self-centering walls structure. In this study, several innovative connections have been developed for different infill types. The performance of the infill walls in combination with self-centering concrete walls are evaluated through large-scale cyclic lateral loading tests. Generally, in this study, the connections between the infill walls and the main structure (self-centering wall) are so called flexible connection. A total of five specimens have been tested in the study, with different additional energy dissipators (U-shaped steel damper and viscoelastic damper) between the wall panels, and different infill types (wall panel or masonry). The integral seismic performance of the test specimens in various aspects are reported in this paper, including force-displacement relationships, performance degradation, residual displacement, response of energy dissipator, etc. Results indicate that the tested self-centering wall structures incorporating innovative infill walls exhibit great seismic performance, most importantly achieving low damage and self-centering behavior as expected.

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Residual drift-based seismic vulnerability assessment of RC bridges

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4B Resilient and low-damage seismic design, Dobson 1, November 12, 2024, 1:00 PM - 3:00 PM

The post-earthquake residual drift (RD) has received increasing attention to become an important indicator to quantify the performance level of reinforced concrete (RC) bridges. However, vulnerability assessment concerning RD remains limited to date. While the Cloud method is widely utilized to estimate structural seismic vulnerability, its effectiveness is doubtful once using RD as engineering damage parameter (EDP), since the substantial randomness of RD may significantly deteriorate the precision of Cloud method. Consequently, this study proposes a procedure utilizing the maximum drift (MD) as intermediate variable to obtain the seismic vulnerability for RD. In this procedure, the IM-MD relationship is obtained by Cloud method, and the distribution of RD given MD is described by q-Weibull distribution. Through total probability theorem, the exceeding probability for RD given IM can be obtained rapidly. A typical regular RC bridge, which can be simplified as an SDOF system, is selected as illustrative example to validate the efficiency of the proposed procedure. Using 600 ground motions as input, the insufficiency of establishing IM-RD relationship directly using Cloud method is demonstrated. While implementing the proposed procedure with MD as intermediate variable, the obtained vulnerability results found similar to those of the IDA method, indicating the efficiency of the proposed procedure in evaluating the exceeding probability of RD. Meanwhile, the computational effort of proposed procedure is reduced compared with IDA, making it a competitive choice in residual drift-based vulnerability assessment of RC bridges.

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Enhancing seismic and climate resilience of existing buildings through low-damage external exoskeletons

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4B Resilient and low-damage seismic design, Dobson 1, November 12, 2024, 1:00 PM - 3:00 PM

In recent years, devastating earthquakes and climate-induced events have raised societal awareness of the urgent need to enhance resilience against extreme hazards. This becomes crucial when dealing with existing buildings. Many of these structures were built before the enforcement of modern seismic codes and energy regulations. Consequently, existing buildings are exhibiting a lack of resilience not only during earthquakes but al-so in case of extreme climatic conditions. Moreover, the energy inefficiency of the building stock should not be viewed solely as a problem related to its thermal vulnerability. It also requires an unprecedented effort to meet the goals outlined in the Europe-an Green Deal, specifically targeting energy savings and decarbonization by 2030 and 2050, respectively, to increase environmental sustainability.

This work explores the feasibility of employing external low-damage exoskeletons consisting of rocking-dissipative structural connections for seismic strengthening. The implementation of exoskeletons is nowadays crucial, given the possibility of carrying out the intervention from the outside with limited disruption for occupants. Moreover, the exoskeleton serves as a support for a “double-skin” facade system offering opportunities to enhance the envelope energy performance, thereby enabling an integrated (i.e., seis-mic and energetic) rehabilitation.

This paper discusses the advantages of using external exoskeletons compared to more traditional strategies (e.g., seismic local interventions combined with thermal coatings) by a case study application. The overall performance of as-built and retrofitted configurations is assessed through seismic and energy dynamic analyses as well as integrated loss modeling for resilience evaluations. The findings provide evidence of the efficiency of the proposed strategy and its potential.

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Strain ageing effects in reinforcing bars subjected to earthquake damage

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4B Resilient and low-damage seismic design, Dobson 1, November 12, 2024, 1:00 PM - 3:00 PM

One of the factors affecting repair feasibility of buildings damaged by earthquakes is the potential effects of strain ageing of reinforcement. Since strain ageing can lead to an increase in structural member strength and ductility reduction, the strength hierarchy set through capacity design disruptions can be disrupted leading unexpected seismic response of individual members or the structure as a whole. In this study, from simple tensile tests on reinforcing bars, we identified three factors that affect strain ageing: vanadium content, ageing period, and pre - strain, and constructed a formula for predicting changes in reinforcing bar properties using these factors. And, from seismic response analysis of Japanese RC buildings and experiments on RC beam members, the maximum strain of reinforcing bars was 1.7% and 2.3%, respectively, in response to design level 2 earthquake motion. Using the simple relationships between the expected strains of members in this analytical model, we created a building model that adjusted for the effects of strain ageing on reinforcing bars after an earthquake, and performed seismic response analysis again. As a result, no major differences were observed in future seismic responses. The reason for this is thought to be that Japanese RC buildings have high rigidity and yield is limited.

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Study of A Novel Precast RC Shear Wall with Replaceable Self-Centering Energy-Dissipation Components

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4B Resilient and low-damage seismic design, Dobson 1, November 12, 2024, 1:00 PM - 3:00 PM

In this study a novel precast reinforced concrete (RC) shear wall with re-placeable self-centering energy-dissipation components (RSECs) is proposed for seismic resilient application. The bottom corners of the shear wall are de-signed as RSECs which are connected to the precast wall panel and founda-tion via high-strength bolts, while the vertical reinforcements in the web of the precast wall panel are unconnected to the foundation. The RSEC is aimed to dissipate most of the seismic energy and reduce the residual defor-mation of the shear wall. Compared to conventional RC shear wall, the ma-jor advantages of the novel shear wall include simplified vertical connection of the precast RC wall, main structural damage concentrating on the re-placeable components, and rapid recovery of structural function after earth-quakes. The structural details and design considerations of the novel precast RC shear wall with RSECs are introduced firstly. Then, a reliable numerical model is built to simulate the hysteretic behavior of the novel shear wall. The seismic performance of the structural wall is investigated using various parameters and evaluated in terms of stiffness, strength, energy-dissipation capacity, and residual deformation. The results indicate that the proposed precast RC shear wall with RSECs has a similar bearing capacity and lateral stiffness compared to the conventional RC shear wall, and performs better in energy-dissipation capacity and residual deformation control.

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Penalty Method for Optimisation of Reinforced Concrete Structures in Serviceability and Ultimate Limit State

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4B Resilient and low-damage seismic design, Dobson 1, November 12, 2024, 1:00 PM - 3:00 PM

Existing methods for optimising reinforced concrete (RC) structures predominantly concentrate on either the Serviceability Limit State (SLS) or the Ultimate Limit State (ULS), restricting their applicability. This paper introduces a novel approach to optimise the layout of RC structures, simultaneously addressing both limit states.

The proposed method employs an iterative process that approximates the elastoplastic behaviour of balanced reinforced cracked concrete, incorporating convex optimisation techniques. The initial layout is determined through Finite Element Limit Analysis and further refined using a penalty method until all requirements are satisfied. The penalty method linearises the problem and is thus solved iteratively. The structural response due to the nonlinear material behaviour is calculated by applying the principle of minimum potential energy.

The method is verified against known solutions and applied to more complex structures.

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Modeling and seismic response of self-centering reinforced concrete frames with viscous dampers

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4B Resilient and low-damage seismic design, Dobson 1, November 12, 2024, 1:00 PM - 3:00 PM

Compared with traditional cast-in-place reinforced concrete (RC) frames, self-centering reinforced concrete (SCRC) frames demonstrate better reparability with minimal residual deformation after severe earthquakes. However, they often exhibit larger displacement responses due to their inferior energy dissipation capabilities. To deeply investigate the dynamic response of SCRC frames, finite element models based on a prototype 5-story teaching building are developed using the OpenSees platform, and viscous dampers are chosen to be as the primary energy dissipation components. Two configuration methods of viscous dampers including diagonal configuration and chevron brace configuration are investigated. Nonlinear dynamic time-history analysis reveals that viscous dampers play a crucial role in reducing displacement responses of SCRC frames, particularly for frames with chevron brace configuration. By exclusively installing viscous dampers in the first floor of the SCRC frame, the structure achieves dynamic responses better than those of conventional frames. This investigation offers valuable suggestions for the vibration control of SCRC frames.

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A mechanics-based approach for modelling dowel cracking in RC beams

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4C Mechanics, analysis, and design, Dobson 2 & 3, November 12, 2024, 1:00 PM - 3:00 PM

Dowel action is recognized as one of the major shear resistance mechanisms. Although the dowel action only contributes a relatively small portion of the total shear resistance, the shear failure of reinforced concrete members without shear reinforcement usually occurs accompanied by unstable dowel cracking. This paper presents a new description of the dowel action based on two mechanical models, namely Beam on Elastic Foundation (BEF) theory and fracture mechanics. The mechanical model analytically describes the three stages during the dowel splitting of the longitudinal rebar in an RC beam, which are the elastic stage, stable cracking stage and unstable cracking stage. An analytical expression of the critical shear displacement that induces the unstable cracking is also presented. The proposed model was validated by 53 specimens collected from literature. The comparison shows that it can predict the maximum dowel force with convincing accuracy. Moreover, the proposed model can capture the post-peak behaviour of the nature of dowel action. This is also validated by the full load-displacement curves obtained in literature. Finally, a simplified equation for engineering practices is proposed. The proposed expression shows promising agreement with respect to the experimental data.

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Towards a reliability-based design concept for concrete discontinuity regions using strut-and-tie models

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4C Mechanics, analysis, and design, Dobson 2 & 3, November 12, 2024, 1:00 PM - 3:00 PM

An accurate strength prediction of concrete structures is paramount to develop economic and performance-based designs that meet safety regulations without undue conservatism. This is particularly crucial from a sustainability perspective, as a more accurate prediction of structural safety can reduce material usage and hence the environmental footprint, whereas in the past a rather conservative design approach was used for concrete discontinuity regions.

Commonly, structures are designed with safety factors to address uncertainties tied to material properties, geometric parameters and loads. This approach is effective for linear components such as columns and beams, which adhere to the Euler-Bernoulli hypothesis. However, in discontinuity regions, where strain distributions are disturbed, strut-and-tie models and stress fields are necessary to determine the elements' strength. Both methods originate from limit analysis, for which a comprehensive probabilistic framework for adequately handling uncertainties remains unavailable. In this contribution, a reliability-based model is developed to facilitate a probabilistic design of concrete discontinuity regions incorporating limit analysis to assess their strength and safety. In particular, there is a focus on half-joints, which were widely applied in bridges in Europe during the last century. Through Monte Carlo simulations, the stochastic nature of the input variables is integrated to account for the inherent uncertainties. Furthermore, a sensitivity analysis is executed to determine the most important input variables and their effect on the achieved reliability level.

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Spring models for the design of fastening systems: Requirements and challenges

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4C Mechanics, analysis, and design, Dobson 2 & 3, November 12, 2024, 1:00 PM - 3:00 PM

In the field of fastening technology, spring models are being increasingly utilized to model the behaviour of fasteners in concrete. This is mainly because the spring-based modelling approach can be generalised, thus making it possible to analyze anchor configurations not covered by EN:1992-4. Different spring model proposals with varying degrees of complexities, suitable for designing and/or analysing anchorages can be found in literature. The paper presents a comparison of different spring models available in literature with a new simplified proposal for spring model for anchorages. The proposed simplification is aimed at minimizing the number of inputs required to define a spring for an anchor, while maintaining reasonable accuracy in terms of the predicted anchorage capacity.

To compare different spring models numerical investigations were conducted using the FE-Software ANSYS. The anchor plate is modelled using shell elements and the anchors as tension only spring elements. The compression forces are assumed to be transferred to the base concrete by the anchor plate. The interaction between the anchor plate and the concrete is defined using a frictionless contact. The anchor plate is assumed rigid since the numerical results are compared with EN:1992-4 calculations which are valid only for rigid anchor plates.

Based on the analysis of 6 different anchor group configurations. It is shown that in comparison to the multilinear spring models which require large number of input parameters, the proposed simplified bilinear spring model (with fewer inputs) also delivers acceptable results. Thus, is sufficient for designing anchorages.

Furthermore, the paper also highlights the general limitations of the spring models and identifies the research gaps which need to be addressed for generalizing the spring modelling approach for anchorages. For example, considering different failure modes in the spring model, the effect of stiffness and ductility of single anchor on the group response etc.

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Numerical investigation of anchorage mechanism of rebar hook using 3D-RBSM

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4C Mechanics, analysis, and design, Dobson 2 & 3, November 12, 2024, 1:00 PM - 3:00 PM

In reinforced concrete (RC) structures, rebar end anchorages with bent bars are very common and rebar hooks provide a secure and efficient way to connect and anchor reinforcing bars to the concrete. This study aimed to numerically investigate the anchorage mechanism of the rebar hook in terms of pull-out behavior clarifying the local damage propagation such as internal cracks and stress distribution at the anchorage part. Numerical analysis was based on the Three-Dimensional Rigid Body Spring Model (3D-RBSM) and validated with the rebar hook pull-out test results. The Voronoi mesh and beam element were used to model concrete and reinforcement respectively and the rebar hook was modeled by dividing the beam element into multiple fiber elements to reproduce the strain localization on the rebar surface. The rebar hooks with different configurations considering inner radius of rebar hook, were investigated. The model demonstrated that the larger inner radius had a positive influence on the ultimate failure load. Besides, the smaller inner radius had a negative influence on slippage at the hook start point. Furthermore, the proposed model enabled the evaluation of the detailed damage propagation behavior, including rebar hook deformation. This numerical investigation is expected to be beneficial in optimizing the rebar hook anchorage designs and reviewing established standards or guidelines.

Key Words : hook inner radius, hook deformation, beam element, strain localization, splitting crack

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A novel analytical model to determine the composite action between concretes cast at different times: experimental validation

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4C Mechanics, analysis, and design, Dobson 2 & 3, November 12, 2024, 1:00 PM - 3:00 PM

The design rules to establish composite action between concretes cast at different times are described in EN 1992-1-1, prEN 1992-1-1, and the MC2010. These codes provide similar equations for the shear resistance at the interface due to transverse shear forces. The equations and the coefficients of the interaction mechanisms have been derived based on pure shear tests, whereas they have been used for various load scenarios in practice. Classification of the roughness of the surface is linked to prescriptive rules or the so-called sand patch test. Previous research conducted by the authors stated that these current design rules and interaction factors are inappropriate to describe the slip behaviour because of shear stresses during bending tests. An analytical model based on the same influences of the interaction mechanisms has been derived in the past. However, it was shown that this model requires thorough refining. Therefore, a novel analytical model for composite beams has been developed. This model is based on the stiffness of both concrete phases and a more realistic interface behaviour instead of a resistance-based model as in the current standards. The effects of the occurring interaction mechanisms are grouped in a slip stiffness factor k. To validate the new approach, 12 tests were performed with a three-point bending test, consisting of a thicker reinforced first phase and a thinner unreinforced second phase concrete. Various configurations of the interaction plane were made to study the influence and value of the different mechanisms (as prescribed by the current codes). The results show a better agreement with the proposed model than the model based on EN 1992-1-1, prEN 1992-1-1, and MC2010. Future research will include the contribution of reinforcement crossing the interface as well as the influence of fatigue and impact loading.

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Load-bearing behavior of prestressed concrete towers with dry horizontal and vertical joints based on warping theory

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4C Mechanics, analysis, and design, Dobson 2 & 3, November 12, 2024, 1:00 PM - 3:00 PM

Wind turbines already account for the second largest share of electricity generation from renewable energies worldwide. In order to further increase the output, the trend is towards taller towers and larger rotor diameters. Hybrid towers have been particularly successful with large hub heights. The upper part is made up of several steel sections, while the lower part consists of precast concrete elements that are stacked dry on top of each other and connected by external tendons. In addition to the horizontal joints, vertical joints divide the segments into even smaller components. This leads to a complex load-bearing behaviour that has not yet been fully understood.

At the Institute of Concrete Structures at TU Dresden, the load-bearing behaviour of prestressed segmented concrete towers is being analysed and evaluated in large-scale experimental studies. For this purpose, concrete tower models with horizontal and vertical joints are being built on a scale of approx. 1:10. The aim of these investigations is to determine the load-bearing behaviour of segmented prestressed towers with dry joints under prestressing, bending, shear force and torsion. The model segments are equipped with a variety of measurement technology. The occurring concrete strains are recorded with a large number of strain gauges and fibreoptic sensors over the entire segment height and circumference. Inductive displacement sensors are used to measure the displacements of the segments in relation to each other. Before the tests were carried out, a high-resolution 3D-scan of the segments was performed to detect local effects due to imperfections in the measurement data.

Research in this field aims to gain a better understanding of the load-bearing behaviour of such towers. This is an essential prerequisite for further optimisation of the structure and thus for more sustainable and economical energy generation.

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Global resistance methods on the design with nonlinear finite element analysis of hybrid fiber reinforced industrial pavement supported on piles

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4C Mechanics, analysis, and design, Dobson 2 & 3, November 12, 2024, 1:00 PM - 3:00 PM

The use of fiber reinforcement has been explored as an alternative to conventional steel bars and grids, with technical and economic advantages, mainly in slabs supported on soil and structures with redundant support conditions. The possibility of using this reinforcement on slabs supported on piles is still scarce, and reliable advanced numerical simulations can help on demonstrating its potential. The present work describes the methodology adopted to design a concrete pavement of 300 mm thickness supported on piles forming a square grid of about 4 m distance between piles. This pavement has an area of about 135000m2 and was composed of panels of different area separated by construction joints. For the design, a representative module, considered the critical one, of an area of about 42×38m2, was adopted. A steel fiber reinforced concrete (SFRC) of strength class 30/37 and toughness class 5c was adopted. The fiber reinforcement was complemented with a strip of 0.9 m width of prefabricated welded steel mesh disposed in the alignment of the piles, at the bottom face of the slab, with 30 mm cover thickness. Prefabricated welded steel mesh was also applied in the bottom face of the slab of the mod-ule's contour for attending the highest positive bending moments occurring in this zone. No conventional reinforcement was applied in the top part of the slab to facilitate a fast execution of the pavement. For the design, a software based on the finite element method, including constitutive models capable of simulating the nonlinear behavior of SFRC since its fresh state up to their rupture at hardened state, was adopted. SFRC maturation, including creep and shrinkage was considered in the analysis to estimate the cracking risk during the curing process of the SFRC, by performing a thermo-mechanical analysis. The deformation restrictions imposed in the contact between the SFRC slab and the caps of the piles was considered in this analysis by adopted interface finite elements with proper constitutive law. The design considered the verifications for serviceability and ultimate limit state conditions by using a global resistance method, namely the Method of estimating the coefficient of variation of the structural resistance (ECOV). The adopted hybrid reinforcement solution demonstrated to be competitive over a traditional reinforced concrete alternative.

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Enhancing the bearing capacity of concrete slabs through the load redistribution capacities of masonry walls

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4C Mechanics, analysis, and design, Dobson 2 & 3, November 12, 2024, 1:00 PM - 3:00 PM

Load redistribution significantly influences the response of structural systems during both normal service conditions (the ultimate and service limit state) and hazardous events. However, only limited research has focused on this topic. Load effects often act as the main contributor to uncertainties in the limit state functions, while load and uncertainty reduction options are limited. The load redistribution, however, can beneficially affect the load effect that acts on bearing elements.

This contribution addresses load redistribution in masonry walls, which have the potential to enhance the bearing capacity of supporting concrete slabs. While ACI 318-14 has recognised the contribution of walls in earthquake design subjected to mainly lateral forces, the vertical redistribution capacities of masonry walls remain underexplored. Therefore, the masonry wall behaviour is studied through numerical models validated by two scaled (1/2) tests. Numerical simulations are developed using both linear-elastic and non-linear finite element analysis including interface characterisation. The results of both modelling approaches are compared to each other and the observed measurements.

The scaled tests consist of a masonry wall on a two-span hollow core slab with topping, utilising mortar joints in the first and adhesive joints in the second test setup. The tests encompass various loading circumstances: during construction with struts, service limit state loading, ultimate limit state loading, and a column loss scenario loaded until failure. The loads are measured directly at the wall-slab interface by state-of-the-art ultrathin pressure sensors characterised by a negligible bending stiffness, ensuring minimal impact on the load distribution. This novel application of pressure sensors diverges from conventional practices in civil engineering based on indirect measurements such as strain. It is shown that the load effect of a combined slab-wall arrangement differs significantly from expectations based on a simplistic load arrangement.

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Wake-up call for creep dimensioning: The case of cyclic loading

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4D Special Session: Fatigue of Concrete in an Experimental-Virtual-Lab, Dobson 4, November 12, 2024, 1:00 PM - 3:00 PM

The expected deformations during the service life of concrete structures are calculated using creep models, assuming a constant mechanical loading. However, many structures such as bridges are not only subjected to constant creep loads. The creep load is superimposed with cyclic loads e.g. due to traffic. The superposition leads to significantly increased long-term deformations compared to deformations predicted by static creep models. This underestimation of deformations might cause serious damages and safety risks. Further, microstructural changes or even damages due to the superimposed cyclic loading cannot be ruled out, thus requiring a scientifically validated extension of existing creep models.

Within a joint research project funded by the German Research Foundation (DFG), the strain developments of concrete due to creep and cyclic loading are investigated for comparable stress levels on a normal-strength concrete. After several days of loading, in both cases, a recovery phase follows during which creep recovery is examined. This allows to quantify the effect of both load types on the strain development and the separation between different strain components such as elastic, viscoelastic and viscoplastic parts. Further material properties, such as the modulus of elasticity before and after loading, are investigated in order to characterise the degradation processes.
In the proposed paper, the time-dependent strain due to creep and cyclic loads at comparable stress levels and the irreversible strain after creep recovery are presented and compared. The results show that the time-dependent strain due to cyclic loading increases up to 290 % compared to creep loading at mean stress level. Hereby, the irreversible strain component is higher for cyclic loading. Additionally, a reduction of the modulus of elasticity due to cyclic loading was observed, hinting to potential microstructural damage mechanisms. Overall, the authors conclude a high urgency for adapting existing creep models to reflect these new experimental findings.

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The effect of concrete moisture on the fatigue resistance of HPC under uniaxial and triaxial loading

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4D Special Session: Fatigue of Concrete in an Experimental-Virtual-Lab, Dobson 4, November 12, 2024, 1:00 PM - 3:00 PM

As a result of research activities on the topic of concrete mixtures in the last few decades, the compressive strength of concrete has increased massively. At the same time, the lifetime of concrete structures has been continuously extended. As a result, the fatigue behaviour of high-performance concrete is becoming increasingly important with a view to durability engineering. Previous studies on concrete have shown that the number of cycles to failure in compressive loading depends mainly on the frequency and amplitude. By conditioning the moisture content of high-strength concrete test specimens, a significant change in the number of cycles to failure can be identified. Other research on high-strength concrete indicates that concrete heats up significantly under cyclic compressive fatigue loading. Surface temperatures of over 100°C have been measured in the literature. This heating effect depends primarily on the load level, the load frequency and the humidity and influences the static compressive strength.

This paper shows the results of fatigue tests with two different moisture contents. The samples were stored under water and have a moisture content of around 5 mass-%. Some of the samples were dried at 105°C to minimise moisture in the sample. In this way, the largest possible moisture difference is analysed. Both moisture contents were analysed at a test frequency of 2 Hz. The fatigue resistance of samples was analysed under uniaxial load and under triaxial load with a surface pressure of 20 MPa. The results show that moisture has a significant influence on the fatigue resistance regardless of the type of load. Furthermore, the concrete moisture also has an influence on the temperature development and consequently also on the specimen temperature, which influences the static compressive strength.

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Moisture-induced damage mechanisms in high-strength concrete due to compressive fatigue loading

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The fatigue behaviour of concrete in wet environments has become an important subject of interest with the expansion of offshore wind energy farm and grouted joints used in such structures. Previous investigations showed a major impact of the concretes moisture content on the fatigue resistance. It was found that the number of cycles to failure significantly decreases with an increasing moisture content of the concrete. Although the phenomenon of moisture-induced damage of cyclic-loaded concrete has been recognised many years ago, there is still a pronounced lack of knowledge, especially concerning the mechanisms responsible for the accelerated degradation.

In a joint research project at the Institute of Building Materials Science, Leibniz Universität Hannover, as part of the DFG priority programme “Cyclic Deterioration of High-Performance Concrete in an Experimental-Virtual Lab”, the influence of moisture in the concrete`s microstructure on the fatigue behaviour is investigated. For this purpose, high-strength concrete specimens with different moisture contents are tested with respect to different influencing parameters, such as stress level and load frequency. The results further show a notable frequency and stress-level dependency with increasing moisture content, exhibiting a pronounced reduction of fatigue resistance with decreasing frequency and decreasing stress-level. The results are therefore have pronounced significance for the design of water-prone, fatigue subjected structures. Furthermore, clear indications for differences between moisture-induced fatigue damage and dry fatigue damage can be observed from acoustic emission measurements. Further microstructural investigations of porosity, pore size distribution and nanoscale moisture distribution, by means of NMR (nuclear magnetic resonance) techniques, are conducted to obtain more detailed information about the nature of the damage processes at the nano and micro level.

In this contribution, the results of fatigue tests with varying moisture contents are presented combined with selected tests of gas adsorption and mercury intrusion porosimetry. The purpose is to provide insight into the moisture-induced fatigue damage mechanisms and to verify the presence of a specific moisture threshold beyond which these mechanisms are acting.

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DEM-Based Analysis of Fatigue-Induced Damage Using a Cycle-Jump Technique

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4D Special Session: Fatigue of Concrete in an Experimental-Virtual-Lab, Dobson 4, November 12, 2024, 1:00 PM - 3:00 PM

The presented research investigates fatigue-induced damage in Ultra-High-Performance Concrete (UHPC), combining experimental investigations with Discrete Element Simulations (DEM). A comprehensive mechanical characterization involved both static and cyclic tests. The examined concrete is a fine-grained UHPC with a water-to-cement ratio of 0.23. Experimental fatigue tests were conducted at a loading frequency of 1 Hz, with the upper and lower stress levels held constant at 80% and 5%, respectively.

A specially developed rheological fatigue model facilitated fatigue simulations, capturing essential fatigue characteristics of the material. The development of the rheological model was based on insights gained through electron microscopic investigations. The primary approach involves incorporating microstructural changes induced by fatigue into the numerical modeling.

Using this approach, low-cycle simulations were possible to analyze potential damage mechanisms. Notably, the detrimental impact of aggregate was emphasized, leading to stress peaks in the microstructure and playing a key role in mesoscale damage mechanisms. Stress peaks result in heterogeneous stress distributions and increased stresses on the Interfacial Transition Zone (ITZ), leading to a higher degradation of the microstructure. The simulations also revealed that the phase transitions can be detected earlier in the damage of the ITZ, even while the macroscopic simulation specimen remains intact.

Furthermore, a cyclic-jump method was developed within this study to gain deeper insights during high-cycle loading. The cycle-jump method is based on the approach of extrapolating fatigue damage to a subsequent stage, thereby saving a significant number of cycles in the calculation.

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Experimental investigation and incremental modeling of the load sequence effect in plain concrete under mode II loading

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Reinforced concrete structures, specifically bridges and wind turbine towers, are subjected to repeated subcritical loading throughout their operational lifespan, lead-ing to gradual material deterioration and potential compromise of structural integrity. Unlike materials such as steel, where fatigue life estimation is readily possible using single-stage fatigue tests and linear damage accumulation theory, characterizing con-crete is notably more challenging due to its inhomogeneous and quasi-brittle nature. Concrete exhibits variable fatigue lifetimes depending on the loading sequence. Un-derstanding the impact of this so-called load sequence effect on concrete stands as a critical facet in ensuring structural longevity and reliability of current infrastructure. This paper delves into this phenomenon, focusing on unraveling the intricate behav-ior of plain concrete under fatigue loading with variable amplitude.

Due to the significant scatter of test results, experimental characterization of the load sequence effect is highly complex. Thus, a specialized test setup was utilized to study the phenomenon under combined shear-compression loading (mode II). This setup offers precise stress state specification and fracture zone identification, there-by reducing scatter substantially. The systematic investigation of over 50 specimens elucidated the pronounced load sequence effect in concrete and provided valuable insights into underlying mechanisms. Building upon these experimental findings, a deformation-based incremental modeling approach was developed to account for the sequence effect, offering not only fatigue life prediction but also comprehensive deformation evolution. The experimental recalibration underscores the effectiveness of this approach compared to the conventional Palmgren-Miner (P-M) rule.

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Influence of different microfibers on the flexural fatigue characteristics of high-strength concrete

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Slender and filigree components and structures require the use of high-performance concretes. However, a disadvantage is the increasing sensitivity to fatigue failure. High-strength concrete, on the other hand, has a very dense structure compared to normal-strength concrete, which implies a brittle and abrupt failure. To increase the ductility of this material, fibers are often used. The extent to which fibers affect the fatigue failure of high-strength concrete has not yet been sufficiently researched experimentally.

In systematic investigations, the fatigue behavior of high-strength concrete with the addition of steel and carbon microfibers was examined using the flexural fatigue test. The same unreinforced high-strength composition served as a reference. For the investigations, a multiple testing setup was used, which allowed the simultaneous and congruent testing of six beams of the same dimensions. Two different upper load levels were examined for each test series.

Damage indicators such as the number of cycles to failure, a relative dynamic E-modulus after defined load cycles, and the strains in the tension zone of the beams using strain gauges were determined. Additionally, the temperature development in the middle and in the area of a load introduction piston on the surface of the test specimens was determined.

The investigations showed a comparable decrease in the relative dynamic modulus of elasticity for both unreinforced and steel fiber-reinforced high-strength concrete. In contrast, the decrease in high-strength carbon fiber-reinforced concrete was only about half. This was observed for both tested stress levels. The strains in the tension zone of the specimens correlate accordingly, with the carbon fiber-reinforced high-strength concrete showing the lowest strains and thus a limiting effect of the fibers. An increase in temperature due to cyclic loading could not be observed in the conducted experiments.

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Does the fatigue resistance really decrease with higher concrete strength?

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4D Special Session: Fatigue of Concrete in an Experimental-Virtual-Lab, Dobson 4, November 12, 2024, 1:00 PM - 3:00 PM

High-strength concretes enable filigree concrete structures which are prone to cyclic loading. Regarding the design of concrete structures under compressive fatigue loading, the fatigue resistance is increasingly reduced for higher concrete strengths in guidelines and standards, such as Model Code 2020 or Eurocode 2, accounting for the fear of increased fatigue sensitivity with increasing strength and brittleness of the concrete. This reduces their potential dramatically in fatigue-loaded structures. The discussion concerning the influence of the concrete strength on the fatigue resistance has been ongoing for decades. Controversial results are documented in the literature. However, several results show that concretes with higher strengths do not have a reduced fatigue resistance. Nevertheless, the strength-dependent reduction of the concrete's fatigue resistance is still included in standards and guidelines.

The influence of the concrete strength on the fatigue resistance has been investigated for several years within different projects at the Institute of Building Materials Science, Leibniz University of Hannover. Accordingly, concretes of different strengths have been investigated. Furthermore, our own test data and around 2,100 data points available in literature were analysed together to fundamentally answer the question of whether high-strength concretes have a reduced fatigue resistance. Data from our own tests are shown comparatively and the results of the overall analyses of data from literature are presented and discussed in this paper. Altogether, a clear result was obtained: The fatigue resistance of concrete does not decrease with increasing concrete strength. Thus, the design regulations have to be approved to significantly increase the potential of high-strength concrete in fatigue-loaded structures.

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Shifted experimental S-N curves for fatigue verification of structures to consider different bond conditions

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The condition of many prestressed concrete bridges is deteriorating due to increasing traffic loads, leading to the need for strengthening and maintenance. Fatigue is a major issue with these bridges, as the prestressing steel can suddenly fail under loads well below its static bearing capacity.

The Model Code (MC) offers a three-stage verification strategy for fatigue of tendons with increasingly stringent requirements. The most precise and complex stage involves accumulation of relevant fatigue events with the Palmgren-Miner approach, which requires decent knowledge of load histories and an S-N curve. However, the curves actually provided are general and differentiate, based on sometimes scarce experimental data, just a few installation conditions. Only few of the tests in this database usually meet specific conditions on-site.

Consequently, an individual S-N curve for a reference bridge was derived from experiments. 17 fatigue tests were conducted at Ruhr-Universität Bochum, Germany, on plain prestressing wires, which closely match the ones in the structure. The least squares method yields an S-shaped function of the quantile based on the predefined stress ranges and load cycles to failure in the tests. On double-logarithmic scale, the function was linearized applying the stress exponents for straight tendons from MC. Then the stress amplitude ΔσRsk associated to the number of load cycles N* at the kink of the two branches remains the single degree of freedom. It shifts the bilinear curve towards the experimental one.

The parameters for plain prestressing wires and post-tensioned tendons are similar, except for the stress range. Thus, that offset is attributed to the different bond conditions. It is directly transferred to the linearized experimental S-N curve to have consistent properties in the tests and the reference structure. The approach quantifies benefits of specific versus general S-N curves and bears potential to verify critical structures prone to fatigue.

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Service life design of concrete structures considering Belgian production and climate: developing a full-probabilistic calibration as ERC proposal for Belgium

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4E Codes, standards, & guidelines, Bealey 4 & 5, November 12, 2024, 1:00 PM - 3:00 PM

The publication of EN1992-1-1:2023 marks a substantial evolution of the provisions regarding the design of concrete structures, among others related to the treatment of durability. Current durability provisions are often based on deemed-to-satisfy rules, where for different environmental classes acceptable concrete types are classified based on limiting values of their constituent mix-proportions. In the new durability concept within Eurocode 2, exposure resistance classes (ERC) are introduced. Depending on the selected exposure resistance class, the minimum concrete cover is specified that provides an adequate design in order to prevent significant reinforcement corrosion problems during the service life. As such, the treatment of durability switches more to a performance-based approach and opens the door for innovation. To facilitate this transition, the tables specifying minimum concrete cover for durability requirements had to be reestablished through probabilistic service life models for carbonation and chloride ingress.

Although the concept of the ERCs is a more realistic approach, certain conservative assumptions were needed to make it applicable in a broad European context and as such the table with minimum cover has been indicated as a nationally determined parameter (NDP), allowing national standardisation bodies to derive their own minimum values, for example based on a national calibration. This paper explores and compares the methodologies used to obtain the concrete covers stated in EN1992-1-1:2023 and proposes tailored values of basic variables and parameters fit in the Belgian context. The derivation of required minimum concrete covers is carried out using a full-probabilistic approach, taking into account parameters suited for the Belgian climate as well as statistical information available from Belgian concrete production. In this way, within the Belgian national context, less conservative and nationally more relevant performance-based durability requirements are developed.

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Robustness of code formulae for development and splice length of reinforcing bars

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4E Codes, standards, & guidelines, Bealey 4 & 5, November 12, 2024, 1:00 PM - 3:00 PM

Lap splices are the most used systems to connect steel reinforcing bars in concrete. Due to limited concrete cover in practical applications, failure of lap splices (and straight anchorages) mostly occurs by the formation and propagation of splitting cracks along the bond length. Majority of concrete design codes acknowledge the influence of confinement actions on the prevention of bond splitting, by implementing semi-empirical approaches to improve the statistical fit with experiments. The required development/splice lengths given in codes are intended to prevent bond failure and to fully develop the reinforcement to its design yield strength. Codes mostly do not differentiate between bond splitting and bond pullout failure, and one single value of the bond strength is considered. A widely accepted theory in codes is the assumption of the 'uniform bond model', and consequently, the assumption of linearly decreasing tensile stress in the reinforcing bar along the development/splice length. The basis of this paper is a large database (1394 experimental data), collected for splice (905 data) and straight anchorage test results (489 data). The model of the NZS 3101 Concrete structures standard has been selected for detailed parameter analysis and calibration. The NZS 3101 model is largely based on and is very similar in its structure to the model of ACI 318. It was found that the NZS 3101 model is not robust, and its precision cannot be increased if a linear relationship between the stress in the reinforcing bar and the required development/splice length is assumed. A new, non-linear relationship has been proposed that resulted significant increase in the robustness of the model. The findings of the research confirm the similar assumptions made in the Model Code 2020 Final Draft. The results highlight the need of reconsidering the globally available development/splice length models and proposes a potential direction for improvement.

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Validation of Various Australian Standard Concrete Code (AS3600) Shrinkage Prediction Models

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4E Codes, standards, & guidelines, Bealey 4 & 5, November 12, 2024, 1:00 PM - 3:00 PM

Shrinkage strain is a requirement of the concrete design process that has proven difficult to model. The consequences of unacceptable shrinkage magnitudes may lead to negative effects on the structural performance of concrete. In cases where the concrete is restrained, shrinkage may result in appreciably sized cracks. Such cracks effect the aesthetics of the structure and have negative durability related implications. Although laboratory tests may be undertaken to quantify the shrinkage, these are time consuming. For this reason, empirical code-type prediction models are used to predict shrinkage strain.

This paper considers the accuracy of four versions of the Australian Standard Concrete Code (AS3600) shrinkage prediction models (AS3600: 1994, 2001, 2009 and 2018). The models were evaluated, when compared with the actual shrinkage strains measured, over a period of approximately six months, on a range of concretes under laboratory-controlled conditions, for six mixes. The six mixes comprised three aggregate types (quartzite, granite and andesite) and two water cement ratios (0,56 and 0,4).

All four models generally over-predicted shrinkage strain with age. Furthermore, the AS3600 (1994) and AS3600 (2009) yielded the most and least accurate predictions with overall coefficients of variation (ωall) of 88,9 % and 194,8 %, respectively. The AS3600 (2001) was the second most accurate model. When considering the mixes on the basis of the included aggregate type, the predictions were more accurate in the relatively higher strength mix of each aggregate type (in 92 % of cases). Finally, the AS3600 (2009) and (2018) models, that considered the most factors, were the least accurate of the models investigated.

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A Practical Design Method for Increasing Shear Resistance In Existing Concrete Sections Using Post Tensioned Bars

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4E Codes, standards, & guidelines, Bealey 4 & 5, November 12, 2024, 1:00 PM - 3:00 PM

Many concrete structures constructed between the 1950s and 1970s may have strength deficiencies in shear when assessed against today's design standards. Strengthening concrete sections for increased shear resistance can be difficult for a variety of reasons including access constraints and a reluctance to disturb the operation of the structure.

Methods to strengthen the webs of concrete box-girder bridges are necessary to increase the shear resistance of the structure and extend the service life of the bridge. Such methods require consideration of strain compatibility between the existing shear reinforcement and new reinforcement at the Ultimate Limit State (ULS). Existing design guidance on this is found to be limited within current codes and standards.

This paper proposes a practical design method for the application of vertical post-tensioning using hot-rolled steel bars to supplement the shear resistance of existing concrete box-girders. It draws on the provisions of both the Australian Standard (AS5100) and Canadian design standards (CSA S6) as well as industry practice to provide a practical design method which can be applied in conjunction with the standards.

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Bridging the gap between shear strength design models with apparent contradictory initial hypotheses

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Discussions on shear strength models are commonplace among working groups and committees, grappling with the complexity of factors influencing shear and torsional strengths—up to 20 variables or more. The challenge in developing simpler design models lies in the necessity of disregarding secondary factors. In the last decade, debates have focused on the conceptual disparity between shear strength prediction models in reinforced concrete beams, emphasizing shear friction (or aggregate interlock), and those emphasizing shear transferred by uncracked compressed concrete. Recent experimental tests on six RC beams without stirrups, utilizing Digital Image Correlation to analyse the behavior, revealed that the critical shear crack (CSC) undergoes an initial widening, rotating around its tip near the neutral axis without significant sliding. As a result, the contribution of aggregate interlock to shear strength remains negligible until shear forces approach 90% to 98% of the total shear strength. At this juncture, a secondary branch of the CSC forms, accompanied by substantial sliding, significantly enhancing the aggregate interlock's role in shear strength. This redistribution of shear-transfer actions, occurring between the final 2% and 10% of the applied load in these tests, suggests that models such as the Compression Chord Capacity Model (CCCM) and those prioritizing aggregate interlock, as the shear model included in Model Code 2020, are not contradictory. Instead, they represent two closely associated states before and after the observed redistribution. In fact, predictions by the Model Code 2010 and the CCCM for these six tests exhibit practically identical scatter.

The paper concludes by proposing a reformulation of the CCCM looking for a Levels-of-Approximation approach for shear design, which could be particularly useful for assessing existing structures.

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New Guidelines for Maintenance of Existing Post-tensioned Prestressed Concrete Bridges

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4E Codes, standards, & guidelines, Bealey 4 & 5, November 12, 2024, 1:00 PM - 3:00 PM

Currently, there are about 730,000 road bridges with longer than 2 m span in Japan. Many bridges have been constructed from 1970 to 1980's, and about 60% of bridges in the next 10 years will be over 50 years after construction, and the deterioration of bridges is becoming a big social problem. Main structural members of the bridges are steel (39%), reinforced concrete (14%), prestressed concrete (45%) and others. Maintaining post-tensioned prestressed concrete bridges in sound condition for continued service increasingly requires the implementation of measures such as reinjection of grout for prestressed concrete and strengthening by external cables to ensure the safety of such bridges as they age. A number of methods of reinjection of grout for prestressed concrete have been developed and are being used in practice, but the specific performance requirements and performance verification methods for reinjection remain to be clarified. In addition, specific criteria for the method of strengthening by external cables, which are often used to strengthen post-tensioned prestressed concrete bridges, have not been defined. Based on the above, the Japan Prestressed Concrete Institute established the “Guidelines for Maintenance of Existing Post-tensioned Prestressed Concrete Bridges”. These guidelines consist of Basic section, Diagnostic section, Countermeasures section and References of trial design and construction. In the Countermeasures section, nine repair and strengthening methods are described. This paper describes the outline of the Guidelines, the grout reinjection and the strengthening using the external cable based on the recent studies.

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Research on experimental similarity criterion and snowdrifts on two-span single-pitch roofs

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4E Codes, standards, & guidelines, Bealey 4 & 5, November 12, 2024, 1:00 PM - 3:00 PM

In recent years, extreme blizzards have been striking the world, causing widespread building collapses. Among them, two-span roofed structures are incredibly vulnerable to snowdrifts due to the overloaded snow accumulated in the valley area. Considering the widely use of such roof in concrete structures, deep research of snowdrifts on two-span single-pitch roofs were conducted based on the snow-wind combined experiment facility and a new similarity criterion. Firstly, a snowfall-process-based experiment facility and a new Froude similarity number were proposed. The experiment facility is an open wind tunnel, which could simulate the snowfall process by spraying the artificial snow particles into the man-made flow field. The Froude number was revised based on the friction velocity ratio, which could better restore the snow drifting process. Through systematic validation, their reliability in predicting snowdrifts was fully proved. Then, a series of wind tunnel tests of snowdrifts on two-span single-pitch roofs were conducted with various inflow conditions and roof shapes. Meanwhile, numerical simulations were also carried out to help clarify the formation mechanism of snowdrifts on such roofs. The results show that the snow distribution pattern on the roof is mainly determined by the roof slope. The increase in roof slope causes the formation of a bigger vortex between the two spans and more snow accumulation at the valley. While for each type of roof slope, the wind velocity has little effect on the snow distribution. As for the wind direction, two types of typical unbalanced distribution of snow on the roof were observed with the “positive” and ”negative” wind directions. It is found that the peak snow depth is much larger than the provisions in the current structural load code of China, which should draw more considerations.

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Fire resistance of group of fasteners with focus on concrete cone failure

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4E Codes, standards, & guidelines, Bealey 4 & 5, November 12, 2024, 1:00 PM - 3:00 PM

In structural engineering applications the use of fasteners to connect structural elements has increased with the increasing use of prefabricated and composite construction. Since, the structural fire safety design is an integral part of the structural design process. The fire resistance of connections made using post-installed or cast-in fasteners also needs to be verified.

The design of fasteners in concrete is governed by the EN1992-4:2018. The current design method for calculating the concrete cone failure capacity under fire, is based on the extensive numerical study by Periskic (2009) and limited experimental investigations by Reick (2001). But it should be acknowledged that both the investigations, which were also conducted at the Institute of Construction Materials, University of Stuttgart, had been limited to single fastener. Hence, the verification of the design method to calculate the concrete cone capacity of group of fasteners is long pending. Therefore, with this objective a numerical investigation was undertaken to compute the concrete cone capacity of fastener groups consisting of 2 lines each with 2 headed studs (2×2 configuration). The investigation was conducted using a validated 3D thermo-mechanical model developed in Ansys®. The model accounts for the temperature dependent thermal and mechanical properties as per EN1992-1-2. The concrete cone capacity of the fastener groups is computed at 30, 60, 90, and 120 minutes of standard fire exposure (ISO834).

The results verify that the current design guidelines are conservative for calculating the concrete cone failure capacity of group of fasteners under fire. But the safety margins are high for short fire durations as compared to longer fire duration i.e., the design is too conservative for shorter fire resistance durations. Furthermore, modification to the current design method is proposed to realistically predict the concrete cone capacity of group of fasteners.

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Rehabilitation of a prestressed concrete bridge using UHPC

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5A Special Session: Sustainable Structural Strengthening, Auditorium, November 12, 2024, 3:30 PM - 5:30 PM

Strengthening of concrete structures using became an object of an extensive research project carried out at the Czech technical University and Metrostav a.s. At the same time the Czech Concrete Society developed guidelines for application of UHPC in new and existing structures. The results of the research project and existence of the guidelines made it possible to convince some even large clients to accept a new technology for applications in practice. A heavily loaded bridge in Prague (more than 140 thousand vehicles per day) had to be repaired. The road bridge is a continuous beam with 6 spans composed of two separate parallel structures. The main span is 72 m long. Each of the bridges carries 4 lanes. Beside installation of additional external prestressing, exchange of bearings and other activities, the bridge deck was strengthened with a layer of UHPC. The repair should have been executed in 4 stages in 4 years. The two stages (a repair of the south bridge) were completed in 2022 and 2023. The north bridge (stages 3 and 4) will be repaired in 2024 and 2025. The experience from earlier stages was evaluated and slight modifications were planned. The paper will illustrate the technology and experience from the site.

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Light UHPFRCC jacketing with recycled steel fibres

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5A Special Session: Sustainable Structural Strengthening, Auditorium, November 12, 2024, 3:30 PM - 5:30 PM

The new challenges imposed by climate change along with the growing traffic volumes as well as ageing of materials increase dramatically the susceptibility of most of the bridges built in Europe between the 1950s and 1970s. To preserve this huge investment for future generations various strengthening measures are employed. However, most of the solutions implemented are neither sustainable nor environmentally friendly.

This paper adopts a green ultra-high-performance fibre-reinforced cementitious composite (G-UHPFRCC) with recycled steel fibres, by-product of tyre recycling. Thin jackets of the novel high-performance composite are externally applied to concrete beams, representative of existing bridge girders, to eliminate brittle failures induced by insufficient reinforcement detailing.

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A stochastic programming approach for budget allocation to structural strengthening and post-earthquake buildings repair in seismic areas

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5A Special Session: Sustainable Structural Strengthening, Auditorium, November 12, 2024, 3:30 PM - 5:30 PM

In this work we study the optimal budget allocation for proactive reinforcement action on buildings located in seismic areas and reactive repair after an earthquake.

The problem is modeled as a two-stage stochastic model with recursion, in which the goal is to minimize the number of evacuated people. A maximum cumulative budget is allowed for proactive and/or reactive actions. For each building is known the vulnerability level, the cost of three levels of strengthening, (seismic retrofitting, improvement, and local strengthening) as well as the reduction of vulnerability achievable with each type of action. We also know the repair cost corresponding to 5 different post-earthquake damage levels.

A set of earthquake outcome scenarios is generated, for each one of which is found the level of damage which would occur on each building if no strengthening action is undertaken, or the damage suffered depending on the type of proactive intervention (if any) that was undertaken, and the subsequent cost of the repair interventions. We provide a mathematical formulation for the two-stage stochastic problem in which first stage variables address the decisions related to which type of strengthening action undertake on which building, while the second-stage ones deal with the repair decisions. The solution of the stochastic model is compared with several different deterministic approaches in which we follow a deterministic rule to decide about which building to reinforce and at which level, and then we observe what happens on the different earthquake scenarios.

Results show the benefit achievable by exploiting a stochastic programming approach, and determine, under which conditions, a deterministic approximation could be considered a viable option

Detailed results on a real case analysis based on a small town in Sicily will be presented at the conference.

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Treatment of Uncertainties In The Semi-Probabilistic Design Of Precast Concrete Structures With Reclaimed Elements

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5A Special Session: Sustainable Structural Strengthening, Auditorium, November 12, 2024, 3:30 PM - 5:30 PM

The construction industry contributes to a significant proportion of the global annual carbon emissions. To aid in mitigating the negative carbon implications and extend the lifetime usability of concrete components through circular design, the ReCreate project aims to investigate the deconstruction of precast concrete buildings and the reuse of reclaimed structural elements in new designs. In conventional concrete design and code specifications such as EN1990:2002, full and semi-probabilistic methods are available to estimate the reliability of structures. In the case of reuse, how-ever, materials have aged, developed, and plateaued over decades of service, altering the constitutive assumptions underlying many design methods. Essential resistance model considerations include the mechanical properties of the concrete and reinforcement steel, reinforcement layout, geometrical properties, degradation mechanisms, serviceability damage, and bond integrity. Varying levels of information from the original design will be available, including undocumented alterations per-formed during construction or renovation stages. Several variables, such as element geometry and material resistances, can be determined more precisely through post-deconstruction testing and inspections. To understand the implications of material variability in reclaimed precast concrete elements, this paper first provides an overview of existing probabilistic theory and material safety fac-tors for conventional designs, with particular reference to Eurocode 2. An inventory of the relevant variables affecting the reliability of reused elements is presented and discussed. Finally, the reliability of non-destructive testing on reclaimed and in-service reinforced concrete elements is discussed.

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Strengthening concrete members with cementitious composites

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5A Special Session: Sustainable Structural Strengthening, Auditorium, November 12, 2024, 3:30 PM - 5:30 PM

Ageing and degradation of the built environment is a serious problem that can significantly affect existing constructions. Furthermore, a significant part of them was designed according to outdated codes and to sustain loads that are no longer representative of the actual conditions (e.g., traffic loads). To address this issue, the CON_FIT project investigated strengthening solutions able to increase the service life of existing structures, leading to the development of innovative materials and solutions for concrete members based on Textile Reinforced Concrete (TRC) technology. Such solutions were applied, and subsequently tested, on Reinforced Concrete (RC) beams, designed to fail both in bending and shear, and on RC columns, trying to mimic the (realistic) conditions of the construction site. The experimental campaign highlighted how the developed solutions, when appropriately installed, can significantly enhance the performance of the retrofitted elements even with particularly thin strengthening layers. More in detail, the results of the experimental tests showed that the tensile properties of the cementitious matrix utilised to produce the composite can strongly affect the behaviour of the strengthened element. This, in turn, led to the development of an improved material, named Fibre/ Textile Reinforced Concrete (F/TRC). Furthermore, it was observed that the application of such solutions led to a significant performance increase both at SLS level, in terms of stiffness increase, and ULS level, where the strength of the members and, in the case of the RC columns, the post-elastic displacement improved significantly.

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The restoration of steel-reinforced concrete structures with high-performance textile-reinforced mortars

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5A Special Session: Sustainable Structural Strengthening, Auditorium, November 12, 2024, 3:30 PM - 5:30 PM

Numerous reinforced concrete structures, built in the high modern era in Europe, still characterise urban landscapes and are often listed as monuments due to their significance for the history of building technology and architectural design work. Damage, that have occured on these buildings over the decades, must be rectified and suitable repair measures must be taken to ensure their future preservation. It is crucial to find an optimal compromise between a maximum preservation of the building fabric and a most durable restoration possible using compatible materials.

The present research and development study discusses the performance of a textile-reinforced cement mortar for such a damage case, using exemplary the repair planning of the Berus transmission tower in Saarland (Germany). A high-performance mortar was developed, which was adapted to the optical and mechanical properties of the existing structure. Its tensile strength and cracking behaviour were significantly improved by using textile reinforcement.

At first the building was analysed in terms of structural, architectural and conservation aspects. The knowledge acquired were essential for the development and combination of suitable repair materials. In addition to improve the properties of the material combinations, the tensile load-bearing of the composite material and bonding behaviour to the building concrete was examined. The paper focuses on the flexural behaviour of the repaired reinforced concrete, in particular how the used textile reinforcement affects the stiffness and crack distribution in the composite material. Finally an assessment of the achieved reinforcement effect and the crack-bridging ability of the developed material is done.

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Compressive tests on slender RC columns retrofitted with Fibre/Textile Reinforced Concrete

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5A Special Session: Sustainable Structural Strengthening, Auditorium, November 12, 2024, 3:30 PM - 5:30 PM

In the field of structural retrofitting, Textile Reinforced Concrete (TRC) is gaining popularity as an alternative to the well-known Fibre Reinforced Polymer (FRP). This material is composed of a textile fabric incorporated into a thin layer of a cement-based matrix. From previous studies, the beneficial effects of adopting short fibres admixed in the cementitious matrix of the TRC were observed, leading to a material called Fibre/Textile Reinforced Concrete (F/TRC). The current state of research of retrofitting columns with TRC, or F/TRC, contains, for the most part, works concerning the confinement effect of such reinforcements on short columns. Only a few experimental investigations have instead been performed on slender Reinforced Concrete (RC) columns. To narrow such a gap, an experimental campaign was performed at the laboratory for structures of the Carinthia University of Applied Sciences in which these retrofit solutions were applied on 2 m long slender elements. This work presents and discusses the results of such experimental campaign. In particular, an investigation about compressive tests on slender RC columns, retrofitted with F/TRC, is provided. The varied parameters are the number of layers and the materials of the textile fabric (basalt – B, and carbon – C).

From the test results it was observed that the maximum load reached by the retrofitted columns was 28% to 48% higher, compared to the reference specimen. Furthermore, it has been observed that, in terms of maximum load reached by the retrofitted columns, the performances of carbon and basalt textile fabrics are not significantly different. It is therefore concluded that, as observed in short columns, the adoption of B-F/TRC and C-F/TRC retrofits significantly improves the load bearing capacity of slender RC columns.

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Strengthening of Existing Multi-span Bridges for Widening Using FRP Techniques

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5A Special Session: Sustainable Structural Strengthening, Auditorium, November 12, 2024, 3:30 PM - 5:30 PM

The South Australian Government is currently delivering infrastructure upgrades on the state's rural highway corridors. Representing the largest ever rural road investment in South Australia, these upgrades aim to provide a more reliable and safer road network, improve access for high productivity freight vehicles, better connect rural communities, facilitate economic growth and enhance tourism opportunities in rural areas. A large number of existing bridge structures along the corridors will need to be assessed for heavy vehicles from Performance Based Standards (PBS) scheme.

As part of the rural highway upgrades, Jacobs have provided design services for the widening and safety barrier upgrades of seven existing bridge structures along Princes Highway to accommodate larger PBS vehicles. This included site investigation, concept design, optioneering, multiple criteria assessment, preliminary design and detailed design stages.

This paper focuses on the structural assessment, and the design of strengthening and widening for the cantilever deck slabs or pier headstocks of, two of the existing bridge structures, including one seven-span continuous concrete slab bridge and one three-span simply supported concrete deck slab / steel girder bridge. The paper describes the challenges encountered during the design, including the need to maintain traffic flow during construction stages, to minimise impact to the existing structure, to design for strengthening of the existing lightly-reinforced cantilever concrete slab, and to consider the slab support conditions at various construction stages and the durability of the materials used near the coastlines. The use of Fibre Reinforced Polymer (FRP) techniques has allowed for a successful design solution that satisfied the various design constraints and led to improved safety for road users. The FRP materials are very durable, which will reduce future maintenance costs, help to extend the design life of the existing structures and benefit the local community.

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The Canadian shear design provisions for UHPFRC reinforced and prestressed members

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5B Shear analysis and design, Dobson 1, November 12, 2024, 3:30 PM - 5:30 PM

Ultra-High-Performance-Fibre-Reinforced-Concrete (UHPFRC) generally contains a sufficient quantity and quality of steel fibres that the material will show strain hardening behaviour after cracking. This characteristic makes it behave in a different fashion to conventional reinforced and prestressed concrete. While it has a higher embedded carbon content than conventional concrete, it also has sufficiently higher performance than conventional concrete that the reduced quantity of material required can result in a better environmental footprint overall when the design is complete.

Until recently, an area that needed technical progress for this material was the lack of a standardized design method for shear. This paper presents the 2025 Canadian Bridge Code method for design of fibre-reinforced members containing hardening quantities of fibres. It will be shown that this method is compatible with the Model Code 2020 design approach allowing engineers to see the consequences of various design choices.

The paper will present the design equations, justify why the changes were made from the existing methods in the Model Code and discuss the consequences of these changes. The paper will also present comparisons of the results to existing shear tests as well as to the behavior of shell elements with UHPFRC concrete.

It is hoped that with the presentation of this method and comparisons to other national standards that an international consensus can be achieved for this high-performance material.

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Influence of Compressive Membrane Action on Shear Capacity of RC Members without Shear Reinforcement

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5B Shear analysis and design, Dobson 1, November 12, 2024, 3:30 PM - 5:30 PM

In the 1960s and 1970s, RC slabs in ribbed ceilings were constructed with very low thicknesses. Applying the shear design of the current Eurocode 2 (EC2), these structures would fail in shear, but examination of existing ribbed ceilings generally gives no indication of shear failure. This implies that there are significant load-bearing reserves in these structures not accounted for in the codes. One possible reason is the semi-empirical nature of the design formula, which was calibrated on a database with mainly simply-supported test specimens subjected to concentrated loads. However, slabs are usually built as multi-span systems, thus benefitting from effects such as Compressive Membrane Action (CMA) evolving from the deformational restraint formed by adjacent slabs. These beneficial effects are so far not accounted for in shear design according to EC 2 and the influence of CMA has mainly been studied for bending, although some studies on the influence of CMA on shear behavior have been carried out in recent years.

For further examination of CMA, experimental investigations on shear behavior of slab segments without shear reinforcement featuring both distributed and concentrated loading and additional external loading representing the effect of CMA have been conducted in a new test setup at the Institute of Structural Concrete of RWTH Aachen University, Germany. Prior to the experimental shear tests, numerical studies on a continuous slab system were carried out to identify the additional normal force and bending moment resulting from CMA in dependence of the applied vertical loading in the span. The load-deflection curves and the crack pattern from the tests showed a good agreement with the numerical simulations and a significant increase in shear capacity was observed.

In this contribution, selected results from the experimental investigations will be presented.

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Rigid Plastic Upper Bound Shear Capacity Model for RC Members without and with Very Small Amounts of Shear Reinforcement

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5B Shear analysis and design, Dobson 1, November 12, 2024, 3:30 PM - 5:30 PM

Many existing reinforced concrete structures older than 40 years do not satisfy the requirements for the minimum shear reinforcement ratio and the maximum spacing of stirrups according to the current design codes. Consequently, the shear reinforcement is neglected when estimating the shear capacity of such structures. This omission of shear reinforcement can lead to an underestimation of the actual shear capacity of these structures.

This paper presents a shear capacity model for reinforced concrete members with small amounts of shear reinforcement. The model enables estimation of the shear capacity of members with less shear reinforcement than the minimum shear reinforcement specified by the current design codes, as well as members with greater stirrup spacing than the maximum limit. The model considers the shear contributions from sliding in cracked concrete, dowel action of the longitudinal reinforcement and activated stirrups by the dowel action and the critical shear crack.

Comparison of the proposed model with experimental results shows a good agreement, highlighting its potential applicability in assessing the shear capacity of existing concrete structures.

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Shear capacity of RC slabs without shear reinforcement.

A review of the available literature and Code provisions

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5B Shear analysis and design, Dobson 1, November 12, 2024, 3:30 PM - 5:30 PM

The shear capacity of reinforced concrete slabs has been a contentious topic in the global engineering community, owing to diverse analytical models that yield varying shear strengths for identical concrete members. This paper reviews New Zealand national and international standards and code provisions regarding the design of reinforced concrete structures, specifically focusing on requirements for estimating shear capacity in suspended concrete slabs without shear reinforcement under concentrated loads close to their supports. A comparison was made between the shear capacity estimates derived from various concrete standards, utilizing existing data from shear tests conducted on suspended slab specimens. The paper further endeavors to assess shear failure in these slabs through analytical models implemented in commercial Finite elements analysis (FEA) software, using material models based on the modified Compression Field theory. The paper compares the analytical results and models, scrutinizing their alignment with experimental data obtained from thick slabs (30cm, 35cm, and 40cm) and thin slabs (10cm) without shear reinforcement. The authors present their findings on the most effective model for predicting shear capacity in slabs without shear reinforcement and discuss potential enhancements within the current NZS3101 concrete code concerning the shear capacity of RC slabs without shear reinforcement. The authors also review the efficiency of the available material models implemented in commercial FEA software to predict the shear capacity of concrete slabs without shear reinforcement.

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Analytical model for punching shear assessment due to column removal incorporating dynamic effects

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5B Shear analysis and design, Dobson 1, November 12, 2024, 3:30 PM - 5:30 PM

Punching shear is typically the governing failure mode in flat slabs, concerning both their static response and response to extreme events, such as column removal. Current design codes predominantly focus on static loading conditions, and do not provide specific tools, particularly simple approaches, for assessing the dynamic loading associated with column removal scenarios. This paper addresses this limitation by developing analytical closed-form equations to evaluate the punching shear resistance in cases of column removal with due account of dynamic effects. This is achieved by appropriately modifying the load-rotation curve to account for column removal, based on an existing analytical dynamic model developed at the University of Surrey. Accordingly, the Critical Shear Crack Theory is adopted to define the failure criterion, while the dynamic nature of the loading is considered through energy balance considerations. The proposed analytical model is eventually applied to a flat slab reinforced concrete building, which represents typical residential and commercial buildings in the UK. The results demonstrate the importance of incorporating the dynamic effects to achieve accurate estimates of the punching shear resistance in column removal situations and highlight the inadequacies of most current code provisions. In addition, the significance of various parameters that are included in the proposed equations is investigated through a sensitivity analysis. Importantly, the model is compatible with new EN 1992-1-1:2023 (Eurocode 2) and Model Code 2020 formulation for punching shear assessment. Hence, the suggested methodology provides a valuable contribution to the ongoing efforts in generalising design codes based on mechanical models, ultimately enhancing the safety and robustness of structures subjected to extreme events.

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Punching shear behaviour of flat slab systems: Experimental investigations on flat slab cutouts with external loading conditions

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5B Shear analysis and design, Dobson 1, November 12, 2024, 3:30 PM - 5:30 PM

Due to the desire for slender buildings with variable room layout, flat slabs are a popular load-bearing element in building structures. However, the slab-column connection is often a governing detail in design due to concentrated load application and the associated risk of punching shear failure. To counter this, the punching shear behavior of flat slabs has been intensively studied in recent decades, mostly on flat slab cutouts, as the production and testing of flat slab systems is expensive and time-consuming. The main phenomena of the punching shear behavior were hereby investigated and form the basis for today's design equations. However, the system load-bearing effect, which has a significant influence on the punching shear behavior as a few investigations have shown, is unconsidered. The investigations revealed considerable load reserves in flat slab systems caused by the emerging effects of compressive membrane action and moment re-distributions. These effects are only considered to a limited extent or not at all in today's design equations.
To fill the gap in experimental data for the derivation of more advanced design provisions, a novel test setup was developed for the efficient investigation of system behavior using flat slab cutouts with load-dependent boundary conditions. An extensive test pro-gram with two test series and a total of ten test specimens was carried out. The test results of the second test series, investigating the influence of concrete compressive strength, show increased punching shear resistances with simultaneously reduced deformations compared to conventional flat slab cutouts.

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Finite element modeling of punching shear behavior of concrete slabs with shear reinforcement

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5B Shear analysis and design, Dobson 1, November 12, 2024, 3:30 PM - 5:30 PM

Nonlinear Finite Element Analysis (NLFEA), which is currently available in many commercial FE programs, can be efficiently used for the analysis of reinforced concrete slabs. Testing of large scale structural concrete elements is expensive and time consuming and thus only selected specimens are tested. Calibrated FEA is a valuable tool that can be used to supplement experimental results by providing analysis related to many parameters influencing the behavior. Structural concrete shows distinctly nonlinear behavior and thus the available constitutive models, within FEA packages, include considerations for nonlinear material constitutive behavior, damage, plasticity, and concrete-reinforcement interactions. This paper presents a NFEA formulation which was developed to study punching shear behavior of flat concrete plates supported on columns. The analyses are done using the concrete damaged plasticity (CDP) model available in ABAQUS. The calibration analyses for the NLFEA model are presented first with the focus on modelling shear reinforcing elements in concrete slabs. Comparisons with experimental results are shown and the recommendations are provided on how to effectively analyze slabs with shear reinforcement using NLFEA. The calibrated FEA model is then used to conduct parametric studies on the effects of shear reinforcing spacing, openings in slabs and types of shear reinforcing elements on punching shear strength of slabs. The conclusions and recommendations on FEA modelling and on shear reinforcement placements are provided.

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Basis for a Simplified Topology Optimisation Strategy for Reinforced Concrete Beams Based on Inclined Stirrups

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5B Shear analysis and design, Dobson 1, November 12, 2024, 3:30 PM - 5:30 PM

The production and use of concrete has a significant global environmental impact, mak-ing it crucial to explore methods for reducing its carbon footprint. This study, conduct-ed at the Institute of Green Civil Engineering of the University of Natural Resources and Life Sciences, Vienna, focuses on developing and evaluating a simplified strategy for topology optimisation of reinforced concrete (RC) beams. The approach involves in-clining stirrups reinforcement at angles of 30°, 45°, and 60°, along with combined incli-nations of 45°_60°, starting from the middle of the RC beam and connecting initially to the bottom reinforcement, subsequently to the top reinforcement, followed by voiding concrete between the stirrups with triangular void shapes matching the inclined stirrups' angles. The numerical analysis of seventeen RC beams with different void shapes is pre-sented and compared to a solid RC beam without voids designed according to Eurocode 2 guidelines. The assessment of the load-bearing capacity is based on force-displacement curves extracted from calibrated ABAQUS models and observed failure modes, followed by a life cycle assessment (LCA) for the solid RC beam and the promising optimisation trials. The results demonstrate significant potential for reducing concrete by up to 19%, stirrups reinforcement by up to 1.4% and CO_2 emission reductions of up to 14.6% in the most promising optimisation trial, with potential for further improvement. Addi-tionally, the study contributes to establishing a database detailing the behaviour of voided RC beams, laying the groundwork for a digital toolset serving as an optimisation plug-in for RC beams.

Keywords: Life Cycle Assessment, Numerical Analysis, Optimised Structural Element, Rein-forced Concrete Topology Optimisation, Sustainable Building Construction.

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Understanding the behavior of concrete blocks exposed to 20 years of marine environment with accelerated laboratory experiments

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5C Concrete durability, Dobson 2 & 3, November 12, 2024, 3:30 PM - 5:30 PM

The main cause of premature deterioration of reinforced concrete structures is the corrosion of steel bars, induced by chloride ions (for example in marine environment) or by carbonation. At the same time, environmental-induced degradations of concrete can also affect the structure, such as external sulphate attack leading to the formation of ettringite, inducing expansion inside the materials and finally degradation.

In this paper, concrete blocks (with supplementary cementitious materials), exposed to real environments, are studied and compared to laboratory experiments. Various aspects of the microstructure and of the pore structure are investigated, by using Mercury Intrusion Porosimetry and XRD, TGA, 27Al NMR, in order to better understand the results obtained relatively to the apparent chloride diffusion coefficients and to the chloride binding for example in marine environment.

Results show the difference between the microstructures of the various materials and their consequences on the ingress of aggressive agents. In addition, chloride ingress increases when sulphates are present in the contact solution for all cement materials tested. It appears that presence of sulphate decrease chloride binding, thus explaining the results.

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Corrosion Resistance of Self-Healing Concrete Using Alkaliphilic Bacteria

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5C Concrete durability, Dobson 2 & 3, November 12, 2024, 3:30 PM - 5:30 PM

The objective of this study is to explore the effect of alkaliphilic bacteria as an oxygen reducing admixture to inhibit corrosion of steel bar in concrete under corrosive environment. In experimental investigation, prism specimens, of cross section 100x100 mm, and 200 mm long were cured in water tank until the age of 7 days, and then cured in room condition controlled at 20°C until the age of 28 days. They were subsequently exposed to wet and dry conditions using water tank containing NaCl 10%. In addition, specimens with bending cracking were also tested in this study to examine the self-healing efficiency of cracking as well as effect of inhibiting corrosion of steel bar. The corrosion behavior was examined by electro-chemical measurements such as macrocell corrosion current density, half-cell potential, polarization resistance and anodic/cathodic polarization curves. Based on results obtained, the possibility of corrosion was greater than 90% based on the haff-cell potential and microcell corrosion based on polarization resistance in the case of cracked specimens with alkaliphilic bacteria. However, the macrocell corrosion current density was observed to be comparable to OPC (control) specimens without cracking. This could be explained by the fact that the cathodic reaction is controlled by limiting current density associated with the diffusion of oxygen which is effectively reduced by the metabolism of the alkaliphilic bacteria. This is also the case for the specimens with bending cracks. This study extends previous work on oxygen reducing materials in inhibiting corrosion in cracked concrete via lower oxygen permeability, which could be obtained by alkaliphilic bacteria used in this study.

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Theoretical prediction of chloride profile based on probabilities of particle movement and its application to real data from existing bridges.

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The article will present the methodology developed in a research project focused on a more accurate prediction of concrete contamination with chlorides promoted by carbonation, based on data obtained from existing bridges. The methodology is based on simulating the penetration of particles, whose driving mechanism consists of a random motion through concrete layers according to Einsten´s - Brownian motion. The particles are considered as non-interacting single species that approximate real chloride ions. The measured chloride profile is simulated considering the moving boundary problem, which represents the carbonation front, where different diffusion probabilities of particles are assumed in the carbonated and sound concrete at each time step. Based on measured data from in-situ samples, the average annual surface concentration of chlorides is assumed. The unknown probabilities for the concrete layers are computed iteratively based on satisfying the convergence criterion, which is defined based on the laboratory-derived concentrations at a given depth and bridge age. After obtaining the probabilities of particle motion in the concrete cover, the diffusion coefficients for the individual layers are calculated and various situations can be further simulated. One of them is the simulation of the impact of various repair solutions on the development of the chloride profile within the concrete in time.

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Application of Digital Image Correlation (DIC) Method to Evaluate the Water Absorption in Different Qualities of Concrete

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This study primarily focuses on the application of digital image correlation (DIC) to assess the water penetration distribution and volumetric changes in concrete resulting from water adsorption by the cement hydrates considering three different water to cement ratios. One dimensional water absorption test was performed on thin slice specimens of different qualities in concrete. During water absorption tests, the strain gauges and DIC were applied on the surface of slices to evaluate the expansion and the strain distribution. The strain gauges measured the expansion in terms of generated strains at the gauge location due to water absorption, while DIC quantitatively evaluated the areas of strain generation due to water ingress with respect to time of saturation/absorption. The extent of strain generation and the strain areas in low-quality concrete was clearly larger than those in medium and high-quality concretes. Conclusively, it was found that the strain gauges and DIC can quantitatively assess the strain development process in concrete caused by volumetric expansion of cement hydrates (especially, C-S-H) due to the water adsorption.
Keywords: water absorption, strain generation, strain gauge, DIC

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Concrete Technology, Durability and Sustainability in the Department of Transport and Main Roads Queensland Australia

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5C Concrete durability, Dobson 2 & 3, November 12, 2024, 3:30 PM - 5:30 PM

This paper will give a brief history of our concrete technology and concrete durability journey within TMR (Qld Department of Transport and Main Roads) over the last 20 years together with our present position and issues, and where we see some of our future challenges and development.

Some of our future challenges associated with material and concrete supply and achieving sustainability goals, along with our current research and development areas are also outlined.

A particular focus will be what we have achieved to date on our journey to making our concrete more sustainable and reduce the carbon footprint of our concrete, and our current road map to achieve further reductions.

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Reevaluating the Significance of Concrete Cover Depth in Mitigating Carbonation-Induced Corrosion Damage

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The European durability design codes addressing reinforcement corrosion induced by carbonation primarily focus on inhibiting corrosion by preventing carbonation of the concrete cover. This philosophy to ensure the durability forms the foundation for both the current method employed in codes with exposure classes and the forthcoming strategy incorporating exposure resistance classes. Thus, current and future norms evaluate concrete performance primarily based on resistance to carbonation. The current limit state concerning carbonation of the cover depth is notably conservative and lacks a direct link to structural damage. To enhance the efficient use of material resources, it is imperative to establish limit states with practical relevance, such as concrete cracking. Unfortunately, to date, a scientific foundation and engineering judgment to reliably model the time to cover cracking are absent. The moisture conditions at the depth of the reinforcement appears to be key parameter controlling the corrosion rate. One additional crucial indicator for preventing structural damage due to carbonation-induced corrosion is the concrete cover with its ability to limit its carbonation under cycling drying/wetting conditions and to limit moisture ingress through the carbonated microstructure to the depth of the rebar.

Is this approach imposing excessive and potentially ineffective requirements particularly on modern cementitious binders with low clinker content, with the objective of reducing carbon emissions? The consequence of this for the overall global warming contribution of concrete is highly significant; given concretes preventing carbonation-induced damage constitute a substantial 60-70% share. Maintaining the current highly conservative limit state significantly curtails the construction sector's contribution to the UN Sustainability Development Goals. In the meantime, immediate benefits may be obtained from implementing relatively simple design strategies. In particular, conducting a thorough evaluation of the chosen exposure class for various structural elements during the design phase, with the aim of minimizing the exposure class to the absolute essential level, would yield immediate benefits in terms of mitigating the environmental impact of concrete. This paper aims to address this issue by providing a critical examination of existing durability design rules and offering recommendations for revision supporting sustainable solutions.

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Limit of Chloride Ion Concentration on Corrosion of Steel Bar in PAE-Based Polymer Cement Mortar

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5C Concrete durability, Dobson 2 & 3, November 12, 2024, 3:30 PM - 5:30 PM

This study reports on corrosion properties of polymer cement mortar (PCM) mixed with PAE, which is commonly used as a repair and strengthening material for concrete structures. It has been reported that chloride ion concentration which initiates corrosion of steel bars in PCM could be higher compared to those of conventional concrete mixtures. However, the higher corrosion resistance is not comprehensively examined with respect to anodic region associated with the formation of passive film and cathodic reactions leading to the reduction of oxygen and moisture in the corrosion cell. In particular, the limit of chloride ion concentration that initiates corrosion of steel bar is central to this study. In experimental investigation, PCM specimens were cast with Cl- concentrations of 0 (control), 3, 6, 9, 12 kg/m3. After specimens were cured in room conditions controlled at temperature of 20±1°C until the age of 28 days, they were immersed in water tank with a chloride concentration of 10%. Segmented steel bars comprising round bar □22 which is split into two pieces i.e. upper and lower parts connected by epoxy resin were embedded in the specimens in which corrosion behavior such as localized and/or uniform corrosion of steel bars could be examined by electrochemical measurements. Based on the results of half-cell potential, polarization resistance, macrocell corrosion current density up to 182 days of monitoring, the corrosion of steel bar was observed to occur in the specimens mixed with chloride ion concentrations of 6, 9, and 12 kg/m3. In contrast, corrosion seemed to be not observed in the specimens mixed with a chloride ion concentration of 3 kg/m3. These results suggest that the limiting chloride ion concentration for initiating corrosion for the PCM used in this experiment could range from 3 to 6 kg/m3 which is generally higher compared to normal concretes.

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Investigation on bond failure mechanism of corroded rebars in concrete by X-ray CT method

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5C Concrete durability, Dobson 2 & 3, November 12, 2024, 3:30 PM - 5:30 PM

Bond of rebars is quite important considering that rebars and concrete are supposed to be well-integrated in design. It is known that the bond strength of deformed bars in concrete decreases due to steel corrosion. There are two possible causes of the bond degradation, (1) reduction of confinement of the cover concrete due to corrosion cracks, and (2) changes in the shape of the deformed bars. The aim of this study is to investigate the influential degree of these two factors on the bond strength of corroded deformed bars. In this study, corrosion acceleration tests of cylindrical concrete specimens with deformed bars embedded to the center were carried out to induce steel corrosion. Target amount of corrosion was set so that the pull-out strength becomes approximately half of that of the sound specimen. An X-ray CT method was used to capture images of the inner cross sections before and after the corrosion to visualize the occurrence and patterns of corrosion cracks. The shape changes of the deformed bars were also investigated by CT images after the pull-out loading tests. The results of the experiments showed that corrosion cracks can be visualized in CT images. Analysis of the CT images revealed typical patterns of corrosion cracks around a deformed bar. It was also observed from detected crack , how corrosion cracks propagate from a rebar to the outer surface of concrete. Reduction of the cross-sectional area was also investigated, and it indicated that distribution of corrosion is not uniform.

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Seismic C2 performance of post-installed fasteners in tension: Low-strength undercut anchor compared to other anchor types

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5D Special Session: Post-installed connections, Dobson 4, November 12, 2024, 3:30 PM - 5:30 PM

Post-installed anchors are widely used to connect structural or nonstructural elements to concrete structures. Expansion anchors, screw anchors, and bonded anchors are the most common anchor types, each of them having product depending pullout capacities and their own merits depending on the application. Undercut anchors, on the other hand, are not as common as they are relatively complex and expensive. When made of suitable steel grades and designed properly with sufficient embedment depth, undercut anchors do not get pulled out and therefore activate the full concrete capacity while the steel capacity is controlling the design strength. High performing undercut anchors can maintain all of their static design strength also for seismic design cases. Moreover, the sleeve encasing the anchor rod allows free deformation along its length and therefore undercut anchors can develop pronounced ductility. This paper gives an example design strength comparison of the basic anchor types for static applications as well as for seismic applications requiring the performance category C2, introduced for design situations of highest load demand. This design data is then compared to the performance of a generic undercut anchor which ductility is demonstrated by test data.

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Tensile behaviour of post-installed fasteners in early age concrete with and without steel fibres

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5D Special Session: Post-installed connections, Dobson 4, November 12, 2024, 3:30 PM - 5:30 PM

Post-installed fasteners are widely used in the construction industry to connect structural and non-structural elements to existing concrete. However, the design of these fasteners is often based on the assumption that the concrete is at least 28 days old, which may not be the case in some applications. Moreover, most design standards rely on the compressive strength of concrete as the main indicator of the concrete-related strength, neglecting the influence of the tensile strength and fracture energy of concrete on the anchorage performance. This paper aims to investigate the tensile behaviour of post-installed fasteners in early age concrete, with and without steel fibre reinforcement. A series of experimental studies were conducted to understand the material properties of normal and steel fibre reinforced concrete (SFRC) from 18 hours to 28 days after casting, and to evaluate the pull-out resistance of fasteners installed at different ages. The results show that the concrete properties vary significantly with age, and that the addition of steel fibres enhances the tensile strength and fracture energy of concrete. The paper also discusses the implications of the findings for the design of post-installed fasteners in early age concrete.

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Fire Design of Post-installed Anchors with EN1992-4 and EOTA TR082

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5D Special Session: Post-installed connections, Dobson 4, November 12, 2024, 3:30 PM - 5:30 PM

The design of Post-Installed Anchor (PIA) for seismic loads has gained significant attention after the incorporation of post-installed connections into NZS 3101 after Amendment 3, in 2017. However, the design of PIA for fire actions is not well addressed in the standard, and the awareness of proper consideration and design is very limited. The possibility of fire in a building transcends geology and fault lines and is an ever-present hazard for which to design post-installed anchors. This is specifically important in Seismic countries, as the likelihood of fires increases significantly after an earthquake. This paper outlines the assessments, pre-qualifications, and design methods of post-installed mechanical and bonded anchors, allowing steel, concrete, and pull-out/bond failure modes of anchors to be calculated based on EN1992-4 (Annex D) for mechanical anchors and the recently published EOTA TR082 for bonded anchors.

A case study and comparison of the design using mechanical anchor and bonded anchor is also provided to demonstrate the governing failure mode associated with each type of anchor.

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Fatigue resistance of anchors in concrete under shear load with lever arm

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5D Special Session: Post-installed connections, Dobson 4, November 12, 2024, 3:30 PM - 5:30 PM

In construction practice, fastenings to the concrete structure are often designed with a levelling layer of mortar between the anchor plate and the concrete surface or as a stand-off installation. Typical applications include connections between steel plates and concrete foundations or anchorages of facade systems in which the anchor plate has no contact to the concrete. If a shear load is applied in these cases, the anchors are subjected to bending due to the increased lever arm.

Under fatigue-relevant actions, these bending stresses represent an unfavorable loading scenario particularly for threaded fasteners, which may lead to a considerable reduction of the fatigue resistance. As there is no sufficient knowledge on this subject so far, the fatigue verification in the current design regulations is limited to shear loads without lever arm and the design of fasteners under cyclic shear loads acting with lever arm is not permitted.

This paper presents the findings of an experimental study on the fatigue behavior of fastenings in concrete subjected to bending with regard to steel failure of the anchor. Post-installed bonded anchors of size M20 were tested in uncracked concrete C20/25, where the fatigue failure was characterized by a formation of cracks in the area of the thread. The test program therefore includes pulsating shear tests on single anchors with different lengths of lever arm. Within the experiments strain measurements were performed to analyze the bending strain in the anchor to get a better understanding of the correlation and interaction between bending and shear stresses.

The test results were used to evaluate the fatigue resistance in relation to the nominal stress range acting in the edge fibre of the decisive cross section that fails. A direct comparison with further fatigue data available from the literature shows that the fatigue strength for bending stresses is larger than for pure tension or pure shear stresses.

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The Australian journey for harmonising design, prequalification and installation of fastenings into concrete with international practice

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5D Special Session: Post-installed connections, Dobson 4, November 12, 2024, 3:30 PM - 5:30 PM

The landscape for the Australian fastening industry has evolved rapidly since 2012. A collaborative initiative was formed between industry and academia to uplift and safeguard the performance of fastening industry. A level-playing field for assurance of fastenings performance in Australia was achieved through the introduction of an Australian standard for design of fastenings to concrete which was adapted from the Eurocode EN 1992-4, mandating product prequalification and introduction of a nationwide certification program for installers of fastenings to concrete.

Governance in all three critical areas: design, product prequalification and installation was introduced in a span of less than a decade. The speed of such achievement is unprecedented not only in the Australian market but also internationally. This paper discusses the current Australian practice in safeguarding the fastenings industry and current research trend in Australia in areas such as fastenings performance in steel fibre reinforced concrete, high performance concrete and low carbon concrete.

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Design and construction aspects of shear-friction applications (concrete overlays) using the EOTA TR 066

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5D Special Session: Post-installed connections, Dobson 4, November 12, 2024, 3:30 PM - 5:30 PM

Buildings and bridge structures involve reinforced concrete (R.C.) as one of the most commonly used building materials around the globe due to its advantages of tailored strength and flexibility in construction. The existing R.C. elements may require structural interventions in terms of strengthening, retrofitting, and functional repurposing due to factors such as deterioration through aging, increased risks related to hazards (e.g., earthquakes and fire), adoption of improved building codes and regulations, changes in building functionality, sustainability requirements, etc. Hence, planned retrofitting of existing concrete layers with new structural overlays in buildings and bridges, such as slabs/decks, beams/girders, and walls/piers, is becoming increasingly relevant. The connection between the existing and new concrete layers is fundamental to the monolithic behavior of the entire section and typically must achieve sufficient resistance to shear-friction at the interface. Employing easy-to-install, reliable, economical, and compliant solutions such as post-installed shear connectors or hooked bars ensures safety and durability against static and dynamic actions.

This paper discusses the load-bearing mechanism and the state-of-the-art design methods for shear-friction applications as per the European regulatory framework involving Eurocode EN 1992-1-1, NZS 3101:2006, EOTA TR 066, and the Hilti method, and the applicability of those in New Zealand. Design provisions for static loads, as well as for seismic and fatigue load actions, are presented. The importance of construction procedures, such as the treatment to achieve the required surface roughness of the existing concrete layer, usage of qualified product solutions, and their combined influence on the economical design of post-installed shear connectors for concrete overlays, are also highlighted through design examples. The advantages of using design software for quicker and more efficient design of shear-friction applications are also briefly presented.

Keywords: strengthening, retrofitting, post-installed shear connectors, concrete overlays, shear-friction applications, reinforced concrete, seismic, fatigue.

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Retrofitting Concrete Structures with Post-installed Rebars in New Zealand: Design methods and Compliance pathways

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5D Special Session: Post-installed connections, Dobson 4, November 12, 2024, 3:30 PM - 5:30 PM

The need to meet an increase in load demand due to changes in the design standards or the functional use of the structure, as well as restoring the capacity of deteriorating old buildings and enhancing seismic capacity to increase safety, are some of the most common reasons for retrofitting of concrete structures in New Zealand. Techniques such as concrete jacketing, plate jacketing, addition of shear walls, etc., are often used to retrofit a concrete structure. This paper focuses on the use of post-installed rebar for retrofitting of concrete structures. Though there is not much guidance on the subject in national codes and standards, international guidelines such as TR069 and TR066 published by the European Organization for Technical Assessment (EOTA) can be referred to. This paper reviews the most common retrofitting applications using post-installed rebar in New Zealand and the current design practice. This paper then presents a short literature review of international design guidelines as well as practice on the subject and examines their applicability to New Zealand construction. In conclusion, this paper advocates for the need to have a more comprehensive guide on retrofitting concrete structures, including post-installed rebar applications - aligning with some international practices.

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Influence of different modelling approaches on the predicted concrete edge failure of fasteners

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5D Special Session: Post-installed connections, Dobson 4, November 12, 2024, 3:30 PM - 5:30 PM

Design of anchorages is an integral part of the strengthening of structures. The design of anchorages currently relies on empirical relationships given in EN1992-4. Since these guidelines are based on experimental database, their applicability is limited to the configurations tested. Numerical simulations are gaining more importance in the design of structures and fastening technology is no exception to this development. Numerically assisted design provides flexibility to the designer to also design anchorage configurations that are not covered by the norm, which is very common in practice. But the reliability of numerical simulation results depends on a large number of factors, the important ones being the reliability of the material model and the assumptions made in order to simplify the modelling approach. Therefore, numerical models have to be validated using results from experimental investigations.

The paper presents the results of a numerical investigation conducted to understand the effect of following parameters on the predicted concrete edge failure capacity: 1) types of constraints used in experiments and 2) the assumptions made regarding the fixture and the loading setup used for applying the shear load on the fastener. In this paper, 3D Finite Element (FE) simulations are performed for headed studs and bonded anchors with 4 different types of constraints and 4 different assumptions for the loading fixture. The FE models are developed using ANSYS® Mechanical. The nonlinear behaviour of concrete is modelled using Drucker-Prager model under compression and Rankine’s yield surface under tension.

The predicted edge failure capacities were found to be more sensitive to the modelling assumptions for the loading fixture as compared to the constraints. In the end, the modelling approach which delivered the most realistic results is used to perform further simulations covering a broad range of edge distances to generalise the validity of the proposed modelling approach.

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Repair and Strengthening of Concrete Bridges with Post-installed Anchors

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5D Special Session: Post-installed connections, Dobson 4, November 12, 2024, 3:30 PM - 5:30 PM

Cyclone Gabrielle hit New Zealand in February 2023 and caused catastrophic damage to many areas on the east coast of the North Island. Extreme levels of rainfall caused extensive flooding and river levels to rise across the region, and with this, came damage to numerous bridges.

This paper will cover a range of concrete structures that have been damaged as a result of the cyclone and will provide details of the innovative repair and strengthening techniques that have been used to bring the structures back in to use and maintain their working life. The paper will typically focus on remedial works to substructure elements.

Once example of this is Makarika Bridge No.2, a 148m long, six span structure crossing the Mata River near Waipiro Bay. As a result of the flooding, one of the concrete piers was damaged by debris impact causing the pier to partially buckle, showing significant cracking and exposing reinforcement. This led to closure of the bridge to all vehicles, leaving hundreds of local residents cut off from the rest of the country. To strengthen the damaged pier, a new concrete shell pier built around the existing was proposed. To tie the new shell pier to the existing, new reinforcement was anchored to the existing concrete pier, pile cap and cross beam using epoxy mortar.

An example involving alternative strengthening is the Esk River Bridge located on State Highway 2. Vertical dowels grouted into pre-drilled holes have been installed between the concrete deck and beams to improve the shear capacity of the structure. This offered an economic solution that was safe to construct from the top of the deck.

This paper will explore the above, as well as other examples, in more detail to provide an overview of the effectiveness of modern-day concrete repair and strengthening methods.

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Experimental and numerical study on long-span retard-bonded-prestressed RC frame with openings

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5E Experimental tests on structural members, Bealey 4 & 5, November 12, 2024, 3:30 PM - 5:30 PM

The mechanical performance of a long-span retard-bonded-prestressed RC frame with openings (LRRCFO) was carried out. The effect of openings on crack patterns, failure modes, load-deformation curves, load-maximum crack widths curves, load-strain curves, ductility, and energy absorption capacity was analyzed. Mid-span and beam end appeared the ideal plastic hinges. The cracks in the corner of the openings developed faster than those in the mid-span, and the maximum crack appeared in the corner. After the openings were strengthened, there was no sudden influence on the deformation of the LRRCFO. Furthermore, the influence of different sizes of the openings on LRRCFO was analyzed by the verified finite element model. With the increase of the opening length (>1.24h), the bearing capacity gradually de-creased, and the shear failure of the openings occurred. Compared with specimens without openings, the opening length of 0.74h has no significant effect on bearing capacity of the beam, however, it influences the peak displacement. In a word, the reasonable strengthened of the openings could not weaken the stiffness, and the scheme of LRRCFO is feasible.

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Experimental Investigation of Key Structural Parameters for Structural Design of 3D-Printed Concrete

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The use of robots to produce 3D-printed concrete structures is developing rapidly. The technology offers promising potential to change the way we design and optimise concrete structures. This has already been shown by numerous publications in academia and showcased in the industry.
The research and development within 3D-printed concrete structures have until now largely been focused on the development of material composition, the print process and the development of the robots. There is still a lack of knowledge on the design and load-bearing capacity calculation of 3D-printed concrete structures. Current projects in practice are often based on "Design by testing".

Determination of the bearing capacity of conventionally cast concrete structures is based on the compressive strength of the concrete, which is determined by testing cast cylinders. From this, the concrete tensile strength can be calculated and the compressive strength is assumed to apply in all directions. When printing concrete structures, these assumptions cannot be assumed to be valid. As shown in the literature the layering of the concrete often gives an anisotropic compressive strength. Furthermore, the calculation of the tensile strength cannot be based on the model from cast concrete and the tensile strength will vary in different directions.

To be able to develop reliable mechanical models and to design 3D-printed concrete structures with mechanical models, it is important to develop a better understanding of the material characteristics and the structural behaviour. This includes understanding the anisotropic material behaviour in tension and compression and the relation in between. Furthermore, standardised methods for testing the material characteristics are needed. This is important to be able to use the same methods for producing experimental evidence in the laboratory as will be used for material characteristics in practice.

This paper provides experimental evidence on the material characteristics of 3D-printed concrete. This is done by taking samples from 3D-printed structures, cast structures, and cast mould samples. From these samples, the concrete compressive and tensile strength are tested in three directions. Furthermore, to take the influence of the print process and the design of the layered structure into account, different printers and locations are used in the study. The print setup includes a robotic arm printer and a gantry printer. Furthermore, different material mixes and different sizes of layers are considered.

By use of multi-linear regression modelling, it is shown that there is a relation between the tensile strength and the anisotropic compressive strength.

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Large-Scale Experiments of Voided Shear Walls with Pre-Walls

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Aiming to reducing the carbon footprint of concrete structures, there is a pressing need to optimize the geometry of concrete members, which in turn can reduce the amount of cement needed for construction. In this context, an experimental investigation was conducted on a common element in concrete buildings, namely shear walls. The experimental program included lateral monotonic testing up to failure of three full-scale voided shear walls, in addition to a reference specimen. The walls featured two outer precast pre-walls, a middle cast-in-place core with voids, and a cast-in-place tension flange. The introduced voids were circular with a fixed diameter for each of the specimens. The main test variable was the volumetric void ratio, which varied between 8.7% to 15.6%. The voided walls failed in a nearly identical manner by the crushing of the concrete across the web. The experimental results show that the maximum reduction in strength for the walls was only 23% compared to the solid wall without voids. Moreover, it is demonstrated that there was no significant reduction in stiffness of these walls compared to the reference specimen. The results presented in this paper illustrate the feasibility of optimizing the geometry of shear walls in order to mitigate the green gas emissions.

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Experimental survey on corroded reinforced concrete and prestressed concrete beams

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Steel reinforcement corrosion represents one of the major degradation causes of reinforced concrete and prestressed concrete structures, as witnessed by recent cases worldwide. The paper presents and discusses the outcomes of a wide experimental survey, carried out at the University of Rome "Tor Vergata" within the framework of an Italian PRIN project on both types of elements, for the evaluation of their flexural response when subjected to corrosion. The experimental campaign, including seven reinforced concrete beams and six prestressed concrete beams tested in four-point bending, was subdivided in two groups. A first group of beams were tested at the end of an artificial corrosion process through electrolytic cells, provided to obtain different damage levels. A second group of beams were instead tested with a more realistic Laboratory procedure, consisting in a simultaneous application of loading and artificial corrosion. These last tests interested one reinforced concrete beam and one prestressed concrete beam. All the beams featured a length of 3700 mm and a rectangu-lar 200 mm x 300 mm section. Particular care was devoted to the calibration of the corro-sion process, to the assessment of the morphology of the corroded steel rebars and strands and to the interpretation of the results of traditional (potentiometer and linear variable dis-placement transducers) and innovative measure devices and sensors (MEMS accelerometers, MEMS clinometers and stress sensors). The paper shows the potential consequences of steel corrosion in terms of variation of the ultimate strength, displacement capacity and failure mode, that can turn from ductile to brittle. Furthermore, the experimental outcomes highlight the importance to account for the combined effect of reinforcement corrosion and loading and for the morphological aspects of the corrosion phenomenon, when assessing the structural performance of reinforced concrete and prestressed concrete beams.

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Experimental and Numerical Investigation on Uniaxial Compressive Performance of Hollow Circular High-strength Precast CFST Piles

Ms Clarissa Jasinda[1], Professor Susumu Kono[1], Dr. David Mukai[2], Dr. Taku Obara[3], Ms Mami Yamaji[4]
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5E Experimental tests on structural members, Bealey 4 & 5, November 12, 2024, 3:30 PM - 5:30 PM

Hollow circular high-strength precast concrete-filled steel tube (hereafter, hollow CFST) piles are commonly used as a foundation member in Japan and some Asian countries for low- or mid-rise earthquake-resilient buildings. Despite the high usage of this pile, there is currently no guideline supporting the compressive capacity design of these high-strength hollow CFSTs without extrapolating experimental data of similar CFST columns. The commonly used guidelines for CFST members (Eurocode 4 and AISC 360-16) do not have provisions to account for hollow concrete core, and the most recent update of Japanese AIJ foundation guideline (2022) only provided simple material strength summation to calculate the compressive capacity of hollow CFST. Some researches proposed equations to calculate the compressive capacities of hollow CFST members, but are limited to f'c of less than 102 MPa.

Previous research highlights the distinctive behavior of hollow CFSTs with concrete compressive strength of more than 80 MPa and the need to establish a new equation to evaluate the compressive capacity of hollow CFST considering the influence of various parameters. To propose a suitable equation, the mechanism and contribution of concrete and steel tube needs to be clarified. Three-dimensional finite-element analysis is conducted to investigate the detailed compressive behavior of hollow CFSTs which could not be observed from the experiment. From the calibration and verification of the model with experimental results of four specimens, proper modeling parameters are discussed. Concrete damage plasticity model and steel bilinear with strain hardening model successfully captured the axial load-average strain curves of four hollow CFST specimens. The individual contributions of concrete and steel, and the development of confinement are also discussed to clarify the composite action.

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Analyzing structural behavior of prestressed continuous beams with tendon breakage tested in combination of bending, torsion and shear

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5E Experimental tests on structural members, Bealey 4 & 5, November 12, 2024, 3:30 PM - 5:30 PM

A number of medium span prestressed concrete bridges are constructed with internal prestressing strands installed in ducts that are filled with cement grout. One drawback of this method is that the possible deterioration of the prestressing steel is hidden deep inside the structure, which heavily relies on the presence of prestressing force and the prestressing steel in its ability to bear the traffic loads on the bridge. Additionally, one aspect of these medium span beam bridges is that due to their quite high width-to-span ratio, the torsion stresses in the beams can be relatively large for the size of the cross-section. At the same time, the demand has increased for shallower super-structures and more economical use of concrete, which has led to reinforcing ratios of the structures to become higher. To study the effect of the tendon breakage and to verify different analysis methods for the bending-torsion interaction, four large scale prestressed concrete beams were loaded to failure in laboratory conditions. The beams were continuous with spans of 10 m + 10 m and with beam width and height being 0.7 and 0.5 meters respectively. All beams had eight 150 mm² strands for prestressing steel and in three beams half of the strands were cut at the middle support during the load test. The effect of different reinforcement ratios was studied by adjusting the amount of reinforcement bars at the middle support area. Heavy instrumentation of the test specimens allowed the careful examination of the structural behavior of the beams and made it possible to compare the results of analytical models, which previously have been verified only by experiments with fairly small size test specimens. The results show that analysis methods presented could be used in the design and in the assessment of prestressed concrete bridges with internal tendons.

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Study on the combined effect of grout compressive strength and rebar embedment variation in a grouted mechanical coupler

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5E Experimental tests on structural members, Bealey 4 & 5, November 12, 2024, 3:30 PM - 5:30 PM

Grouted mechanical couplers for reinforcement bars need to allow for a certain tolerance, in terms of grout compressive strength and rebar embedment depth, which is required for constructability and challenging site conditions.

With this paper, the authors wanted to study how the simultaneous and independent variation of the bar embedment and of the grout compressive strength can influence the strength of the connection. We have used test data to develop and validate a simplified empirical model for the rebar pull-out failure mode. Using the Montecarlo method, we have performed a statistical analysis on the proposed pull-out model, to compare the results against the available long term quality production data of the reinforcing bar.

This allows for a better understanding of the robustness of the system, particularly around the lower limits of the tolerance range.

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Experimental study on the maximum punching capacity of slab-column connections

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5E Experimental tests on structural members, Bealey 4 & 5, November 12, 2024, 3:30 PM - 5:30 PM

Using shear reinforcement is one of the most effective ways to enhance the punching capacity and ductility of slab column connections in flat slab floor systems. However, results of some specific experimental tests have shown that an increase in punching strength has some limits independent of the amount of shear reinforcement. These limits (VR,max) are defined in two ways, i.e. by the capacity of the concrete strut at the column periphery (EC2) and as kmax or ηsys times the punching capacity without shear reinforcement (ACI318-19, EC2, prEC2). Since the values of kmax and ηsys are very different depending on the country's experience and standard or code it is still a very important topic of the research, and experimental tests are demanded mainly for a very small database of the specific test results. The paper presents some results of the experimental program that was focused on the maximum punching capacity. The obtained test results were then included in the database that was used for the evaluation safety and accuracy of 8 different models for predicting VR,max. The best performance provided the model with ηsys from prEC2(2023) when the dataset included test results of flat slab specimens reinforced with either double-headed studs (DHS) or stirrups. If the dataset included the only results of the tests with DHS, the best performance provided model introduced by Schmidt et al. (2021) with a constant value of ηsys (kmax) = 1.75. In the case of flat slab specimens reinforced with stirrups, the most accurate was the model introduced in the Slovak NA to EC2 (2004) with kmax ranging from 1.40 to 1.70 depending on the value of the slab effective depth

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The Italian Experience – The increasing use of FRP strengthening solutions after recent earthquakes

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6A Special Session: Seismic strengthening of concrete structures using Fibre Reinforced Polymers (FRP), Auditorium, November 13, 2024, 10:00 AM - 12:00 PM

FRP applications have been rapidly grown in Italy in recent years. Several devastating earthquakes have clearly confirmed the strong need to adopt effective solutions to mitigate the seismic risk at national scale. The reconstruction process of damaged area in the aftermath of recent earthquakes has demonstrated that FRP strengthening represents a sound and cost-efficient solution to improve the seismic capacity of existing buildings. Furthermore, the definition of economic incentives at national level for seismic strengthening and energy efficiency of existing structures have strongly highlighted the need to develop fast, sustainable, and integrated strengthening interventions. FRP has raised as a sound solution to provide effective responses to such questions. The paper firstly presents the statistic on the use of FRP as well as the type of solutions adopted in the reconstruction process following recent Italian earthquakes. The costs related to the use of FRP solution to improve the capacity of structural and non-structural members are also presented. Then the focus is on the recent research developed by the research group of the Department of Structures for Engineering and Architecture of University of Naples to validate the effectiveness of FRP based strengthening solutions applicable with a minimum level of disruption and low impact on buildings. The innovative solutions layouts and design procedures have been validated by experimental test programs on members or on full scale structures; they have shown the high potential of composite materials for repairing and increasing the seismic capacity of existing buildings by only acting from the exterior and in combination and in combination with interventions targeted to energy efficiency.

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The Turkish Experience – Resilience in a newly industrializing country through FRP strengthening

Professor Alper İlki

6A Special Session: Seismic strengthening of concrete structures using Fibre Reinforced Polymers (FRP), Auditorium, November 13, 2024, 10:00 AM - 12:00 PM

In Türkiye, a remarkable portion of existing buildings, particularly those built before 2000s, do not comply with the provisions of current and previous earthquake-resistant design codes. This unfortunately results with huge loss of lives and built environment after severe seismic events as recently demonstrated by the February 2023 earthquakes, which caused more than 50.000 casualties and heavy damage or collapse of over 300.000 buildings. Since the country experiences severe earthquakes quite frequently and the probability of an earthquake with an approximate magnitude of 7.0-7.5 is quite high in coming years for the heart of country, Istanbul, urgent intervention is needed to the existing substandard buildings to avoid catastrophic consequences. Fiber reinforced polymers (FRPs) offer rapid, occupant-friendly and effective solutions for seismic improvement of substandard buildings with competitive costs. In this study, the research conducted in Türkiye for last 20 years on seismic retrofit of substandard structural members/structures are outlined and potential gains that can be obtained through FRP-strengthening are anticipated in terms of prevention of future losses. Furthermore, concepts of "partial/local seismic retrofit" and "low-level seismic retrofit" are discussed in terms of avoidance of total collapse of existing substandard buildings and in terms of costs and benefits.

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Seismic strengthening with FRP in the US - current state of design guidelines and path forward

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6A Special Session: Seismic strengthening of concrete structures using Fibre Reinforced Polymers (FRP), Auditorium, November 13, 2024, 10:00 AM - 12:00 PM

Fiber reinforced polymer (FRP) materials have been used for seismic strengthening of concrete building structures for several decades. However, design guidance for such applications was first published only in the 2017 edition of ACI PRC 440.2-17. Since this first publication, the interest in the development of design provisions for seismic strengthening with FRP has grown rapidly. The new 440.2-23 contains improved guidelines for seismic strengthening of shear walls. It is apparent, however, that a lot more work is needed to address the wide range of seismic strengthening applications being already deployed in the field. In the USA, ACI 369.1 is the standard for seismic evaluation and retrofit of existing concrete buildings via inclusion in ASCE/SEI 41. It is anticipated that ACI 369.1 will include some design provisions for FRP seismic strengthening in the 2028 edition. ACI Committees 440 and 369 are currently discussing avenues to work collaboratively, to generate design guidelines for other applications such as shear walls, diaphragms, beam-column joints, etc. Such design guidelines could contain information for general seismic design requirements, such as provisions to calculate strengthened capacities and material and detailing requirements. There is strong interest in making guidelines available to the design community as soon as possible. Eventually, these guidelines will be incorporated, as appropriate, in the consensus codes and standards produced by the ACI 440S, ACI 369S, and ASCE/SEI 41committtees. This paper will describe the current state of the design guidelines for FRP seismic strengthening, layout the proposed next steps for the development of design guidelines and discuss possible pathways for the eventual adoption of the provisions into US standards.

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Whole-of-Building Approach to Improve Seismic Retrofits of Reinforced Concrete Buildings in New Zealand

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6A Special Session: Seismic strengthening of concrete structures using Fibre Reinforced Polymers (FRP), Auditorium, November 13, 2024, 10:00 AM - 12:00 PM

In response to the pressing need for retrofit guidelines in New Zealand identified by the Building Innovation Partnership (BIP), Toka Tū Ake, and the Joint Committee on Seismic Assessment of Existing Buildings (JCSAEB), an effort has been initiated to develop a retrofit guide for existing reinforced concrete (RC) multi-storey buildings. New Zealand's unique construction practices, such as the combination of precast and cast-in-place RC and the use of structural systems with limited stiffness, create unique challenges for seismic retrofitting. The proposed guide shall assist engineers in a) prioritizing vulnerabilities in existing buildings, b) ensuring compliance with regulations, and c) adopting new knowledge on retrofit practices.

The guide shall address:

a) global retrofit focusing on techniques that can be applied to change the performance of the overall structure, often through addition of structural components to increase overall stiffness and strength.
b) retrofit techniques intended to increase strength and/or deformation capacity of individual structural components (e.g. jacketing, FRP wrapping, and mechanical clamping).
c) retrofits for floors and diaphragms – an issue particularly relevant in New Zealand.
d) general considerations regarding base isolation,
e) geotechnical considerations including changes to the foundations, installation of additional foundations, and ground improvement.
f) international practices.
g) Key questions being studied include:
h) To what degree can or should the stiffness and strength of the existing structure be considered to contribute to seismic resistance?
i) If the contribution of the existing structure is ignored, what deformation limits should be imposed on the resulting system to avoid failure of existing elements?
j) As an alternative to question b): does it suffice to size the added elements and their connections to the existing elements to reach a strength target and ignore the effects of deformation demands?
k) If the existing structure is considered to resist seismic demands in parallel with the added structural elements, what deformation limits should be imposed to ensure that the assumed contribution from existing elements can be sustained through repeated displacement cycles?
l) In force-based design approaches, how should force-reduction factors be selected? Should they be selected considering the properties of the new components, the properties of the old components, or both?

m) In absence to an objective answer to e), would it be acceptable to base the design of the supplemental structural elements entirely on comparisons between estimates of displacement demand and displacement limits set to control damage supplemented by checks on global base-shear strength?

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The circular economy and bridges: proposals to take this forward

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6B Special Session: Circular Economy approach in making Concrete Structures Sustainable, Dobson 1, November 13, 2024, 10:00 AM - 12:00 PM

This paper looks at two fundamental aspects in the need for circular economy principles to be considered in the design of bridges. Firstly, in the depletion of finite natural resources required for bridge construction materials and secondly the effects in global warming due to greenhouse gas emissions. The concept of the circular economy is to keep each material circulating in its most current form, minimising leakages to energy recovery and landfill. The lack of a strong statutory imperative for sustainability means that in most parts of the world, decisions on bridge type, materials and bridge form are generally not made with the knowledge of the planet's finite construction resources and also the impact of the construction, maintenance and eventual demolition on producing greenhouse gases and contributing to global warming. This presentation addresses the need and identifies project examples where circular economy principles have been implemented. The role of Codes and Standards in the promotion of the broader sustainability principles is also discussed.

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Circular Design Framework for Concrete Bridges

Mr Jamil Khan[1], Mrs Tania Hyde[1]
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6B Special Session: Circular Economy approach in making Concrete Structures Sustainable, Dobson 1, November 13, 2024, 10:00 AM - 12:00 PM

Beca has developed a Circular Design Framework for designers to implement broader outcomes and circular design principles on projects. This approach is a system thinking shift from sustainable to regenerative, circular design. Regenerative design is part of the Framework that takes us a step further than sustainable design, moving beyond net zero to create positive outcomes on natural systems. It is with this idea that the concrete bridges we are designing are catalysts for positive change, which enhances the communities and surrounding natural systems over long periods of time. We design today for the future, so our resources are available to use 100 years or more in the future. For Concrete Bridges the Circular-Design-Framework themes are:

1. Integrate cultural perspective to improve the quality of life through enhancing the unique characteristics of a place and its people?
2. Move beyond a liner ‘take-make-west system’ by designing out waste and pollution and to look for new/old ways to design and use product and materials to protect the finite resource on our planet?
3. Reduce our human footprint by reducing extraction of virgin material by keeping assets, materials, and products in use through refuse, reuse, repair, remanufacture.
4. Regenerate natural system by actively looking for opportunity to support nature to thrive, grow biodiversity and create flourishing future for people and planet.
5. Take a more people cantered approach to local economic development that works to produce shared economic prosperity, equity, and positive outcomes for all.
6. Increase resilience and adaption by considering known and unknown climate-related risk and build a flexibility given the uncertain nature of future impacts.

The use of framework will tell us how sustainable our recent concrete bridges are and steer the Kiwi bridge engineers for future improvements in their practices to ensure circular economy design principles are embedded in their future bridge developments.

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Steel reuse for the transition of the construction industry to a circular economy

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6B Special Session: Circular Economy approach in making Concrete Structures Sustainable, Dobson 1, November 13, 2024, 10:00 AM - 12:00 PM

The steel industry annually emits 2.6 gigatonnes of carbon dioxide (Gt CO2), constituting 7% of the total carbon dioxide emissions from the global energy sector. The primary objective of the circular economy is to promote reuse, effectively mitigating environmental impacts throughout the entire life cycle of a product, from production to post-consumer phases.

In New Zealand, structural steel holds a national market share exceeding 50%, and the construction industry contributes to 20% of the country's total greenhouse gas (GHG) emissions. Given the carbon footprint associated with the initial life cycle of structural steel, the development of sustainable solutions for the reuse of structural steel elements could result in substantial carbon reductions within the construction sector.

This paper will discuss the barriers and opportunities to reuse steel in New Zealand and will highlight future research and development to facilitate steel reuse in the construction industry.

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A Qualitative Sustainability Assessment of Peka Peka to Ōtaki (PP2Ō) Expressway Project Bridges using a Circular Design Framework

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6B Special Session: Circular Economy approach in making Concrete Structures Sustainable, Dobson 1, November 13, 2024, 10:00 AM - 12:00 PM

This paper will showcase the Peka Peka to Ōtaki Expressway project bridges, where many initiatives were undertaken with focus on urban design, environmental protection, construction efficiency, and seismic resilience, now can be seen in hindsight meeting the sustainability and circular economy principles. These small sustainability initiatives fall into various themes of the Circular Design Framework developed by Beca.

The Circular Design Framework themes include:

- Integrating cultural perspectives
- Designing out waste and pollution
- Cycling materials and assets at their highest value
- Regenerating natural systems
- Creating socio-economic benefits
- Increasing resilience and adaptation

The PP2Ō bridge designs align with the framework themes through the following:

- The cultural artworks and other cultural narrative features integrated on the project.
- The waste and pollution were reduced by replacing 30% cement with flyash, offsite production of steel and precast beams, locally supplied materials/products, efficient and cost-effective modular construction, eliminating high maintenance expansion joints, and using exposed aggregate finishes to deter graffiti. The use of bank-seat abutments on MSE walls reduced about 7,831 t CO_2 emissions.
- The project team used 334 tonnes of flyash as a SCM in concrete, used demolished concrete in road embankment fill, and reconstructed the historic brick built Mirik Smišek kiln in a new location.
- All concrete laden stormwater was neutralised before discharging to the stormwater system. The team has incorporated six new wetlands to protect the habitats and ecology of the surrounding environment.
- The materials, resources, and products were sourced from the local region. This improved the local economy, provided value back to the local economy and placed ownership and participation into the hands of local people.
- The bridges are designed to resist at least two ULS (1/2500 year) earthquake and flood events during their design life. Furthermore, the bridges shall not collapse in a ME (1/10,000 year) earthquake event.

The project outcomes demonstrate that the designers, constructors, and other stakeholders of this major infrastructure project have already taken a qualitative shift from the current linear economy to move towards a circular economy, leading others in this regard.

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Bridging the Gap Between Risk and Resilience

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6C Special Session: Peer Exchange for Resilient-Eco & Socially-Sustainable bridges and structures (PxRESS-1), Dobson 2 & 3, November 13, 2024, 10:00 AM - 12:00 PM

In 2023 the wide-ranging effects of our changing climate were acutely felt across New Zealand through multiple events; most notably through Cyclone Gabrielle, which caused major damage across the North Island. It left in its wake multiple bridge collapses and significant damage to both structures and the road network; severing critical lifeline routes; causing significant disruption to travel and trade; significant cost of remediation; and tragically, loss of life.

Through this event, roading authorities, contractors and consultants worked hand in hand, responding under immense pressure. As efforts continue to reinstate disrupted networks, a wealth of insights await discovery — lessons not only in the realms of response, and recovery but also in managing structural vulnerabilities and performance deficiencies. We see the challenge of a dynamic and progressively impactful natural hazard environment as our industry's urgent call to action in extracting and enacting these crucial insights for a more resilient future.

This presentation will examine the approach taken before during and after Cyclone Gabrielle with a focus on immediate response, and deepening understand of risk and risk management. We will discuss lessons for asset owners and engineers; good practice and understanding of risk to improving the resilience of bridges and other critical assets; and processes to respond during emergencies.

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Reducing the environmental impact of bridges using a common LCA framework

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6C Special Session: Peer Exchange for Resilient-Eco & Socially-Sustainable bridges and structures (PxRESS-1), Dobson 2 & 3, November 13, 2024, 10:00 AM - 12:00 PM

While reducing the greenhouse gas emissions associated in buildings has been a priority in the United States’ construction industry for some time, considerably less attention has been paid to reducing the environmental impacts of bridges and other civil engineering works. However, as the focus has shifted from operational to embodied environmental impacts in buildings, a new focus on other structures has begun to emerge. As such, concrete and steel industry associations have identified a lack of guidance on evaluation the environmental impacts related to bridges. They have responded by collaborating on an life-cycle assessment (LCA) framework for bridges. This presentation will highlight how this unlikely partnership emerged; how collaboration was made possible by focusing on technical accuracy, good science, and ISO standards; and progress made to date on the LCA framework. The presentation will also include best practices related to LCA for bridges, and a status update on the publication and adoption of the framework.

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The 200-year Bridge: Resilient, Economical, Environmentally & Socially Sustainable

Mr Steven Nolan[1], Dr. Thomas Cadenazzi[2,3], Dr. Chase Knight[4], Dr. Marco Rossini[3], Prof. Antonio Nanni[3]
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6C Special Session: Peer Exchange for Resilient-Eco & Socially-Sustainable bridges and structures (PxRESS-1), Dobson 2 & 3, November 13, 2024, 10:00 AM - 12:00 PM

Beyond the need to provide resilient and durable bridge foundations to meet existing codified service lives (50, 75, 100, & 150-years) there exists multiple accelerated bridge construction and material technologies for rapid and economical replacement of bridge superstructures. Therefore, the potential reuse of existing foundations and/or repeat widening of existing structures to achieve an extended service life, economically relies on the original bridge foundations to remain in good condition. Additionally, the potential for adaption of existing bridges to meet other functional needs, primarily relies upon foundations remaining in good condition to provide a cost-efficient solution and low environmental impact. Experience over the last 200-years reveals the transient nature of surface transportation design criteria, public travel needs and expectations, design methodologies and risk assessment, which constantly evolve. Considering current trends towards greater use of autonomous vehicles and increasing fixed-guide-way adoption, predicting future travel lane widths, capacity needs, environmental, climate, and vehicle loadings is very challenging for asset owners and custodians. Span length selection and bridge vertical clearance height must be set appropriately with consideration for future underpass needs and changing environmental conditions. Even anticipating these needs within the next 50-years, which is a lower limit of service life expectations is challenging. Beyond the obvious need for extended durability, a successful 200-year bridge design should also feature adaptability to accommodate this uncertainty, and the increasing sustainability demands from governments and society. At the very minimum, design success is dependent on selecting the appropriate materials, geometry, and hydraulic parameters for the anticipated needs. For waterway crossings, obvious considerations include: sea-level rise, increasing scour, flow rates, storm surge, and wave crest elevations. This presentation explores some of the latest reinforced and prestressed concrete bridge solutions that are emerging to meet these challenges and attain an ambitious (but worthy) service life goal beyond 150 years.

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Key Focus Areas to Assure the Longevity of Resilient and Sustainable Concrete Structures in Australia

Mr Scott Munter[1], Mr Eric Lume[1]
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6C Special Session: Peer Exchange for Resilient-Eco & Socially-Sustainable bridges and structures (PxRESS-1), Dobson 2 & 3, November 13, 2024, 10:00 AM - 12:00 PM

Reinforced concrete is the most common and versatile construction system in buildings and structures worldwide. Ensuring resilience to survive extreme loads with minimal maintenance for preservation over future generations without the need for demolition and replacement, improves built environment sustainability.

With increasing regularity and severity of natural disasters including floods, fires, cyclones, severe storms, hail, heatwaves, coastal inundation and earthquakes, the importance of providing a resilient built environment is becoming an essential part of engineering design. Detailing for negligible damage or being repairable after design events, without causing severe economic and social costs is fundamental.

In 1895 reinforced concrete was adopted in Australia from the many benefits that it continues to offer in terms of resilience against fire, termites, water and hot and cold weather, as well as long life, low maintenance and sustainability. The current focus to reduce embodied carbon in materials is essential but sustainability is a balancing process and proven longer lifespans with minimal maintenance makes reinforced concrete inherently sustainable.

This paper highlights key focus areas across the value chain to assure lifespan extension outcomes including quality and traceability in procurement of conforming reinforcing materials, site practices, often overlooked with steel reinforcement, which significantly impact performance requirements and simple design and detailing for life safety and resilience. Resilience against earthquakes first appeared in Australian Standards in 1979. AS 3600 was revised in 2018 based on the Christchurch lessons learnt to further improve resilience, robustness of this long-lasting solution.

The Steel Reinforcement Institute of Australia (SRIA) developed Guidelines supporting these engineering challenges consolidating essential technical information to improve resilience and facilitate preservation and sustainable reinforced concrete solutions. These include seismic design and detailing plus a unique Guide for assessment of existing concrete buildings and structures, facilitating rehabilitation options for lifespan extension now part of the fib model code.

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Future Proofing Concrete Infrastructure through Climate Resilient Composite Technologies

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6C Special Session: Peer Exchange for Resilient-Eco & Socially-Sustainable bridges and structures (PxRESS-1), Dobson 2 & 3, November 13, 2024, 10:00 AM - 12:00 PM

Most of the widespread corrosion deterioration of reinforced concrete infrastructure is due to direct contact with and exposure to seawater in coastal environments. This problem costs the Maritime Safety Queensland of the Queensland Department of Transport and Main Roads at least $10 million per year to repair and maintain boating and marine infrastructure. This case study presents the construction and loading test for a boat ramp infrastructure in the Mooloolaba Parkyn Parade (Sunshine Coast, Australia). It involves a comparative evaluation of the manufacturing and structural performance of precast-concrete boat-ramp planks reinforced with glass fibre reinforced polymer (GFRP) bars or galvanized-steel bars. In addition, two reinforcement mesh designs stemmed from a similar design reinforcement requirement were implemented in building the approach concrete slab: 16 mm diameter GFRP bars spaced every 150 mm in both directions and 24 mm diameter GFRP bars spaced every 300 mm in both directions. Loading tests and monitoring of the in-field performance were conducted by running a fully loaded 15-tonne water truck over the slab where the strain in the embedded GFRP bars and concrete as well as the displacement of the slab were measured. This case study demonstrates the durability and resilience of GFRP-reinforced concrete as boating infrastructure. These benefits led to approval and publication of the standard drawings for a new plank and approach slab design for implementation in boating-infrastructure projects in Australia.

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Project Case Study: Repair of Gisborne Port Breakwater Utilizing GFRP Rebar

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6C Special Session: Peer Exchange for Resilient-Eco & Socially-Sustainable bridges and structures (PxRESS-1), Dobson 2 & 3, November 13, 2024, 10:00 AM - 12:00 PM

The Gisborne Port Breakwater was in a very poor state of repair due to corrosion of the steel reinforcement. The structure is more than 80 years old. With retaining walls which were rotating outwards, significant stabilisation was required to prevent eventual collapse.

The repair involved casting a concrete capping anchor slab which was tied into the retaining walls, to prevent further wall rotation and provide additional strength for continued port operations.
The anchor slab design required sufficient capacity to support loading and unloading crane operations for the foreseeable future.

Since the anchor slab is exposed to the ocean, corrosion of traditional steel rebar was a major concern, so the designers opted to use Glass Fibre Reinforced Polymer (GFRP) rebar to reinforce the concrete slab. This investment will ensure operational longevity of the structure with minimal future maintenance costs.

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How healthy are Japanese piles and foundation members?

Dr Susumu Kono[1], Dr Shreya Thusoo[1], Miss Clarissa Jasinda[1], Dr Taku Obara[2], Dr Naresh Subedi[1], Dr David Mukai[3]
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6D Seismic design and retrofit, Dobson 4, November 13, 2024, 10:00 AM - 12:00 PM

Seismic design of piles and foundations in Japan is based on the working stress concept for minor- and intermediate-scale earthquakes, even if the seismic design of upper structural system of buildings has been gradually moving toward the performance based design. The legislature does not require consideration of the ultimate state of piles and foundations for severe earthquakes, mainly because very few buildings have collapsed due to damage to piles and foundations and the study on these structural members has been left out from the main stream of seismic engineering for many years. The issue is even difficult due to the complexity and uncertainty of surrounding soil and boundary conditions of piles and foundations. Some buildings, however, were demolished after damage to piles in the 1995 Kobe earthquake, 2011 Tohoku earthquake, and 2016 Kumamoto earthquake. The Japanese engineers and researchers started to study the ultimate flexural/shear behavior including load carrying capacity and deformation capacity of piles and foundations in order to use buildings continuously even after severe earthquakes. There are various design issues on cast-in-place piles, precast concrete piles, and pile caps, and it is not easy to make regulations or design guidelines for ultimate conditions. Engineers evaluate the seismic behavior of piles and foundations based on existing knowledge for beams, columns, beam-column joints, and sometimes unavoidably underestimate load bearing and deformation capacities for safety reason since there is not enough experimental data to explain their ultimate behavior under different axial load levels. Real scale test under large axial load level is very important to study seismic behavior of piles and foundations in order to design them with a performance based design concept. However, very few experimental works have been conducted to clarify the ultimate behavior of these foundation members. The paper introduces recent Japanese efforts to build experimental data on real scale or large scale concrete piles (prestressed high strength spun concrete piles, prestressed high strength reinforced spun concrete piles, steel encased high strength spun concrete piles, cast-in-place reinforced concrete piles, cast-in-place steel encased concrete piles) and foundations (column-beam-pile connections) so that engineers are able to use performance based design concept for piles and foundations.

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Behaviour of Reinforced Concrete Encased Steel Lattice Elements under Cyclic Loading

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6D Seismic design and retrofit, Dobson 4, November 13, 2024, 10:00 AM - 12:00 PM

The seismic behaviour of concrete encased steel members is a complex issue. Ignoring deformation compatibility between concrete and steel can be overly conservative, while assuming full deformation compatibility can overestimate component capacity and not capture seismic risk. This study investigates the behaviour of reinforced concrete encased steel lattice frames under cyclic loading.

To investigate behaviour, two half-scale column specimens and two half scale beam column joints were constructed based on a 1960's building in Wellington. Both columns are non-prismatic, narrowing at the base, and consist of a welded steel plate lattice frame encased in reinforced concrete. The beam column joints consist of a combination of welded steel lattice frames and steel plates with penetrations. Specialty frames were constructed to conduct the uniaxial cyclic testing and the primary focus of the results was strain behaviour and composite action between the two materials.

Prior to completing the experimental testing, a finite element analysis was undertaken to estimate the component behaviour and provide a numerical model to estimate performance that will be validated by the experimental testing.

This study contributes valuable insights into the structural reliability of reinforced concrete encased steel lattice frame elements, offering guidance in the assessment of seismic behaviour and contribute to effective and reliable retrofit solutions.

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Damage states and fragility curves for lightly reinforced concrete walls

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6D Seismic design and retrofit, Dobson 4, November 13, 2024, 10:00 AM - 12:00 PM

Lightly reinforced concrete (LRC) walls are widely used as infill in the moment-resisting framed buildings in Japan. Though not designed for seismic load resistance, some of these walls resist it, resulting in damage of some kind. Past earthquakes have shown that even though the structural elements are intact, the LRC infill walls can be severely damaged, causing building dysfunctions. Component fragility curves play a crucial role in Performance-Based Earthquake Engineering that can be used to target the resilience and functionality of the building. Due to the limited availability of extensive experimental results relating to the damage states of the LRC walls, numerical simulation of the global and local response is necessary. In this study, a two-dimensional fiber-based macroscopic model was selected to obtain a reliable prediction of the inelastic behavior of LRC walls. The numerical model was validated using available experimental results obtained from four full-scale LRC infill wall specimens. Four damage limit states were characterized based on the damage progression observed in the experiments. The onset of each damage limit state was defined using material strain from the wall simulations. LRC wall models, designed to replicate infill walls in Japan, were generated and simulated under a quasi-static cyclic loading protocol. Based on the result of damage analyses of these walls, fragility curves describing the probability of experiencing or exceeding a particular damage state as a function of the experienced drift ratio were drawn. The proposed drift-based fragility curves can be used in the performance evaluation and seismic loss assessment in performance-based earthquake engineering of buildings.

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Preliminary Study on Lateral Response of Lightly Reinforced Concrete Non-Rectangular Walls

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6D Seismic design and retrofit, Dobson 4, November 13, 2024, 10:00 AM - 12:00 PM

Rectangular and non-rectangular reinforced concrete (RC) walls are commonly used as the primary seismic force-resisting systems in multi-storey buildings. Recent studies focused on the longitudinal reinforcement content for the rectangular cantilever walls resulted in the revised minimum reinforcement limits being adopted in concrete design standards. However, the flanged wall sections exhibit a significant reduction in the margin between nominal flexural strength and cracking strength when compared to rectangular wall sections. The lower margin ratios highlighted the potential vulnerability of non-rectangular walls designed with light reinforcement contents that may exhibit reduced plastic hinge lengths and low displacement capacities. The objective of this study was to investigate the lateral load response of non-rectangular designed with light longitudinal reinforcement contents, focusing on the spread of plasticity in cantilever non-rectangular walls. Models were developed using displacement-based beam-column elements for the non-rectangular walls that were validated against the experimental results to confirm the accuracy of the proposed model schemes. Pushover analyses were then conducted on the 20-storey C-shaped walls with the light longitudinal reinforcement contents subjecting the orthogonal loading (parallel and perpendicular to the web). The model results indicate the non-rectangular walls with a lower margin between nominal flexural strength and cracking strength would result in concentrated plasticity at the base and a low drift capacity.

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Butterfly-shaped wooden Estone blocks for seismic retrofitting

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6D Seismic design and retrofit, Dobson 4, November 13, 2024, 10:00 AM - 12:00 PM

In Japan, most of the strengthening of existing vulnerable buildings has already done at present. However, some of hospitals, hotels, tenanted buildings have not done until now, these buildings could not approve retrofitting noise, vibration, dust and unsanitary condition during operating their functions. In 2016, one of solution has been dealt with and an innovative method, called "ESTONE Block seismic retrofitting", has been developed with almost no disturbance to the facility users and minimum disturbance of facility operation during strengthening, as well. The method consists of constructing infill walls within the existing structural frames of the facility to be strengthened using butterfly-shaped hollow concrete blocks. After piling up the blocks, high-strength mortar is injected within the hollow blocks as well as the whole peripheral interface between the wall and the existing structural frame to unite them. Several structural tests have been carried out in TAKENAKA corporation. ESTONE Block seismic retrofitting has already been put to practical use for more than 50 projects in Japan. As a next sustainable solution, in this paper introduce the wooden Estone block for seismic retrofitting for existing buildings. The wooden Estone block is made of Cross Laminated Timber with butterfly-shaped. The blocks are assembled using epoxy resin adhesive joint, the experimental test showed a good behavior and proved the effectiveness of the strengthening method. The shape of the blocks proved to be very efficient in transferring the horizontal force through the wall, even without reinforcement within it. Until now, the retrofitting technology were applied two actual projects in Japan.

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Approach to Find Suitable CO_2 Capturing Amines for the Prevention of Steel Corrosion in Carbonation Environment of Cement-Based Materials

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6E Low-carbon concrete and innovative materials, Bealey 4 & 5, November 13, 2024, 10:00 AM - 12:00 PM

To reduce CO_2 emissions and mitigate global warming, the authors developed a new method that simultaneously enables the accelerated fixation of CO_2 in concrete buildings and structures, and the corrosion protection of internal steel reinforcements using amines.

In this study, the authors assessed the effectiveness of amines as corrosion inhibitors for steel in a saturated aqueous calcium hydroxide solution ($Ca(OH)_2$), using electrochemical techniques. Two amines, N-methyldiethanolamine (MDEA) and 1-(2-hydroxyethyl)piperazine (HEPZ), were used at a concentration of 10 wt.%.

The results showed that both amines exhibited corrosion protection effect by inhibiting the anodic reaction of the steel, even when the pH decreased from 12.6 to 8.8 due to carbonation. However, when 0.1 mol/L of NaCl was added to the solution, HEPZ demonstrated similar corrosion protection effect to the case without NaCl, the effect of corrosion protection by MDEA was reduced with the decrease in pH of the solution.

The corrosion protection of amines on steel embedded in mortar were also evaluated. It was demonstrated that by pre-impregnating the mortar with amines, the internal steel remained protected against corrosion even when the mortar was carbonated. Although a certain level of corrosion protection was maintained when chloride ions penetrated the mortar, the effectiveness was significantly reduced compared to that before the penetration.

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Addressing the Implementation Challenges of a Performance-Based Approach for Sustainable Concrete: Insights from the Swiss approach.

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6E Low-carbon concrete and innovative materials, Bealey 4 & 5, November 13, 2024, 10:00 AM - 12:00 PM

In response to the imperative of decarbonizing cement and concrete production, Switzerland embarked on a pioneering journey in 2014 to establish a regulatory framework for novel cement solutions not addressed by existing standards and lacking requisite long-term field experience. This initiative will culminate in the publication of a new national appendix (ND) to the concrete standard SN EN 206 in 2024. This appendix empowers concrete producers to design their concrete without prescriptive limits on cement content and water-cement ratio, using approved components. The evaluation of these concretes is based on two primary criteria: a) conformity and production control, and b) a pure performance-based assessment. However, adopting such an innovative concrete design approach poses challenges to the producers in order to achieve the desired rheological, structural, and durability performance within the dynamic conditions of a concrete plant.
This paper delineates the framework established by the standard to surmount the absence of long-term empirical data and first experiences in applying this design standard.

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Enhancing mechanical properties of recycled aggregate concrete prepared with waste soaking solution from acetic acid pre-soaking treatment

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6E Low-carbon concrete and innovative materials, Bealey 4 & 5, November 13, 2024, 10:00 AM - 12:00 PM

Promoting sustainable development and increasing the demand for sustainability in construction, acetic acid pre-soaking treatment is frequently employed to modify and enhance the performance of recycled aggregate (RA). Although the improvement in RA quality through acetic acid has demonstrated to be one of the most effective and environmentally-friendly methods for promoting high-quality RA, the value-added application of acetic acid waste soaking solution after treatment is still overlooked. Thus, this study aims to explore the possibility of using the waste soaking solution as mixing water to enhance the mechanical properties of recycled aggregate concrete (RAC). This approach involved soaking RA in acetic acid solutions with different concentrations. Subsequently, the waste soaking solutions were collected and directly used as mixing water in the preparation RAC samples. To examine the impact of the waste soaking solution on the improvement of the mechanical properties of RAC, the ion composition of the waste soaking solution and its effects on compressive strength and splitting tensile strength were investigated. The results indicated that the compressive strength and splitting tensile strength of RAC increased with acetic acid concentration, and were higher than those of the reference group. Based on these findings, the application of acetic acid waste soaking solution as a mixing water source showcases significant potential in enhancing the mechanical characteristics of RAC, thereby facilitating a broader integration of RA in sustainable concrete construction.

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Life Cycle Assessment of an Innovative Fireproof and Thermal Insulating Geopolymer

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6E Low-carbon concrete and innovative materials, Bealey 4 & 5, November 13, 2024, 10:00 AM - 12:00 PM

This paper presents the environmental impacts associated with manufacturing an innovative fire-resistant and thermal insulating composite made with recycled ceramic tiles using geopolymerization. A Cradle-to-gate analysis is conducted using SimaPro based on the Life Cycle Assessment (LCA) methodology. The environmental impacts associated with the manufacturing of the novel composite geopolymer product are presented and the overall findings were analyzed utilizing the European Product Declaration (EPD) assessment method. Comparison with commercially available materials indicate an overall positive environmental impact. The negative impact associated with transportation, raw material pre-processing (e.g. milling and sieving of recycled ceramic tiles), mixing of constituents and oven curing is essentially outperformed by the inclusion of recycled materials as the main constituent of the novel product, contributing to reduction of the volume of Construction Demolition Waste (CDW) that will end up in landfills, while also reducing the amount of new, raw material necessary for manufacturing fire resistant and thermally insulating products, mitigating raw material depletion.

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Design of high-strength and high-elastic modulus strain-hardening cementitious composites: Towards prestressed structures

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6E Low-carbon concrete and innovative materials, Bealey 4 & 5, November 13, 2024, 10:00 AM - 12:00 PM

Strain-hardening cementitious composites (SHCC) with high/ultra-high strength and ductility have been widely studied, whereas enhancing the elastic modulus of SHCC remains challenging. In this study, high-stiffness iron sands were utilized to develop a novel SHCC with a high elastic modulus of over 45 GPa based on the micromechanical design theory and multiscale homogenization scheme. The effects of water-to-binder ratios, sand-to-binder ratios, and fiber volume fractions on the mechanical properties of SHCC with quartz sands (QS) and iron sands (IS) were investigated. Results indicated that IS-SHCC exhibited a more robust strain-hardening behavior due to its decreased matrix toughness compared to QS-SHCC. Selecting stiffer sands, lower water-to-binder ratios, higher sand-to-binder ratios, and lower fiber volume fractions could result in a higher elastic modulus of SHCC. The multiscale homogenization model to analyze the effective elastic modulus based on the Mori-Tanaka method was verified at C-S-H, cement paste, and SHCC levels. Taking the effects of the above factors into account, experimental results agreed well with the predicted values from the proposed model. The developed high elastic modulus SHCC overcomes the contradiction between the modulus and toughness of conventional SHCC, and it would be regarded as a promising material for applications in prestressed structures.

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Properties of calcined clays in cementitious systems

Professor Horst-Michael Ludwig

6E Low-carbon concrete and innovative materials, Bealey 4 & 5, November 13, 2024, 10:00 AM - 12:00 PM

Due to the closing of coal-fired power plants and the transition of the steel industry to direct reduction, the two most important cement substitutes fly ash and granulated blast furnace slag will only be available in reduced quantities in Europe in future. Calcined clays will increasingly be used as an alternative. The precondition for this is that the performance of the corresponding concretes is in a similar range to that of conventional concretes. To this end, extensive tests have been carried out on fresh and hardened concrete and on durability.

In addition to the type of clay (type and quantity of clay minerals, impurities), the production of the calcined clay (firing aggregate, grinding) also determines the properties. Clays rich in kaolin (two-layer clay minerals) show better properties in concrete in terms of strength and durability than the three-layer clay minerals (illite, smectite, etc.). However, they have a very high water demand and therefore lead to poorer workability of the concrete. New superplasticisers have been developed specifically for this problem and can be used successfully in systems rich in kaolin.

Like almost all composite materials (SCMs), calcined clays also lead to lower early strengths compared to concretes rich in Portland cement. This is of little significance for the ready-mixed concrete sector. On the other hand, ways of increasing the early strength must be found for the precast concrete sector.

Durability is positively influenced by the structural densification associated with the use of calcined clays (Figure 1). By reducing the capillary pore content and the resulting pore refinement, capillary transport into the concrete is considerably reduced, which significantly increases resistance to frost attack in particular, but also to external sulphate exposure. However, the prerequisite for this is that the clay has a sufficient degree of hydration to achieve such structural densification at the beginning of the exposure. In addition to the influence of the microstructure, various chemical-mineralogical factors also play a relevant role in the resistance of concretes to different exposures. Here, the calcined clays must be assessed differently depending on the type of attack. Two factors are often decisive here: the reduction of calcium hydroxide as a result of the pozzolanic reaction and the binding of damage-causing ions in the corresponding hydrate phases. In the case of carbonation, the reduction of calcium hydroxide has a negative effect on the carbonation resistance of systems containing clay. In contrast to carbonation, the chloride resistance is increased when using calcined clays, in particular due to the chemical incorporation of the chlorides into Friedel's salt, and significantly lower chloride penetration depths are measured. However, it should not be forgotten that, on the other hand, the corrosion-inducing critical chloride content is reduced due to the lower pH value. The influence of calcined clays on sulphate exposure and the prevention of a damaging alkali-silica reaction (ASR) can be assessed as positive. In addition to lowering the calcium hydroxide content, the incorporation of alkalis into the C-(A)-S-H phases plays a decisive role in preventing ASR. In principle, the investigations showed that most clays (regardless of their composition) can be used in calcined form as a cement substitute on the basis of optimised production and with the aid of suitable concrete admixtures.

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External Biopolymer Layers for Effective Crack Sealing on Cementitious Substrates

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7A Strengthening and repair, Auditorium, November 13, 2024, 1:00 PM - 3:00 PM

The presence of cracks poses a threat to the durability of current concrete structures, as these cracks serve as pathways for harmful substances that can further degrade the overall integrity of the structure. Ideally, it is crucial to avoid the formation of cracks whenever possible, and immediate repair becomes most important upon the occurrence of cracks. However, conventional repair methods are both time-consuming and expensive, often involving the use of repair mortars with high cement content. To enhance the sustainability of the construction industry, an alternative approach is proposed in this paper. It suggests an economically viable and practical method of applying biopolymers as an external treatment on horizontal concrete surfaces. This treatment aims to seal cracks, thereby minimizing the entry of harmful substances and subsequently increasing the durability of the structure. The study investigates two biopolymers—crosslinked calcium alginates and gelatin—with varying concentrations of initial products and application methods. The results of the research indicate a reduction in water permeability, enhanced resistance to chloride intrusion, improved freeze-thaw resistance, and acceptable adhesive strength of the repair layer to the concrete substrate under dry conditions. The application of calcium alginate as a biopolymer layer exhibits greater potential for external crack sealing compared to the gelatin approach. Its ease of application, effective crack sealing, and improved durability make it a promising choice for future application. Moreover, its low viscosity during application enables usage in hard-to-reach areas, depending on the concentrations of the raw materials used. This application paves the way for more sustainable repair and preventive applications in existing civil infrastructure and renovation projects.

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Effect of Adhesive on Effective Bond Length of EB FRP-RC Beams

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7A Strengthening and repair, Auditorium, November 13, 2024, 1:00 PM - 3:00 PM

Over the last two decades, the global popularity of externally bonded fiber-reinforced polymer (FRP) composites for strengthening and repairing concrete structures has surged. However, a persistent challenge is the premature failure due to FRP debonding. Despite various research approaches addressing this issue, a comprehensive assessment of effective bond length (EBL) determination remains incomplete. This paper meticulously examines eight EBL equations proposed in global design codes. By analyzing composite single and double lap joints and employing an elastic-perfectly plastic behavior for the adhesive bond layer, a new equation is proposed to accurately predict EBL of externally bonded FRP for shear strengthening in reinforced concrete beams. The equation is further calibrated to incorporate concrete strength and widths of concrete and FRP. Due to limited experimental data on adhesive characteristics, a database of 23 test data points was compiled from various literature sources. This database was used to validate the developed equation resulting in improved results for the ratio of actual to calculated EBL (mean ratio: 1.10, standard deviation: 0.49). Among design codes, the JSCE (Japan) is found to be more effective. It is recommended to conduct a thorough review and revision of EBL equations provided in ACI 440.2R-17 and CSA S806-12 due to fundamental flaws in accurately representing EBL behavior.

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Integrating An External Post-Tension Strengthening System Into An Existing Box Girder Bridge Using Ultra High Performance Fibre Reinforced Concrete Blisters

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7A Strengthening and repair, Auditorium, November 13, 2024, 1:00 PM - 3:00 PM

The 312 m precast segmental box girder Victoria Bridge is a key Brisbane River crossing opened in 1969. The structure is a central link for public transport, pedestrians and cyclists within Brisbane and will be required to operate, carrying increased loading beyond its intended purpose.

As part of the Brisbane Metro Project, several areas of the structure required strengthening including flexural strengthening of both anchor spans using external post-tension tendons. The structure has various constraints in the form of existing services, risk of vehicle strikes, aesthetic requirements and its original structural form which result in a series of unique tendon anchorages within the design.

The strengthening system incorporates a series of precast blisters which utilise Ultra High Performance Fibre Reinforced Concrete (UHPFRC) to allow a lightweight, maneuverable anchorage which can be quickly attached to the structure through transverse prestress over both roadways and river. Additionally, a single in situ anchorage block is also used within the strengthening system, designed to be visually inobtrusive between box girders while accommodating two major sewer connections which cross the structure.

Both tendon anchorage types were found to have their own specific set of design challenges when considering the integration of the local connection into the existing global structural system. Conflicting drivers frequently existed between the local and global systems with improved performance in one area coming at the expense of another. As a result, each anchorage required specific consideration and required effective integration of two independent design teams.

This paper provides and overview of the flexural strengthening system and key design challenges, including local strengthening of the existing structure, consideration of creep and shrinkage of existing and new concrete and the determination of optimum core hole locations within the existing prestressed structure.

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Local Strengthening of Poorly Executed Plain Tunnel Linings: Design And Construction Features

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7A Strengthening and repair, Auditorium, November 13, 2024, 1:00 PM - 3:00 PM

Several roadway tunnels built in rock masses are made of plain concrete or weakly reinforced with high-bond bars. The geo-radar investigation carried out at the end of the execution in some tunnels along the variant of the pass in the Barberino del Mugello section, aimed at the understanding of the source of a crack pattern appeared few months after the completion of the works showed a significant reduction up to 90% of the designed thickness in some situations of the internal concrete final lining. In order to locally intervene, the use of a corrugated curved sheet metal hang to the vault of the tunnel by means of chemical steel anchors is used as a stretched reinforcement for a positive bending moment. Fibre reinforced concrete is used to fill the inter-space layer of at least 30 mm between the metal sheet and the original lining. It is worth to note that even if FRC is commonly used to produce tunnel segments to substitute totally or partially the conventional reinforcement [1-4], very few papers consider FRC for local strengthening of existing tunnel linings. For this reason, four prototypes 2.95 x 2.00 m2, each one made of 4 corrugated steel metal sheets assembled by means of 24 tightened bolts are tested to verify the sagging and hogging bending moment bearing capacity. Four holes 200 mm are made in the original lining, 50 mm thick to reproduce the worst situation, to favour the shear transmission between the FRC layer and the plain concrete lining. An AR glass fabric is glued to the original plain concrete lining to improve also the hogging bending moment bearing capacity. The predicted values according to the FRC class specified in the Model Code 2020 by means of a plane section computation and a more careful prediction carried out by means of a Finite Element model are considered for the discussion of the experimental results.

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Simplified Computation Model for RC Elements Strengthened with CFRPs On Low Stiffness Adhesives

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7A Strengthening and repair, Auditorium, November 13, 2024, 1:00 PM - 3:00 PM

External strengthening of reinforce concrete (RC) structural elements, using fiber reinforced plastics (FRP) composites on epoxy adhesives, have been used for the last 30 years. Lots of research carried out on externally bonded carbon fiber reinforced plastics (EBCFRP) showed that such strengthening of RC bent elements is not fully effective because of the stress concentrations caused by stiff epoxy adhesive layers with Young's module ranging in 4-15 GPa. This phenomenon is responsible for brittle and sudden failure in form of composite debonding due to relatively low tensile and shear substrate's resistance compared to the generated stress values and relatively short effective bond length.

One of solutions of this problem is the use of flexible polyurethane (PU) adhesives instead of stiff epoxy ones. This system was developed at the Cracow University of Technology and was investigated using various polyurethane adhesives of orders lower stiffness than epoxies, with Young's module ranging in 2-8 MPa. Such flexible adhesive layers transfer high loads and high deformations simultaneously, which reduce stress peaks and redistribute them more uniformly along a bond length. Moreover, it is possible to obtain a cohesive failure in the PU layers, protecting the concrete substrate against failure. Inexpertly, load-deflection characteristics of these carbon fiber reinforced polyurethane (CFRPU) systems are similar or even more efficient than the CFRP ones.

Computational models for RC elements strengthened with EBCFRP systems follow the Bernoulli's hypothesis of plane cross-sections. In the CFRPU system, bent layers should be modeled with the use of the Bernoulli–Euler beam theory and, with regard to the adhesive layers of small rigidity, the adhesive is approximated with the simple shear state. This analytical approach related to the results of experimental tests carried out on beams strengthened with CFRPU will be presented in the paper.

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Design and construction of slab replacement work between the Kaga and Katayamazu Interchange

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7A Strengthening and repair, Auditorium, November 13, 2024, 1:00 PM - 3:00 PM

This project involved the strengthening of the Kamoike, Inunosawa, Tajirigawa, Daishojigawa, and Shinborigawa bridges on the Hokuriku Expressway between the Kaga and Katayamazu Interchange. This work included replacement the slabs of steel plate girder bridge, replacement the slabs and reinforcement of external cable on the prestressed concrete composite girder bridge, replacement the bearings and detailed designs. The construction section is located near the coast of the Sea and is exposed to severe salt damage that requires the application of deicer salt during the winter season. Since about 50 years have passed since the bridge was put into service and the deterioration of the existing reinforced concrete slabs was recognized in the bridge survey conducted in previous years, the replacement of the slabs with precast prestressed concrete slabs and the replacement of the slabs of the prestressed concrete composite girder bridge are to be carried out. Therefore, it is important to consider measures to improve durability against salt damage in the renewal design. In addition, the construction section is close to the Kanazawa urban area, where traffic is relatively heavy, and the construction period is limited due to snow accumulation during the winter season. In this paper, we report on the measures to improve durability and productivity in slab replacement work, the selection of slab replacement methods based on the structural characteristics of the existing bridges, and the design and construction methods based on the structural characteristics of each bridge, which were adopted in consideration of such bridge environment.

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Transformation of singular joint deformations into multiple cracks in carbon-reinforced concrete pavements

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7A Strengthening and repair, Auditorium, November 13, 2024, 1:00 PM - 3:00 PM

Deformations within jointed plain concrete pavements (JPCP) are concentrated in the joints, which are also weak-points of such pavements. To prevent pollutions in the joints and in the construction at all, they have to be sealed. However, the current sealings are not very durable and must be renewed already after a few years. For this pupose, an alternative method is currently under development. The basic idea is, to overlap the existing joints with a thin concrete with an adequate carbon reinforcement (CRC). This CRC-layer enables the formation of plural fine cracks in a small range, where the bond between CRC and the lower concrete is interrupted. Besides an adequate limitation of the crack witdths, also – in case of expansions – a delamination must be prevented. In order to investigate this system in large-scale tests, an innovative test setup was developed to simulate positive and negative joint deformations on specimens under practical conditions in the lab. This device allows to test the specimens under static as well as under cyclic loadings. The test setup and also first test results will be presented.

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Concrete repair and retrofitting of columns without mechanical anchorage, an analytical and experimental study

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7A Strengthening and repair, Auditorium, November 13, 2024, 1:00 PM - 3:00 PM

Simple concrete repair methods based on replacing missing concrete with mortar-based products have become commonplace without the perception that this is a complicated technique. In addition, construction practice shows satisfactory results for this type of repair (without jacketing). The origin of the removed concrete is varied: It can be due to defects in the compaction of the fresh concrete, frost damage during construction, vehicle impact, local corrosion, or cut-outs for technical installations. In these cases, the damage is localized, whereas in retrofitting it may extend over the entire length of the element.

However, the challenge is to determine which part of the forces is carried by the damaged residual section and which part is transferred to the newly added concrete (or mortar layer). The proposed analytical approach, based on the assumption that the plane section remains plane before and after loading and taking into account time-dependent effects (shrinkage and differences in creep), shows that the damaged residual section will be loaded even more than it was immediately after the damage appeared. An experimental campaign was started at the Campus De Nayer of KU Leuven, using concrete cubes with different finishes and six scaled columns to understand the possible misunderstandings of the phenomena that appear.

The main finding is that, due to the different shrinkage behaviour, Bernoulli's hypotheses are no longer valid, and (partly loaded) planes no longer remain plane. A more refined methodology is needed that takes into account the elasto-plastic behaviour of the interface. In addition, interface failure leads to severe concrete spalling, resulting in a dangerous brittle failure mode and an ultimate load significantly lower than an unthreaded column. A proposal is formulated to tackle all the observed challenges.

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New Nowra Bridge, NSW, Australia - Incremental Launch Design

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7B Projects and construction methods, Dobson 1, November 13, 2024, 1:00 PM - 3:00 PM

The New Nowra Bridge is the third crossing over the Shoalhaven River at this location, and will carry all northbound traffic on the Princes Highway through Nowra. It is one component of the design and construct Nowra Bridge project, which widens 1.7 kilometres of the Princes Highway including the bridge approaches, key intersection improvements and modifications to the local road network.
The bridge is located to the west (upstream) of the two existing bridges crossings the Shoalhaven River and it has an overall length of 359.7m. The 10 span length and arrangement was dictated by the geometry of the existing bridges.

The piers comprise of reinforced concrete V-shaped elements supported on pilecaps and piles. With the exception of the northern abutment that has a spread footing and pier one's concrete bored piles, the remaining of the bridge foundation has adopted driven steel tubular pile with a concrete infill plug due to the depth of up to 58 metres depth to bedrock below the tidal waters.
The incrementally launched double T girder superstructure is continuous for the full length and it has longitudinal and transverse post-tensioning.

The paper will discuss the design adopted considering marine conditions to meet the project specifications. Another focus will be on the incremental launch design and construction of the bridge.

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Seismic Strengthening of Concrete Reservoirs

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7B Projects and construction methods, Dobson 1, November 13, 2024, 1:00 PM - 3:00 PM

Seismic Strengthening of Wellington Water Reservoirs

There are many hundreds of reservoirs and other water retaining structures throughout New Zealand. These reservoirs vary in age, volume, shape and criticality. Over time, the demands on each reservoir have changed, due to increasing populations, improved un-derstanding of expected seismic actions and required functionality of the water assets following significant disaster events.

WSP have been working with asset owners in carrying out investigations of existing reservoirs, considering options to reduce demands (e.g. reduce top water level or im-portance level) and undertaking the design of strengthening works where the structure has considerable remaining service life but is found to be underperforming due to changes listed above. This approach, to strengthen the reservoirs, has considerable bene-fits when compared to a new build, by reducing cost, extending the service life of exist-ing structures, reducing network water wastage, reducing use of new materials, lower-ing carbon emissions, and minimizing disruption to the local area.

This paper discusses the numerous challenges typically faced in assessing and strength-ening existing concrete reservoirs and concludes with lessons learned that can be ap-plied by both asset owners and structural designers who undertake reservoir design and strengthening.

This paper also includes two Case Studies of reservoir strengthening projects: Grenada North Service Reservoir and Wainuiomata Service Reservoir. These reservoirs are circular reinforced concrete 20 to 35m in diameter, between 30 to 50 years old, with pre-stressed, post-tensioned walls, concrete roof supported by roof beams and internal columns. The strengthening works address the key performance issues including new concrete overlay base slab, new connection of the base slab to the reservoir walls, new/improved connection of the roof slab to the walls, and new concrete roof support beams.

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Construction of Natural Draught Cooling Tower at Ohaaki Geothermal Power Station

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7B Projects and construction methods, Dobson 1, November 13, 2024, 1:00 PM - 3:00 PM

This year is the 40th anniversary of the start of construction for New Zealand's first natural draught Cooling Tower at Ohaaki Geothermal Power Station 30 km north of Taupo. This Cooling Tower is still the sole example of its type in New Zealand and is used to cool condensate from the turbines by about 17^{o}C, and at the rate of 5.6 Cumecs.

The tower shell derives its strength from double curvature and is 100 m in height with diameters of 66 m at the bottom, 41 m at the throat and 53 m at the top. Apart from tapered thickenings in the bottom 6 m and top 5 m, the concrete shell is 160 mm thick.

The contract to "Design and Build a Natural Draught Cooling Tower at Ohaaki" was let in February 1984 to a Joint Venture comprising Wilkins & Davies Construction Company Limited from Auckland and Multi Construction Enterprises from Sydney.

The writer was appointed as Engineer's representative for this contract and this paper reflects on historical aspects of the contract and shell construction, in the context that it occurred prior to the availability of personal computers, internet, emails, mobile phones, digital cameras, and even facsimile machines. Inspections by drone were also unheard of.

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Aerial demolition method for prestressed concrete bridges above intersections with heavy traffic

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7B Projects and construction methods, Dobson 1, November 13, 2024, 1:00 PM - 3:00 PM

Large-scale replacement projects for the restoration of old or heavily deteriorated expressway bridges, have recently become a major topic of discussion in Japan’s expressway bridge maintenance. In most situations, it is extremely difficult or almost impossible to prepare ground-level construction yards for the demolition of existing viaduct bridges built in already urbanized and high-density land-use areas with limited width roads. The degree of difficulty or impossibility becomes even more severe when the replacement takes place directly above an intersection with heavy traffic. This paper will introduce an aerial-demolition method for an existing bridge (prestressed concrete bridge, 154 meters long) that allows continuous uninterrupted vehicular traffic and pedestrian access on the ground even while the demolition is taking place above the ground. The feature of this aerial-demolition method is to complete all the demolition processes that take place above an intersection, such as cutting the bridge into small pieces, lifting them, and conveying them in the air, by using movable workstations, cranes hanging at or placed on the temporary girder laid over the bridge to be demolished. This demolition work was successfully completed without accident or injury in the summer of 2023. This paper describes this demolition method in detail.

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Integration of industrial robots for sustainable and efficient production of concrete elements with advanced formwork towards industry 4.0

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7B Projects and construction methods, Dobson 1, November 13, 2024, 1:00 PM - 3:00 PM

Concrete is the most used construction material worldwide and is responsible for a considerable environmental impact. Necessary developments are the reduction of the environ-mental footprint of the material itself per unit weight and the optimisation of the geometry of the used structures. In addition to the material specific problems, the sector is characterised by outdated production methods as well as an increasing shortage of skilled workers. Leaps towards an industry 4.0, taking the automotive industry as an example, need to be made for the sector to become truly sustainable as well as economically and ecologically efficient. To better understand the current state of the art and research, a comprehensive review of formwork technology with special focus on automation, showing a clear need for a rethinking and redesign of current manufacturing methods, is presented. It shows that with increasing automation and digitalisation, it is possible to de-sign and manufacture more complex structures that lead to potential resource savings and higher utilisation of machines and thus increased production. Based on these findings, the authors present a new modular production approach with integrated 6-axis industrial robots (IR) that can perform various complex tasks simultaneously. The newly developed reusable modular formwork kit, where formwork elements are placed by the IR and are combined to create a variety of geometries, is described in detail. The prototypical production of a first beam with individual multi-shaped voids is presented focusing the variety of possible combinations of the formwork system. The aim is to make the production method and formwork system widely applicable and ensure efficient and adaptable production. The shuttering and deshuttering processes are conducted automatically, allowing for an easy integration of structural optimisation within mass production. One of the main objectives is that individual openings, breakthroughs, and installations no longer need to be placed by hand or realised with bespoke temporary formwork resulting in process-time and resource savings. Furthermore, the presented production approach, in combination with the new shuttering concept, sets less restrictions on the material or location. While the formwork system does not call for any specific concrete mix-es, as is the case when producing structurally optimised elements using 3D printing, the IR production cell can be either integrated in existing prefabrication plants or implemented for on-site production. In further steps, with the help of sensor technology and machine learning, it is intended to simplify geometry input and optimise the production work-flow.

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Incrementally Launched Concrete and Steel Bridges - Case Studies and New Developments

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7B Projects and construction methods, Dobson 1, November 13, 2024, 1:00 PM - 3:00 PM

In recent years, Freyssinet has participated as a bridge construction specialist on a number of conventional as well as un-conventional incrementally launched bridges across Australia and New Zealand, including Nowra Bridge (NSW), Tonkin Gap (WA), Transmission Gully (NZ) and Sydney Gateway (NSW). These projects have all encountered different challenges and lessons learned related to the use of the incremental launching methodology, that have fostered several engineering innovations to help reduce cost and increase safety. This paper will highlight some of the key features and technical challenges that were encountered and explain the design process, the actual implementations and lessons learned from the projects. This include the use of new low-friction sliding materials, new structural and mechanical solutions to increase productivity and safety on site as well as digital innovations. The paper will highlight how these innovations helped overcoming technical challenges on these projects, and how these may be implemented on future projects as well.

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Case study on using a Launching Gantry to Erect Precast Segmental Concrete Box Girders in a Built-up Industrial Environment.

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7B Projects and construction methods, Dobson 1, November 13, 2024, 1:00 PM - 3:00 PM

Freyssinet has participated in the erection of a span-by-span segmental precast viaduct in an Alliance with the head contractor and using a Launching Gantry (LG) specifically designed for the project. The scope of Freyssinet included the erection of 91 spans ranging from 40 to 45m in length and 16 to 17 segments with a weight of more than 1250tons for the heaviest span. Most of the spans were designed as dry-matched but some wider and eccentric spans required wet joints to be used between segments. The location of the project induced the use of a Launching Gantry to minimize the impact on traffic in critical roads serving the Port of Melbourne and connecting the Western suburbs of Melbourne to the CBD. The Launching Gantry allowed to minimise the erection cycle down to 4 shifts per span. The Launching Gantry also needed the ability to side-shift from one viaduct to the other several time during the project to accommodate the various traffic arrangement required to maintain continuous opening of traffic and access to Port of Melbourne. One of the many technical challenges Freyssinet had to face included the development of a completely automated lifting and hanging system for the segments. This was a critical aspect as it eliminated the major risk of having workers accessing onto a suspended load. This paper details how Freyssinet successfully surmounted all those challenges.

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Mitigating Stormwater Pollution with Permeable Concrete

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7B Projects and construction methods, Dobson 1, November 13, 2024, 1:00 PM - 3:00 PM

Traditional urbanisation converts permeable land (i.e., greenfields) to impermeable cover such as driveways, roads, footpaths, and roofs, all of which stop rainwater infiltration. During storm events, pollutants such as motor oil, pet faeces, etc., which settle on impermeable surfaces, flush directly into aquatic ecosystems, causing non-point source pollution and sedimentation. One of the emerging strategies to mitigate this polluted stormwater runoff is to implement permeable concrete.

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Cyclic Testing of Carbon Fiber-Reinforced Polymer-Reinforced Concrete Columns

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7C Composite materials and alternative reinforcing, Dobson 2 & 3, November 13, 2024, 1:00 PM - 3:00 PM

Fiber-reinforced polymer (FRP), a high-strength non-metallic material, has gained significant interest for its potential application as primary reinforcement in concrete structures, particularly in severe environmental conditions. However, FRP reinforcement has a linear elastic constitutive relationship up to brittle failure, resulting in distinctively different behaviour of FRP-reinforced concrete (FRP-RC) members compared with traditional RC members under seismic loading. While there is extensive research on glass FRP and basalt FRP-reinforced concrete columns demonstrating promising seis-mic performance, studies on carbon FRP-reinforced concrete (CFRP-RC) columns are very limited. This study aims to investigate the seismic performance of CFRP-RC columns, in particular failure modes, hysteric behaviour, and drift capacity. Seven full-scale square CFRP-RC columns were constructed and tested subject to reversed cyclic lateral loading and constant axial loading. The test specimens were designed to represent flexural-dominant columns in multi-story buildings and to investigate the effect of reinforcement type and ratio, stirrup spacing, axial load ratio, and material properties. The observed failure modes, crack patterns, and hysteretic behaviour are discussed. The failure of all the CFRP-RC columns was controlled by CFRP rebar compression fracture that was due to a combination of high shear and compression stress demand at locations where stirrups exist. Due to this failure mode, the CFRP-RC columns achieved a lower drift capacity of 5% which is only about half of that of the RC column. The findings highlight the brittleness of CFRP-RC columns and the need for new solutions for CFRP-RC columns to improve their ductility and manufacturing advancements to mitigate the extreme anisotropic characteristics of FRP material.

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Experimental investigations of bent basalt fiber composite tendons for prestressing graded concrete components

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7C Composite materials and alternative reinforcing, Dobson 2 & 3, November 13, 2024, 1:00 PM - 3:00 PM

Current research in concrete construction focuses on developing sustainable technologies to reduce resource consumption and CO2 emissions. As an alternative to conventional steel reinforcement, fiber-reinforced composites can make a significant contribution. Compared to steel, fiber-reinforced composites are insensitive to corrosion and have higher tensile strength. The required concrete coverings thus can be reduced and load-bearing capacities can be utilized more effectively. In this work, a prestressing system comprising basalt fiber composite reinforcements is being investigated as a solution for lightweight concrete structures. Basalt is a type of rock available in large quantities worldwide that forms naturally through volcanic activities. This way, structural components can be produced almost entirely of minerals. For the design of post-tensioned concrete structures with undulating tendons, the reductions in tensile capacity around deflection points are crucial to be known. Therefore, this work accounts for the linear elastic and anisotropic material behavior of basalt fiber composite tendons, while the scope comprises uniaxial tensile tests and tests on deflected tendons. Finally, the reductions in tensile capacity are quantified as a function of the tendon cross-section and the radius of its deflection.

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Confinement model for GFRP spirally confined concrete columns

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7C Composite materials and alternative reinforcing, Dobson 2 & 3, November 13, 2024, 1:00 PM - 3:00 PM

Glass fiber-reinforced polymer (GFRP) bars have emerged as a promising alternative for steel reinforcement in concrete structures, particularly in environments prone to corrosion, such as coastal areas. Despite their advantages, the mechanical properties of GFRP, especially when compared to steel, raise concerns about their seismic performance in regions where energy dissipation is crucial. Using GFRP spirals as transverse reinforcement with steel bars in a hybrid reinforced (HR) concrete design enhances durability while preserving the hysteretic response of the structure.

One significant challenge in the broader adoption of HR-GFRP is the need for robust analytical methods to model the stress-strain behavior of GFRP-confined concrete columns accurately. Addressing this gap, this paper introduces a mechanics-based stress-strain approach to model the cyclic response of circular GFRP-confined columns. Central to this approach is a stress-strain model that calculates the effective lateral confining stress using principles of structural mechanics, explicitly accounting for variability in the mechanical properties of GFRP. As a result, the proposed model applies to a wide range of material strengths, unlike previous models that were limited in scope.

The paper validates the proposed model against a comprehensive dataset compiled from existing literature. The model's precision is further demonstrated in estimating the force-displacement response of columns under cyclic loading conditions.

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Fatigue Behavior of Lightweight Concrete Bridge Deck Slabs Reinforced with GFRP (Glass Fiber Reinforced Polymer) Bars

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7C Composite materials and alternative reinforcing, Dobson 2 & 3, November 13, 2024, 1:00 PM - 3:00 PM

Glass fiber-reinforced polymer (GFRP) bars have been used in concrete bridge deck slabs as a replacement for conventional steel reinforcement, with the aim of solving the problem of corrosion and improving the service life of bridges. Lightweight concrete (LWC) bridge deck slabs decrease dead load, thus reducing foundation and substructure costs, allowing for the strengthening of a bridge during redecking, improving seismic structural response, and being easier to handle and transport. The advantages of GFRP composite reinforcement and LWC in relation to bridge deck slabs encourage the extension of knowledge regarding the possibilities of combining these two materials and using the synergy of benefits that can be achieved in the construction and/or rehabilitation of bridges. However, experimental research on the behavior of LWC bridge slabs reinforced with GFRP bars has been limited, especially in terms of fatigue performance.

Seven full-scale bridge deck slab specimens were constructed and tested under static and fatigue loading. Slab specimens had a thickness of 18 cm, a width of 1 m, and a length of 3 m. Different reinforcement ratios and configurations were used. Fatigue loading was applied until failure or up to two million cycles at a frequency of 1 Hz. Following the fatigue tests, the specimens underwent static testing to compare their pre- and post-fatigue behavior. The results are presented in terms of deflection and crack numbers and widths at various levels of cyclic load. The findings demonstrated the favorable fatigue performance and fatigue life of lightweight concrete bridge deck slabs reinforced with GFRP bars

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Numerical investigation of the seismic performance of bridge piers made of titanium alloy reinforced ultra-high performance concrete (TARUHPC)

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7C Composite materials and alternative reinforcing, Dobson 2 & 3, November 13, 2024, 1:00 PM - 3:00 PM

Traditional reinforced concrete (RC) structures are commonly susceptible to corrosion from diverse environmental factors such as salts, chlorides, carbonation, humidity, etc., leading to a continuous degradation which may comprise their designed service life (reduced durability). Moreover, monitoring and maintaining corroded RC bridges is laborious and expensive. Recently, the use of titanium alloy bars (TiABs) in ultra-high-performance concrete (UHPC), namely TARUHPC, has been proposed as an alternative to increase the durability of RC structures in seismic regions, aiming for a service life exceeding 100 years. Some material and large-scale experimental tests have been conducted on TARUHPC bridge elements; however, their seismic performance and failure modes are not yet fully characterized, limiting the practical utilization of TARUHPC. This paper investigates numerically the cyclic behavior and seismic performance of TARUHPC bridge piers. To this end, detailed nonlinear Finite element (FE) models with distributed plasticity were used to assess the seismic performance of large-scale bridge specimens considering four combinations: (1) normal concrete with conventional steel (NC-NS), (2) normal concrete with TiABs (NC-TI), (3) UHPC with conventional steel (U-TI), and (4) UHPC with TiABS (U-TI). These specimens were investigated by displacement-based, fiber-element models whose parameters were calibrated by model-updating between the models and experimental cyclic test results. The FE models were validated against experimental cyclic tests, previously reported by the authors. The numerical models were accurate in representing the hysteretic behavior, lateral strength, displacement capacity, strength degradation, and energy dissipation of the test specimens; nonetheless, these models showed some discrepancies in capturing bond-slip effects in some specimens. A parametric analysis was also conducted to explore the influence of some design parameters (e.g. reinforcement ratio, axial load level, etc.) on the deformation capacity and energy dissipation of TARUHPC.

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CFRP Prestressing in bridge girders of I and U sections

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7C Composite materials and alternative reinforcing, Dobson 2 & 3, November 13, 2024, 1:00 PM - 3:00 PM

One of the major aspects for sustainability as well as for durability is the service life of reinforced concrete elements. The service life is especially important for bridge girders that have service life of hundred years.

Within a Hungarian Research Grant VKE 2018-1-3-1_0003 “Development of advanced concrete elements based on new results of materials’ science” we were able to apply and test CFRP 7-wire strands that were delivered by Tokyo Rope International Co. from USA together with the anchoring system. These specific strands are called 7-wire CFCC strands.

CFCC strands need special care in various phases of production of bridge girder: design philosophy, handling of strands, cutting of strands, preliminary steps of prestressing, overcome any sensitivities of prestressing strands (e.g. to avoid sharp edges, the strands must run straight), coupling of CFCC strands to the prestressing device, execution of prestressing, release of prestressing, cutting of CFCC strands to the final length. As advantageous the CFCC prestressing is increased durability of the bridge girders, therefore, less maintenance and increased service life.

We were able to successfully apply CFCC strands. Our experimental programme included prestressing of I-shaped and U-shaped bridge girders prestressed with CFCC seven wire prestressing strands and some tests. We intend to report about our experiences of production and the behaviour of the girders.

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Failure Modes of Bent FRP Anchor with Shallow Embedment

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7C Composite materials and alternative reinforcing, Dobson 2 & 3, November 13, 2024, 1:00 PM - 3:00 PM

The use of fibre-reinforced polymer (FRP) anchors is increasingly accepted for bypassing the debonding of FRP sheets from concrete substrate and enhancing the overall capacity of FRP-strengthened reinforced concrete (RC) structures. FRP anchors have proven effective in experimental investigations, but more research is needed to understand the pullout failure mode. This critical failure mode can be prevented through deep embedment depths, but this becomes impractical in some situations, such as when strengthening concrete diaphragms with thin toppings. This paper investigates carbon fibre anchorage in externally bonded fibre-reinforced polymer (EBFRP) on RC, using an unbonded configuration deliberately excluding considerations of interfacial bond behaviour, to determine the failure mode of FRP anchors with relatively shallow embedment depth. Various parameters were examined, including dowel diameter, embedment depths, insert angles, and concrete compressive strengths. Findings identify pullout failure as the predominant mode, but often exhibiting concrete break out at a critical point. Some specimens demonstrated anchor rupture. The study conducted a parametric study to identify key variables influence and formulate fundamental recommendations for designing anchor pullout failure under specific variable conditions. The aim is to advance understanding of contribution and behaviour of bent FRP spike anchor in EBFRP on RC structures, considering essential geometrical and installation parameters for future design and applications.

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Time-Dependent Behavior of FRP-Reinforced Concrete: A Comprehensive Numerical Investigation

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7C Composite materials and alternative reinforcing, Dobson 2 & 3, November 13, 2024, 1:00 PM - 3:00 PM

Externally bonded fibre-reinforced polymers (FRP) composites have become a focal point in strengthening concrete structures due to their proven effectiveness and various advantages. While significant attention has been devoted to understanding the bond behavior at concrete-FRP interfaces experimentally and numerically, current studies predominantly focus on the short-term mechanical behavior based on the instantaneous shear tests or simulations. However, for practical applications of FRP-reinforced concrete structures, it is crucial to consider time-dependent behavior. Yet, there is a notable gap in research regarding the impact of material creep on the bond strength of FRP-concrete interfaces. This study addresses this gap by presenting a comprehensive numerical investigation into the creep behavior of FRP-reinforced concrete. The developed micro-prestress solidification (MPS) model of concrete and viscoelastic (single-chain shear creep) model for adhesive were integrated into a sophisticated multiscale and multiphysics framework. Model parameters were determined by matching collected creep experimental data for bulk epoxy and concrete samples. The calibrated model was subsequently extended to predict the nonlinear creep response of FRP-concrete interfaces. By incorporating the calibrated LDPM parameters for concrete and single-chain model parameters for adhesive modeled in finite element model (FEM), this study offers insights into the long-term mechanical behavior of FRP-reinforced concrete structures.

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Experimental Study on Anchorage Designs' Influence on Shear Capacity of Looped Wire Rope Connections between Wall-Elements in the Same Plane

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7D Precast and prestressed concrete, Dobson 4, November 13, 2024, 1:00 PM - 3:00 PM

Due to significant installation benefits, the so-called looped wire rope connection is getting more popular for ensuring structural continuation between precast concrete elements.

Previous studies have focused on the shear capacity of the connection between two adjacent concrete elements. So far, no attention has been drawn to the shear capacity governed by insufficient anchorage of the wire rope in the precast concrete element. Therefore, the authors recently published an experimental study on the anchorage (tensile) capacity of a single looped wire rope at the end of a precast concrete element. Furthermore, a mechanical model for the anchorage capacity of a single looped wire rope was established. However, how the anchorage capacity relates to the shear capacity of the entire connection is still unknown.

This paper presents an extensive experimental study on how the anchorage capacity influences the shear capacity of looped wire rope connections between wall elements placed in the same plane. In the experimental programme, the tensile anchorage conditions of the looped wire rope are varied by varying the anchorage length, the distance between the looped wire rope, and the reinforcement in the anchorage zone. The failure mechanisms and wire rope forces are studied based on high-resolution 3D photogrammetry. On this basis, the failure mechanism related to the ultimate capacity and the crack widths for the serviceability limit state are studied.

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Safe Working Load of Strand Lifting Eyes for Precast Concrete Construction

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7D Precast and prestressed concrete, Dobson 4, November 13, 2024, 1:00 PM - 3:00 PM

In the precast concrete industry, it is common to install lifting eyes within the slab to use them for lifting and transporting the precast concrete elements. For instance, the shallow precast pre-stressed solid concrete slab units are required to be lifted usually the next day after manufacturing and stored in a precast yard before being delivered to site. Normally, a set of four lifting eyes are located in the corners of each slab. These lifting eyes consist of strands that have been bent into loops and cast within the slabs or beams. It is economical to use strands because short, off-cut lengths have little or no value in production and are normally wasted.

Currently, limited guidelines and standards for the design and installation of these lifting eyes exist. Additionally, the safe working load of such unstressed strand lifting eyes are rarely studied in the extant literature. Therefore, in this research an experimental plan was developed to investigate the safe working load of lifting eyes used in typical commercial precast slab units. A series of tests were conducted on a number of shallow precast concrete slabs with different concrete strength and lifting eye design embedded in the slabs. For each testing scenario, several lifting eyes were loaded to failure to obtain the lower fifth percentile safe working load. The results obtained from different testing scenarios are then evaluated and compared. The findings provide a valuable insight on the behaviour and safe working load of lifting eyes applicable to the precast concrete industry.

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SH94 Homer Tunnel Avalanche Shelter

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7D Precast and prestressed concrete, Dobson 4, November 13, 2024, 1:00 PM - 3:00 PM

State Highway 94 provides the only land route to the spectacular tourist destination of Milford Sound, New Zealand. The Homer Tunnel carries the road through the Darran Mountains and was constructed between 1935 and 1953. During construction, three workers were killed in avalanches and as a result, a 146m long reinforced concrete avalanche shelter was constructed in 1940. However, in 1945 an avalanche destroyed 100m of the shelter and a further 10m was destroyed by another avalanche in 1997.

In 2021, only 35m of the shelter remained, which was in poor condition and had proven to be inadequate for both avalanche and rockfall. Waka Kotahi, the New Zealand Transport Agency, commissioned WSP to design a replacement avalanche shelter to protect the highway.

The project was highly complex and the WSP team needed to overcome some massive challenges to deliver it. These included construction in a National Park, at a remote site, located in an avalanche runout zone, in a high risk rockfall area and in a region of New Zealand which receives nearly 7m of rainfall per year. The site is highly seismic and is located just over 20km from the magnitude 8.0 producing Alpine Fault. The avalanche starting zone extends 900m above the road and can produce massive plunging avalanches. The structural form needed to resist enormous loads from the avalanche and cater for significant uncertainty in the size of the loads.

This presentation will discuss the numerous challenges at this site leading to the use of entirely precast concrete construction and accelerated construction techniques, allowing the resilient shelter to be constructed in the highly constrained period outside avalanche season.

This project is also a showcase of precast construction and connections using aesthetic features including vapour-blasted designs and tinted concrete.

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Experimental Research on Ultimate Bearing Capacity for Local Component of Prestressed Concrete Containment Vessel

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7D Precast and prestressed concrete, Dobson 4, November 13, 2024, 1:00 PM - 3:00 PM

Prestressed concrete containment vessel (PCCV) serves as the last barrier for nuclear power plant (NPP) when suffering severe accidents like a loss of coolant accident. When internal pressure in containment goes beyond the design pressure, severely damaged containment will lose the function of preventing leakage of radioactive materials into environment. Safety margin for containment structures is vital to daily operation of NPPs. This paper examined the failure modes and damage mechanisms of local components cut from cylinder shells of PCCVs through experimental research. Three 1/3-scaled specimens, including eight bundles of vertical tendons, five bundles of circular tendons, and a liner attached to the inner surface of specimens, were produced. Meanwhile, a new experimental setup and loading procedure was developed to satisfy boundary conditions for specimens in the whole containment vessel. A graph was obtained to show the correlation between internal pressure and radial displacement. The graph included data points for concrete unstressed, concrete crack, liner yield, rebar yield, and ultimate displacement. The study found that the ultimate bearing capacity for PCCV was 4.14 times design pressure, indicating that the containment vessel had sufficient safety margin to withstand extremely high internal pressure. After concrete cracking, the contributions of tendons to bearing load force increased significantly. At ultimate displacement point, over 80% of the load was borne by reinforced concrete, with the remaining portion, not exceeding 20%, borne by prestressed tendons. These findings of-fer valuable insights into the mechanical behavior of PCCV from a local perspective, which is crucial for safety assessment and design optimization of both existing and future containment structures.

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Leak-tightness functional failure study of prestressed concrete containment vessels under thermal-pressure coupling conditions

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7D Precast and prestressed concrete, Dobson 4, November 13, 2024, 1:00 PM - 3:00 PM

During the severe nuclear power plant accidents, the prestressed concrete containment vessels (PCCVs) will be exposed to coupled thermal load and internal pressure, which leads to non-uniform thermal field distribution and complex mechanical behavior in the inner wall. In this study, specific segments with defined curvature and height in critical regions of PCCVs are selected, which contains different welds layout of steel liners. Three groups of temperature-pressure loading curves are applied, which represent different severe accidents. The thermal field distribution and mechanical behavior of each segment at various time points is investigated experimentally and numerically. Refined finite element (FE) models considering anchorage and welding details of steel liner are established by the ABAQUS platform, and the concrete damage plasticity model is applied to trace the crack pattern in critical regions of PCCVs. The leak-tightness in different critical regions of PCCVs under the effect of thermal-pressure coupling conditions is analyzed, and the functional failure mechanism are revealed. The results demonstrate that initiation of steel liner plastic strain is influenced by the thermal load, and the burst failure location is determined by the steel liner stiffness discontinuity.

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Validation of CSCT strain-based shear failure criteria for prestressed concrete members without shear reinforcement

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The shear provision for members without shear reinforcement in the second generation of Eurocode has been changed to a new set of formulas based on the critical shear crack theory (CSCT). The formula is based on a shear failure criterion originally developed for reinforced concrete members without shear reinforcement. To allow its application as a design code type for formula, the original CSCT failure criterion undergoes several modifications, such that it can be used to verify the shear resistance of prestressed members as well. Since the new Eurocode shear provision will be applied to design and assess prestressed concrete members in Europe and many other countries in the world, it is important to extensively validate this model. This paper presents a validation study of three different variations of the CSCT strain-based failure criteria, including the one eventually employed in the second generation Eurocode shear provision, using the ACI-DAfStb shear database. The results are also compared with the current Eurocode shear provisions. The second generation Eurocode shear formula appears to be able to determine the shear resistance more accurately than the current one, even for prestressed concrete members without shear reinforcement while it was not actually developed for this. However, Annex I.8 shear formula may lead to an overestimation of the shear resistance for higher values of the effective span to depth ratio (acs/d).

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Standardization of Precast Concrete Beams for Road Bridge Decks

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7D Precast and prestressed concrete, Dobson 4, November 13, 2024, 1:00 PM - 3:00 PM

Precasting in bridge decks, widely applied in the girders, has been presented as a convenient solution for helping, mainly, in accelerated bridge construction, higher quality of the elements, as well as the reduction of work traffic. Since for each project, there may be a new girder cross-section, this may imply in the investment in new formworks and relearning for production, making the process less competitive and time-consuming. In order to answer this question, standardization arises, which consists in the simplification of production, recurring on pre-conceived girder sections. Thus, in the present work, precast prestressed girders for road bridge decks were standardized, where the deck slabs are cast in place, and their design was carried out for spans of 10 to 30 meters, taking into consideration the loads from the Southern Africa Transport and Communications Commission (SATCC), applicable to the Southern African Development Community (SADC) region, in conjunction with extreme weather effects, according to recommendations existing in Mozambique. The design was made with CSiBridge design software, where girders' internal forces were obtained for the applied loads, allowing subsequent verifications to be carried out. During the analysis, long-term effects on the deck slab were studied, namely creep and shrinkage, and the consequences due to the differential behaviour between the girders and the slab, due to these effects. Its design resulted in four sections, a rectangular girder section for spans from 10 up to 15 meters and three "I" girder sections for spans ranging from 16 to 30 meters, where their dimensions were determined so as to optimize formwork use and make their assembly easy at the destination. With the standardized sections, it contributes to a more accelerated construction, lower production costs and a greater incentive for the precast of bridge girders.

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Numerical study on axial capacity of steel-plate grouted connections with shear keys

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The connection between the upper and lower precast concrete components significantly influences the structural performance of precast concrete structures. This paper introduces a new steel-plate grouted connection with shear keys, aiming to simplify connection configuration and enhance construction efficiency, particularly suitable for structures with large diameters and dense reinforcement. To evaluate its axial capacity, the Finite Element (FE) simulations were carried out. The simulated results were in good concordance with our prior experimental findings. Parameter analysis indicated that increasing the distance between shear keys reduced model bearing capacity, increasing the height of shear keys and strength of grouting material improved it, but the thickness of grouting material had minimal effect.

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A New Panel Element Tester for the Investigation of Reinforced Concrete Behavior under Non-proportional Load Paths

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The first Panel Element Tester was conceived by Vecchio and Collins at the University of Toronto in the late 1970s. This apparatus allows for the mechanical testing of concrete elements under combined in-plane normal and shear stresses and provided important experimental insights into the behavior of reinforced concrete leading to the development of the Modified Compression Field Theory (MCFT). A next-generation version of this testing rig has been constructed at EPFL, Switzerland, to study reinforced concrete and other materials subject to general, non-proportional load trajectories. The EPFL Panel Element Tester features increased hydraulic capacity as well as servo-actuator control to allow for real-time, independent command of shear and normal stresses, enabling a more extensive range of testing protocols.

This paper presents the design of the EPFL Panel Element Tester, including descriptions of the mechanical, hydraulic, control, and data acquisition systems. Preliminary measurements of the reaction frame's properties are calculated based on results from instrumentation incorporated into the steel frame. Alternate potential configurations of the modular, bolted design are presented along with considerations for fatigue under cyclic testing. Moreover, it is shown through linear and nonlinear analysis that a redesigned connection point eliminating geometric eccentricity between the actuator links and the reinforced concrete panel improves the uniformity of stresses in the tested panel elements.

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Crack width calculation – nonlinear FE-analysis compared to analytical calculation

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Crack control is essential for the durability of reinforced concrete structures. However, there is no standardized method for calculating the crack width, and the approaches in the standards are based on different models. The bond behavior between concrete and reinforcement is usually considered in a simplified way with a constant bond stress. Otherwise, it is taken into account with slip-dependent bond stress, whereby the actual force transmission via the reinforcement ribs is not explicitly considered. Furthermore, the relationship between calculated crack width and surface crack width is still not clear. In order to address the raised questions, non-linear FE calculations with discrete mapping of the reinforcement including the reinforcement ribs are carried out. The resulting crack width is compared with an analytical calculation with a non-linear bond stress-slip relationship. The calculations show that the crack width of the analytical calculation with a non-linear bond stress-slip relationship corresponds approximately to the crack width at the surface. The local application of force via the reinforcement ribs leads to additional internal cracks on the reinforcement, so that the crack width on the reinforcement is many times smaller than on the surface. Further comparisons with constant bond stress show that the crack width is underestimated in many cases. The results provide detailed information about the crack width along the concrete cover. Additionally, it has been shown that the application of nonlinear bond stress-slip relationships in the crack width calculation can predict the crack width at the surface well. As a result, the complex modeling of the reinforcement including the reinforcement ribs can usually be avoided. Nevertheless, this modeling approach offers the possibility for a deeper understanding of the crack width.

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Evaluation of corner crack widths in dapped-end connections and knee beam-column joints

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7E Mechanics, analysis, and design, Bealey 4 & 5, November 13, 2024, 1:00 PM - 3:00 PM

The main vulnerability of dapped-end connections is the formation of a dominant inclined crack at the re-entrant corner of the connection. Such cracks are difficult to control as they open significantly before the formation of secondary cracks. For this reason, the crack width cannot be evaluated based on conventional methods assuming a stable crack pattern of multiple parallel cracks. Similar dominant corner cracks also occur in knee beam-column joints under opening moments. The opening of the corner crack causes serviceability and durability issues, as corrosive agents can penetrate through the crack. The long-term result is reduced main reinforcement and deteriorated bond between the bars and concrete. Therefore, it is critical for the design of dapped-end connections and joints to accurately evaluate the width of the corner cracks and to ensure their control.

To address this need, the current study proposes a novel mechanical model for simple and accurate crack calculations. In a first step, the model predicts the opening of the corner crack at the yielding of the connection/joint. This is achieved considering the kinematics of dapped ends and joints, as well as the strains along the reinforcement that yields last. The main novelty in this step is the explicit account of the effect of secondary cracking, which occurs depending on the amount of reinforcement. In a second step, the model is developed to capture the complete load versus crack width response, where the load is expressed as a fraction of the failure load. The shape of the response reflects the effect of secondary cracking, as well as the effect of restrained shrinkage at low loads. The paper will present the formulation of the model and its validation with tests. Implications for the design and assessment of dapped-end connections and joints will be discussed based on the proposed model.

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Energy based Calculation of Crack Widths and required Reinforcement for Crack Control

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7E Mechanics, analysis, and design, Bealey 4 & 5, November 13, 2024, 1:00 PM - 3:00 PM

To calculate the crack widths, crack spacings and mean strains are used in the literature and in many standards. In order to obtain the crack spacing, the average bond stress must be known. In many calculation approaches, this is simplistically assumed to be a constant value. This article describes an energy-based approach that can be used to directly determine the reinforcement for crack width limitation for any relationship between local bond stress and slip (bond law). Alternatively, the maximum possible diameter for crack width limitation or the maximum crack width can be determined, depending on the given data. Although mean strains, crack spacing and mean bond stress are not explicitly used in the formulas, the solution is mathematically exact within the framework of the underlying relationship between local bond stress and slip. It is valid for the phases of single crack formation as well as of stabilized cracking. The approach is applied to the well-known bond law with power approach from the fib model- code and examined with regard to the agreement with test results from an extensive database. The comparison with the conventional approach on the basis of a constant value of average bond stresses shows the improved quality of the crack width prediction by the energy - based method.

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Integrating 3D Modelling and Non-linear Numerical Simulations in Concrete Additive Manufacturing

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7E Mechanics, analysis, and design, Bealey 4 & 5, November 13, 2024, 1:00 PM - 3:00 PM

Employing the 3D concrete printing (3DCP) technology represents an important step in the digital transformation of the construction industry. Besides the architectural appeal, the 3DCP accelerates the construction process and addresses the challenges associated with labour shortage and casting in hard-to-reach locations. From the architectural standpoint, it allows the realization of unique and intricate designs. Before the on-site printing, the slicer generates a G-code file from a 3D CAD model. This file serves as a command script controlling the 3D printer. The G-code contains all necessary information about the geometry and construction speed which are the exact inputs needed for numerical simulations.

This study introduces an innovative approach where one or multiple G-code files can be imported into a new ATENA pre-processor, where they are transformed into a finite element mesh. Much like the actual G-code file, the mesh respects the layer-by-layer structure of the printed element and, during the simulation, these layers are then explicitly simulated. Alternatively, the simulation efficiency can be improved by lumping multiple printed layers into a single layer of finite elements. Based on the printing speed, the software activates the elements on the printed trajectory simulating the construction. The solver employs the updated Lagrangian formulation therefore, the nodal coordinates are updated at each solution step allowing capturing of the gradual buckling typical for the 3DCP.

Another critical aspect lies in the material model. For these simulations, a non-linear fracture-plastic material model with time-dependent material parameters is applied. Based on the printing speed, each finite element has its specific construction time when is activated in the model. This construction time also governs the material properties, which are updated at each solution step. This allows modelling of the gradual hardening of the fresh concrete as well as gradually applying the loads such as concrete shrinkage.

Acknowledgement
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Effect of bond on the shear capacity of reinforced concrete beams: Comparison of different FE-models

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7E Mechanics, analysis, and design, Bealey 4 & 5, November 13, 2024, 1:00 PM - 3:00 PM

The shear capacity of Reinforced Concrete (RC) has been investigated over decades which has improved our understanding of shear failure mechanism and lead to various design guidelines. The scope of next generation of guidelines (e.g., fib Model Code:2020) is no longer limited to design of new RC structures but extended to evaluation of the existing structures. This innovative approach referred to as "sustainability-oriented performance-based approach" acknowledges the need of nonlinear Finite Element (FE) analysis to verify the performance objectives. The acceptance of FE analysis as a design tool has already seen a rise in different fields of structural engineering (e.g., prEN1993-1-14:2023, Appendix-A.1 fib-Bulletin-108) as they move towards performance-based design. These state-of-the-art guidelines are general and broad, to cover the wide range of possible modelling procedures and assumptions one may choose/make. The numerical modelling of macroscopic behaviour of concrete had been a challenging task since the inception of FE analysis. Therefore, validation of the model is an important integral FE analysis-based design procedure.
The contribution of reinforcement to the shear response of RC beam depends on its axial stiffness and dowel action. Several FE models are found in literature, each offering its own novel modelling approach and tips on how to model the shear response of RC. In view of the lack of studies comparing different FE modelling approaches and the variety of numerical tools available today, the authors are of the opinion that there is a lack of reproducibility of the numerical results.
The paper compares three different modelling approaches for reinforcement commonly used in literature (viz., truss, beam, and solid element). Furthermore, effect of bond is investigated using each of the modelling approaches. The 3D-FE analyses for the presented numerical investigation are conducted using Ansys®. Moreover, the paper summarizes the limitations of each approach.

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AI Based Surrogate Model for Nonlinear Modelling of Reinforced Concrete Structures

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7E Mechanics, analysis, and design, Bealey 4 & 5, November 13, 2024, 1:00 PM - 3:00 PM

Artificial Intelligence (AI) using Artificial Neural Networks (ANN) is applied for real time fast response surrogate models in the digital twin concept for structural health monitoring.

Digital twin is a modern concept, in which a digital replica of a real product or structure is developed, and the virtual twin i.e., numerical model, closely communicates, and exchanges data with the real structure. The digital twin method is used for the assessments of safety, durability and reliability of rein-forced concrete structures.

The surrogate model based on ANN is used in the digital twin approach for two purposes. The deep learning of the ANN surrogate model is using the sample data generated by sensitivity studies using the virtual twin, i.e. the numerical model based on nonlinear finite element analysis using the software ATENA (www.cervenka.cz/products/atena).

First an ANN model is used in the calibration phase of the virtual twin. Once the virtual twin is calibrated to realistically simulate the real structural behaviour, it is applied for the physically informed deep learning of the ANN model for the fast response surrogate model to provide critical safety information for structural health bridge monitoring. The paper will pre-sent the development of efficient and accurate ANN based surrogate model and the physically informed deep machine learning methods.

The presented approach is applied to pilot bridges in Czech Republic as a part of a research project supported by Czech Technology Agency and Ministry of Transport CK03000023 “Digital twin for in-creased reliability and sustainability of concrete bridges”.

Keywords: artificial neural networks, surrogate model, digital twin, durability, finite element analysis, reinforced concrete structures, structural health monitoring.

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Use of distributed fibre optic sensing to measure structural behaviour in reinforced concrete direct tension specimens

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7E Mechanics, analysis, and design, Bealey 4 & 5, November 13, 2024, 1:00 PM - 3:00 PM

Conventional reinforced concrete (RC) structural testing relies on electrical resistance strain gauges, which provide single point measurements of strain, to characterize structural behaviour. However, detailed strain measurements are required to understand localized behaviour such as the development of cracks and localized breakdown of bond. Distributed fibre optic sensors (DFOS) can provide distributed strains measurements at sub-centimetre intervals and in recent years have been used to measure various structural parameters in RC. In the current research, strain distributions along the reinforcement in RC tension specimens were measured using DFOS, along the entire length of the member. Twelve direct tension specimens were instrumented with DFOS on two sides of the bar and loaded until yielding of the reinforcement. Six specimens had ordinary Portland cement (OPC) concrete with 3 containing a 10M rebar (i.e. a reinforcement ratio of 1%) and 3 containing a 15M rebar (reinforcement ratio of 2%). Six specimens had low carbon concrete (LCC) with 3 – 10M and 3 – 15M specimens. The load-displacement in the composite region of the specimens was derived for each of the members using DFOS data. The strain distributions of members with different reinforcement ratios and different types of concrete were compared to assess the impact of both variables on cracking behaviour. Lastly, crack widths measured using digital image correlation were compared to peak reinforcement strain values amongst the different specimens to understand the impact of concrete type and reinforcement ratio on crack development and stress transfer.

Monitor Presentation

Abstracts

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Reactivity of dehydrated cement pastes to be re-used into cement-based systems

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Monitor Session 1.1E Novel Concrete, Bealey 4 & 5, November 11, 2024, 1:30 PM - 3:30 PM

Circularity and sustainability of cementitious materials are a main concern. Limestone and clay are raw materials present worldwide, although their availability and use must be carefully managed. In this concern, the reduction of CO2 during the preparation as clinker component and the material recycling potential became a future challenge to follow. Ordinary Portland cement (CEM I), limestone cement (CEM II A-LL) and calcined clay cements (LC3) were mixed with water to produce cement pastes. The hydrated materials were grinded to a diameter smaller than 1 mm and the powders were thermally treated at 650 oC and 800 oC for 3 hours and cooled at room temperature. Original cements and untreated hydrated cement pastes acted as reference samples. The untreated and thermally treated powders were added dry to 25 % by weight in substitution of the original cements and mixed with water and aggregate to prepare mortars with a water / cement ratio of 0.5. The compressive strength of the 25 % mixed blends exhibited a slower development as compared to the original cements, but up to 90 days all specimens approached the original cements strength. The samples treated at 650 oC exhibited a significant recovery of the hydraulicity and strength and in the case of CEM II, the strength of the 650 oC treated samples was even superior as the original cement. The durability tests, i. e. accelerated carbonation and freeze / thaw resistance showed variable results, although a better resistance to chloride penetration was observed for the 650 oC treated samples as compared to the references. Therefore, thermal treatments of hydrated recycled concrete fines powder, may be significantly reactivated with respect to the hydraulicity. Lower temperature treatments may even reduce the energy required for the treatments and further investigation need to be carried out.

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How is Carbon Nanotube liquid additive technology improving concrete durability, design life and providing a sustainable alternative?

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Monitor Session 1.1E Novel Concrete, Bealey 4 & 5, November 11, 2024, 1:30 PM - 3:30 PM

Carbon nanotube (CNT) enriched liquid additives, when used in the design and construction of concrete result in improved durability and strength. Nanoparticles serve as nucleation sites during cement hydration to help create a denser, cement paste composition. Australian trials have yielded increases between 10mpa – 20mpa, equaling ~10% - 30% improvements in compressive strength gains as tested to AS1012.9 2014. Reducing the permeability of the concrete, the CNT dispersed additive significantly reduced chloride diffusion coefficient results in one laboratory and one field trial in Australia, tested at 37% and 33% reduced permeability per Method NT Build 443 1995-II. Using service life prediction modelling, this determined a design life extension of 8 and 19 years respectively. Georgia's Dept. of Transport achieved increased abrasion resistance to ~50% and compressive strength increases by more than 25% per ASTM C779, proc. C, and ASTM C39, respectively. A trafficable concrete drainage project, in a flood zone, subject to abrasive conditions including salts and chlorides, placed concrete drain sections with and without CNT additive in the concrete. The result was a tensile strength increase of 25% and abrasion resistance 40%, and after 36 months in service it showed no cracks or pitting vs. the control mix which cracked (>0.3mm) and was deeply pitted. By reducing the slab thickness by 19mm on a USA project, a saving of 430m3 of concrete and 155 ton of CO_2 omissions in reduced cement use alone, was realized. Benefits of CNT technology in concrete will be detailed further in this paper.

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Enhancing geopolymer composites with miscanthus fibers: an investigation of thermal behavior, mechanical strength, and microstructural characteristics

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Monitor Session 1.1E Novel Concrete, Bealey 4 & 5, November 11, 2024, 1:30 PM - 3:30 PM

This study explores the influence of miscanthus fibers (MF) on the thermal properties, compressive strength, and microstructural characteristics of fiber-reinforced geopolymer paste (FRGP). The metakaolin-based geopolymer paste was reinforced with varying percentages of MF and subjected to different curing methods. The addition of 30 wt% (by weight of metakaolin) MF led to a compressive strength of 6.43 MPa at 28 days, suitable for various construction practices, and was accompanied by an increase in water accessible porosity from 37% in the reference sample to 52%. This increase in porosity, further confirmed by Mercury Intrusion Porosimetry (MIP) results, is linked to a lower mechanical strength but improved thermal insulation.

Thermal conductivity tests revealed that a FRGP formulation with 50 wt% MF and sodium silicate achieved the lowest thermal conductivity of 0.21 W.m-1.K-1 and a reduced dry density of 908 kg.m-3, making it suitable for applications like mortars, rendering, and plastering. The type of metakaolin used also influenced the compressive strength, with an increase up to 57%. Similarly, the type of alkaline solution played a significant role, with potassium silicate resulting in higher compressive strength and thermal conductivity than sodium silicate.

More precise microstructural analysis, including MIP and Scanning Electron Microscopy (SEM), revealed a rise in large capillary and macro pores with increased MF content. Additionally, these analyses showed the formation of cracks and relatively good bonding between the fibers and the matrix, highlighting the importance of unreacted and partially reacted particles.

These findings suggest that the optimized integration of MF in geopolymer paste is more effective than in traditional cement mortar or geopolymer foam for enhancing compressive strength and thermal insulation, tailored for applications in sustainable construction materials.

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Study on Self Curing of Concrete Using Highly Concentrated Aqueous Solution as Mixing Water

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Monitor Session 1.1E Novel Concrete, Bealey 4 & 5, November 11, 2024, 1:30 PM - 3:30 PM

Concrete requires curing to maintain the wet condition necessary for hardening for a certain period of time in order to achieve the prescribed performance. Aqueous solution is characterized by the fact that the saturated vapor pressure of the solution decreases as the vapor pressure depression in the presence of solute, making it difficult for the solvent to evaporate. Therefore, when a highly concentrated aqueous solution is used as mixing water, the saturated vapor pressure of the free water in the concrete is decreased, which inhibits water loss in the concrete, and self-curing effects comparable to those of wet curing may be obtained even during air curing.

In this study, I investigated experiment and numerical simulation whether the use of a highly concentrated aqueous solution as mixing water for concrete can achieve the same level of curing effect in outdoor air curing as in sealed curing.

Experiments showed that the use of a saturated sodium chloride solution as mixing water dramatically improved the water retention properties of concrete, and that after one day of formwork curing, the strength of the concrete was as high as that obtained during outdoor air curing as compared to seal curing. Numerical experiments using water transport analysis that took into account the effect of sodium chloride on water transport showed that the use of a saturated sodium chloride solution as mixing water improved the water retention required to achieve the same level of strength development as sealed curing even after outdoor air curing in multiple regions of Japan and in multiple seasons.

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Effect of environmental conditions on shrinkage-induced cracking of 3D-printed mortar

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Monitor Session 1.1E Novel Concrete, Bealey 4 & 5, November 11, 2024, 1:30 PM - 3:30 PM

In 3D concrete printing, the removal of formwork compared to traditional casting has caused an issue regarding the early exposure of the concrete surface to the environment. This early exposure can lead to the immaturity of strength development in the early stages and shrinkage-induced cracking due to excessive water evaporation and lack of coarse aggregates in typical mixes for 3D concrete printing. These challenges highlight the need for careful consideration of environmental factors and the development of specialized techniques to mitigate their impact on the structural integrity of 3D-printed concrete structures. This study investigated the influence of environmental factors (temperature, humidity, and wind) on strength development and plastic shrinkage of a 3D-printed mortar at very early ages. The initiation and development of shrinkage-induced cracks were also studied on 3D-printed samples exposed to different environments. Temperature fluctuations can cause expansion and contraction of the concrete material, leading to internal stress and potential cracking. Humidity levels also play a significant role, as moisture absorption and desorption by the concrete can affect its shrinkage behaviour and strength development. Additionally, exposure to elements such as wind can further exacerbate water evaporation and cause the deterioration of the printed structure. By delving deeper into the environmental factors that impact shrinkage-induced cracking, this study aims to provide valuable insights that can inform the development of more resilient and sustainable 3D-printed concrete structures.

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Importance of Mortar Skin Characteristics in Concrete Surface Layer in Analysis of Delamination Behavior between FRP Sheet and Concrete

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Monitor Session 1.1F Strengthening and Repair, November 11, 2024, 1:30 PM - 3:30 PM

Delamination between fibre reinforced polymer (FRP) sheets and concrete is a major problem in the strengthened concrete structures using FRP sheets. So far, many researchers tried to simulate the behavior of delamination by means of finite element analysis (FEA). However, cracking pattern observed in concrete below the FRP sheet was different from actual situation. We have recently founded that FRP sheet delamination occurs in the surface layer of concrete, which is called as mortar skin, and that the properties of this surface layer have a significant effect on bond characteristics of FRP sheet. In order to reproduce the delamination of FRP sheets, this study clarifies the properties of the mortar skin in the concrete surface layer, and then introduces these properties into FEA.

In this study, three-point flexural loading tests of mortar skin were conducted. Thin mortar specimens with a height of 10 mm, a width of 23 mm, and a span of 100 mm were prepared in the experiment. Some specimens impregnated with primer resin were also prepared. The tensile strength and tensile fracture energy of each mortar skin were determined by inverse analysis using FEA in terms of flexural stress-displacement relationship obtained from the tests. It was clarified that the tensile strength of the mortar skin was higher than concrete and in addition, the strength was increased more when primer was applied. Furthermore, the material constitutive law was introduced into the FEA of FRP sheet bond tests. Finally, this paper shows that FEA with the constitutive laws developed in this study can simulate both strain development in the FRP sheet and cracking behaviour of concrete nicely.

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Seismic strengthening of frame structures with web-type plate

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A new seismic reinforcement method was proposed for frame structures with the new web-type plate. A typical frame structure of 10 stories was designed as a case study. The lateral stiffness of the structure was improved, and the inter-story drift ratio was reduced significantly. The bending moments and shear forces of the beams and columns of the framework without the web-type plate were reduced, while the shear force of the beams connected with the web-type plate was increased. Meanwhile, the bending moment of the beam-column joint was reduced. Thus, the strengthening at the joints can be reduced. Further, the layout and linear stiffness ratio of the web-type plate were analyzed under the earthquake motion. The analysis results showed that the optimum layout position of the web-type plate was 0.3 and 0.7 of the beam span, and the suggested linear stiffness ratio of the web-type plate to column and beam were 0.7-1.5 and 3.5-7 respectively. Furthermore, an elastic-plastic analysis was done, and the web-type plate yielded first, and the energy dissipated by the frame was reduced. Therefore, the frame structure was protected, and became the second seismic fortification line.

Finally, the nonlinear dynamic time-history analysis of an actual engineering project was conducted on the structure before and after seismic upgrading with the web-type plate. The analysis results showed that the lateral displacement and the inter-story drift ratio of the structure with web-type plate were reduced. Compared with the structure before upgrading, the plastic hinges were reduced. The seismic performance of the frame structure reinforced with the web-type plate was improved. The analysis verified that the proposed strengthening method with web-type plate was reasonable and feasible.

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Seismic upgrading of RC frames as a constrained optimisation problem: a rational solution based on Genetic Algorithms

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Monitor Session 1.1F Strengthening and Repair, November 11, 2024, 1:30 PM - 3:30 PM

Seismic assessment and retrofitting of existing RC structures is one of the most timely and tasks for modern structural engineers all over the World. As a matter of fact, the majority of existing structures have been realised in the past decades and designed either according to old seismic codes or only taking into consideration gravitational loads. Therefore, because of the current seismic safety standards, they do no conform to the current codes and need to be upgraded, the their "capacity" is generally lower than the corresponding seismic "demand" in a performance-based design framework. Several techniques are currently utilised to either enhance capacity in under designed members: they are generally referred to as "member-level" techniques. On the other hand, other techniques rather aim at reducing demand on the structural as a whole by adding substructures to the existing one: they are generally referred to as "structure-level" techniques.

Although these two classes of techniques are often considered as part of alternative approaches for seismic upgrading of existing structures, several studies have demonstrated the potential of combining member- and structure-level techniques, whose synergistic effect can lead to a more efficient design.

In this light, seismic upgrading of RC structures can be regarded as a constrained minimisation problem, where a given objective functions (e.g. the intervention cost or other global parameters related, for instance, to its environmental impact) has to be minimised under the constraint that the seismic performance (at all the relevant Limit States) conforms to ten requested seismic safety standards.

Since the number of potential combinations of member- and structure-level interventions is very wide, Genetic Algorithms (GAa) can be fruitfully employed in determining their "optimal" combination.

This paper will outline recent advancements in the in-house implementation of a GA-based Python code, combining member- and structure-level intervention techniques, in order to catch "the most feasible" upgrading solution according to a previously-defined optimization criterion. Particular consideration will be given to how the choice of different objective functions can drive the results deriving from the optimization procedure, taking into account not only the economical, but also the ecological cost associated with the interventions needed to achieve the desired seismic performance.

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Modelling the impact of steel corrosion on the long-term shear strength in RC structures: the CCCM perspective

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Monitor Session 1.1F Strengthening and Repair, November 11, 2024, 1:30 PM - 3:30 PM

Steel corrosion in reinforced concrete (RC) structures triggers a cascade of detrimental effects, leading to reduced reinforcement area, changes in steel mechanical properties, cracking, and eventual concrete cover spalling. Stirrups, with their typically small diameter and reduced concrete cover, are particularly vulnerable to corrosion, which significantly impacts the shear strength, especially in marine exposure classes. Addressing this, the Compression Chord Capacity Model (CCCM), a shear mechanical model previously formulated by the authors, was recently adapted to predict shear strength in corrosion-damaged RC beams. CCCM parameters susceptible to degradation in RC beams were identified and adjusted. Validation against experimental results from 146 slender and non-slender beams, subject to accelerated corrosion of stirrups and/or longitudinal reinforcement, revealed the CCCM's effectiveness. Satisfactory shear strength predictions were achieved by accounting solely for reductions in reinforcement areas and web width but without considering the bond deterioration resulting from steel corrosion. A discussion on this omission will be initiated in this paper based on results reported in the Stuttgart shear test and other experimental campaigns.

Moreover, the CCCM was extended to forecast the long-term shear strength of corrosion-damaged RC members. This extension incorporated two models of material deterioration, including concrete carbonation and chloride-induced corrosion. The paper showcases the model's capabilities and conducts a parametric analysis, revealing the influence of different parameters on long-term shear strength. This exploration emphasizes the critical importance of meticulous attention to design and construction details for researchers and engineers in actual practice.

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Pull-out and bond performance of deformed bars in concrete subjected to freeze-thaw cycles after steel corrosion

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Combined action by steel corrosion and freeze-thaw cycles is a typical deterioration factor of concrete structures especially in cold regions. Bond of deformed bars is quite important to ensure the compatibility with concrete, however, the effects of such a combined action have not been clarified. In this study, the pull-out behavior of deformed bars in concrete subjected to freeze-thaw cycles after steel corrosion was investigated.

Specimens were prepared by embedding a D16 deformed bar to a prism concrete with a size of 100 mm x 100 mm x 200 mm. Each specimen was subjected to steel corrosion by an electrolytic corrosion test, followed by a freeze-thaw cycle test to experimentally reproduce the combined deterioration. The pull-out loading tests were conducted on the specimens subjected to steel corrosion followed by freeze-thaw cycles to evaluate the pull-out capacity of the specimens. The experimental parameters were the amount of corrosion, the number of freeze-thaw cycles, and the presence or absence of AE agent. Three specimens were prepared for each of 15 cases (n=3).

The experimental results showed that the expansive strain during the freeze-thaw test in the cases of specimens after corrosion was relatively small. The results obtained in the pull-out loading tests were evaluated by analysis of variance (ANOVA). The specimens without steel corrosion tended to show a decrease in pull-out capacity due to the freeze-thaw cycles. On the other hand, in the cases of the specimens with steel corrosion, the effect of freeze-thaw cycles on the pull-out capacity was not significant. It indicates that the effects of freeze-thaw cycles differ depending on the occurrence of steel corrosion. It was also found that the AE agent was not significantly effective after the steel corrosion, while it prevented reduction in pull-out capacity in the cases of specimens without steel corrosion.

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Botany Rail Duplication – Innovative Methods for Bridge Construction

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This paper covers the complexities in design and construction of three major post-tensioned concrete bridges along the Port Botany Rail Line around Sydney Domestic Airport, including implementation of innovative materials and construction techniques under extreme time and space-related constraints. On a horizontal curve, Robey Street Bridge consists of a 36m main span and 18m backspan.

O'Riordan St bridge is a single 45m-span structure. Both bridges are through girders carrying two rail tracks that had to replace existing bridges. Each bridge was constructed (after existing bridge demolition) within five days of rail closure and immediately opened to rail traffic. Extremely restrictive space constraints were imposed by third party easements and advertising gantries. The main post-tensioned bridge side girders were constructed beside the existing bridges. The deck consisted of transversely stressed precast planks. The outstanding design feature was the use of ultra-high performance fibre reinforced concrete (UHPFRC) for the transverse and longitudinal in-situ stitches.

The bridge duplication over Southern Cross Drive is a continuous two 32m-span single track through girder bridge constructed entirely offline. Construction challenges included the curved plan alignment, very high skew, extremely busy road below and the very low clearance above due to the restrictive Obstacle Limitation Space (OLS), imposed by Sydney Airport. The adopted solution included the design of a temporary falsework steel truss, bridging over the six-lane road and supporting the formwork for the bridge deck. The deck was constructed in-situ with the benefit of continuous access for all associated activities without disruption of the road traffic below. After deck post-tensioning and removal of the falsework, the bridge was lowered to its final position on the permanent bearings.

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CRL Karanga-a-Hape Underground Railway Station

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The Karanga-a-Hape Station is the deepest structure in Auckland's $5.5billion City Rail Link underground rail project. Two station shafts extend c.30m underground: one supporting a three-storey station building and future five-storey oversite development. Three tunnels penetrate each station shaft at the lowest level.

The construction of the station shafts involved top-down and bottom-up construction with complex design loading and sequencing. Top-down construction involved 800mm-1000mm thick diaphragm walls, temporary steel columns (plunge columns) and 600mm-900mm thick in-situ reinforced concrete floors. The bottom-up construction consisted of steel reinforced concrete floors, columns, and walls which ex-tend from the lowest excavated level to ground level. The design allowed for construction of the underground shaft and above-ground station building to be carried out concurrently. The station mined caverns, shafts and building utilised 57,000m3 of concrete and 8,000T of steel reinforcement.

This paper describes the design procedures undertaken for soil-structure interaction, detailed shrinkage and crack analysis, coupled thermal-structural analysis for petrochemical fire, 3-D modified-compression-field analysis of a storey-deep beam, staged construction analysis and early-age loading of concrete suspended floors, complex precast concrete cladding utilising light-weight pumice aggregate concrete, drainage and waterproofing.

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Central Plant and Tunnel Project - Designing for resilience and the future

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Te Whatu Ora Te Toka Tumai – The Central Plant & Tunnel project is a major services infrastructure upgrade across the Auckland City Hospital campus. The main aim of the project is to enhance the services infrastructure resilience of the hospital site. The project involves the construction of a new Central Plant building, and a new tunnel linking the existing building with the plant. The Central Plant building features diesel & water storage, and houses services plant equipment for distribution for electrical, chilled water and medical gas system. Both the building and the tunnel is designed to withstand major earthquakes with the building designed on Triple Pendulum friction isolators for improved seismic performance and resiliency.

This paper provides an overview of the structural design principles and decisions made to support the project outcome and the consideration for durability, sustainability utilising low carbon concrete, resiliency, constructability in a 24/7 live hospital environment, and design for future development.

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The Design of the Bridges for two grade-separated rail crossings for The Parkes Special Activation Precinct Enabling Works

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The Regional Growth NSW Development Corporation (RGDC) is currently delivering the first Special Activation Precinct (SAP) in Parkes to provide opportunities for investment, business development and employment growth in the Central West of NSW, Australia. The Parkes SAP Enabling Works are currently being delivered by the RGDC and their Design and Construction partners Fulton Hogan and Stantec.

The Steel Bridge over the Parkes to Narromine Rail Line is a crossing of Brolgan Road over the existing Parkes to Narromine Rail Line. The length of the bridge is approximately 53.7 meters and crosses the railway at a skew angle of approximately 55 degrees. The bridge utilizes four weathering steel trough girders supported by reinforced concrete abutments and piles. The bridge abutments are formed of piles founded on the underlying rock stratum and their extensions through an RS wall embankment with a permanent isolation gap and a reinforced concrete headstock.

The Bridge over the Parkes North West Link Rail Line is a crossing of Brolgan Road over the existing Parkes North West Link Rail Line. The length of the bridge is approximately 38 meters and crosses the railway at a skew angle of approximately 30 degrees. The bridge utilizes seven super T girders supported by reinforced concrete abutments and piles.

The paper will discuss the main design features of the bridges, including their construction over the existing ARTC rail lines, geometry constraints, and their effects on the articulation. The differences in superstructure design, influenced by the span and skew angle of the bridge, will be presented. Additionally, the design considerations for substructure elements and their interaction with the embankment will be presented. It will also present the application of a buried RSW behind the abutments, as an innovation developed by the project team.

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Advanced formwork systems - design and construction aspects

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To increase productivity and reduce program risks, along with more complex geometries driven by urban design, increasingly complex but user-friendly formwork systems are required.

The advantages of such bespoke systems in comparison with conventional formwork systems are as follows:

1. Ability to pre-fabricate large elements outside the critical path with simple transport, lifting, assembly. This means less assembly time on site and less labour.
2. The often complicated dismantling of formwork on bridges (due to limited access after the pour) can be considered with bespoke solutions for simple lowering to the ground.
3. Integration of access platforms and reinforcement prefabrication into the system
4. Curved or other complex shapes can be achieved at a small additional cost
5. Simplification of the formwork system resulting in efficiencies in labour, time, finishing works and re-use.

This presentation will show recent Australian bridge examples of cast-in-place construction methodologies such as incrementally launched casting beds and balanced cantilever form travellers and then explain how these design principles can be applied to other, more common structures such as columns, headstocks or parapet barriers.

These formwork systems are explained with visual animations of the construction methodology.

Specific focus will be given to:

1. Performance specifications when defining the required formwork system
2. Best practice on geometry definition and considerations such as curves, inclined faces and voids.
3. Alternative methodologies of precasting and delivering in-situ with SPMTs instead of cranes
4. Combining bespoke fabricated steel formwork with precast components to achieve weight, structural and time savings.
5. Integrating formwork systems with reinforcement placement systems, including access.

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HPC and UHPC with reduced climate footprint based on alkali-activated material

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Monitor Session 1.2E UHPC, Bealey 4 & 5, November 11, 2024, 1:30 PM - 3:30 PM

Ultra-high performance concrete is usually based on ordinary Portland cement (OPC), but UHPC can also be produced based on alkali-activated materials (AAM). Since the reaction products of AAMs differ from those of OPC, other properties in the solid state concerning durability aspects can also be derived. Due to the replacement with granulated blast furnace slag, AAM-UHPC has a lower climate footprint in comparison to OPC-UHPC. However, for AAM-UHPC water glass has to be used in a high concentration, which in turn has a negative impact on the climate footprint. But the overall footprint is reduced compared to OPC-UHPC, in particular the CO2-footprint. With the aim of further reducing this footprint, the AAM-UHPC formulation was adapted by reducing the proportion of binder, the activator concentration and the proportion of silica fume. Although these modifications reduced the performance in terms of compressive strength, a material with sufficient properties for building applications could be achieved with a significant reduction of its climate footprint.

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Engineering Properties and Optimal Design of Ultra-High Performance Alkali-Activated Concrete

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Monitor Session 1.2E UHPC, Bealey 4 & 5, November 11, 2024, 1:30 PM - 3:30 PM

Ultra-high performance concrete (UHPC), as an advanced type of building material, has a wide range of applications, but its high cement content is associated with high CO2 emissions. In order to realize the sustainable development of UHPC, this research systematically investigates using alkali-activated cementitious materials to completely replace portland cement in order to produce ultra-high-performance alkali activated concrete (UHP-AAC). UHP-AAC is capable of achieving over 150 MPa in compressive strength, along with high durability, without the need for high temperature curing. By testing the compressive and flexural strength of 135 prismatic specimens with dimensions of 40mm*40mm*160mm, we explored how factors like water-to-binder (W/B) ratio, alkali equivalent, water-glass modulus, and steel fiber dosage influence the working and mechanical properties of UHP-AAC. The results showed the W/B 0.27 group had enhanced compressive strength compared to UHPC. Additionally, increasing W/B ratio improved the flowability of UHP-AAC,but the compressive strength first increased up to a point, then decreased with higher W/B ratios; increasing alkali equivalent and water-glass modulus boosted flowability and compressive strength; whereas the increase of steel fibers reduced fluidity but improved compressive and flexural strengths. With 1 v% steel fiber, the 3-day compressive strength was 81% of the 28-day, indicating high early strength. Overall, optimizing the mix design significantly enhances the mechanical properties of UHP-AAC. For conclusion, UHP-AAC is a very promising low-carbon building material. Revealing a high potential for improving the sustainability of concrete structures.

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Analytical studies on the flexural behaviors of UHPC composite sandwich panels under different connector configurations

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Monitor Session 1.2E UHPC, Bealey 4 & 5, November 11, 2024, 1:30 PM - 3:30 PM

Abstract. This study presented a thin-walled sandwich panel, namely a UHPC composite sandwich panel (UCSP), comprising inner and outer wythes made of ultra-high-performance concrete (UHPC), with the connection between the two wythes established using Glass Fiber Reinforced Polymer (GFRP) grid-type connectors. However, due to limited research on the in-plane shear performance of connectors in sandwich panels, particularly regarding the standardized definition of their shear stiffness and a quantitative understanding of their influence on the flexural behaviors of UCSPs, an analytical method that can accurately predict the flexural behaviors of UCSPs under different connector types and arrangements has not yet been developed. Therefore, this study proposed the concept of a connection coefficient based on the geometric parameters and arrangement characteristics of connectors and utilized it to establish a shear-slip model for connectors within sandwich panels. The model effectively captured the contribution of connectors in UCSPs, enabling the development of analytical expressions to describe the flexural response of UCSPs under out-of-plane loading. Subsequently, analytical solutions for the deflection of the sandwich panel were derived. This study provided a significant theoretical foundation for the design and performance evaluation of sandwich panels, offering valuable guidance for the practical application of sandwich panels in engineering.

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Full-scale test and finite element analysis of RBP-UHPC variable section cantilever beam

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Monitor Session 1.2E UHPC, Bealey 4 & 5, November 11, 2024, 1:30 PM - 3:30 PM

In order to provide design reference and basis for the main load-bearing members of the open-air cantilever staircase of Shanghai Grand Opera House, the flexural performance test of the longest full-scale RBP-UHPC variable section cantilever beam was carried out. The FEM (finite element model) is established, and the parameters of the cantilever beam are analyzed. The influences of the plate thickness on the side of the beam, the diameter of the steel bars, the number of RBPTs (retard-bonded prestressed tendons), the construction deviation of RBPT and the bonding state of RBPT on the cantilever beam are studied. The results show that RBPT was in unbonded state. The main crack and failure location of the cantilever beam were 2.6m away from the beam root. The finite element simulation results are in good agreement with the experimental results. When the asymmetrical plates thickness are 100mm, the ultimate bending moment of the cantilever beam is the largest, which is 12.8% larger than that of the cantilever beam without plates, but only 1.7% larger than that of the cantilever beam with 250mm thickness plate. Increasing the diameter of ordinary steel bars can effectively improve the cracking moment and ultimate moment of the cantilever beam. The number of RBPTs have no effect on the cracking moment. The construction deviation of RBPT downward will lead to the reduction of the ultimate bending moment of the cantilever beam. When RBPT is in bonded state, RBPT can yield and its strength can fully utilized. The ultimate bending moment of cantilever beam with RBPT in bonded state is 18% higher than that of cantilever beam with RBPT in unbonded state.

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Development and Potential of using UHPFRC for Infrastructure in Thailand

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Monitor Session 1.2E UHPC, Bealey 4 & 5, November 11, 2024, 1:30 PM - 3:30 PM

Ultra-High-Performance Fibre Reinforced Concrete (UHPFRC) is an advanced form of concrete with exceptional strength, durability, and flexibility. It has a compressive strength much higher than traditional concrete, making it ideal for the use in demanding structural applications such as bridges, high-rise buildings, and marine structures.

UHPFRC is made using fine materials like high-quality cement, silica fume, and micro steel fibers, which enhance its mechanical properties and resistance to environmental degradation. Its dense microstructure provides excellent resistance to corrosion, chemical attack, and wear. The micro steel fibres overcome the brittleness of this high strength material and provide the required toughness. Today, with the challenges for modern infrastructure development in Thailand, UHPFRC has become a promising alternative for the structural design of bridges, high-rise buildings and mega structures, allowing for thinner, lighter structures while maintaining high load-bearing capacity. Further, significant long-term durability and reduced maintenance costs are achieved.

The CPAC Pedestrian Bridge Project in Bangkok, the 1st starring project of UHPFRC in Thailand, with a challenging long cantilevered span of 16 metres (52.5 ft), has demonstrated the benefits of using this material for prestressed concrete structures, enabling the very thin and light weight cantilevered beams being the load-bearing structure. It is with pride of the client and the project designer to feature the success of the project which was awarded the ACI Excellence in Concrete Awards 2022 : Infrastructures and the Gold Medal Award 2021 by the Thai Concrete Association (TCA).

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Simplified Approaches for the Structural Analysis of Precast Concrete Sandwich Panels

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Monitor Session 1.2F Precast concrete, November 11, 2024, 1:30 PM - 3:30 PM

Precast concrete sandwich panels (PCSPs) are widely used as insulating panels in many applications. They are comprised of two reinforced concrete (RC) layers separated by a layer of lightweight insulation material. Many of these panels nowadays are designed as partially composite panels and are built with two RC layers of the same thickness and shear connectors embedded in the insulation, which are mostly made from fibre-reinforced polymers (FRP) because of their low thermal conductivity compared to steel. Nevertheless, the analysis and design of such panels is very challenging because each type of connector can impose different mechanisms in the panel, which require special attention in their modelling. This study presents a comparison between three numerical models developed for the structural analysis of composite PCSPs under lateral loading. The first model is based on a full finite element analysis where “slip” between the layers is obtained from the elastic deformability of the various components. The second model is based on a simplified finite element analysis where the effect of the shear connectors is smeared and modelled through an effective shear stiffness of the insulation layer. The third approach is based on the classical sandwich beam theory where the shear connectors are treated through the effective stiffness of the insulation similar to the second model, but it provides closed form expressions for evaluating the deflection. The structural response obtained from the three models is compared for various panels’ configurations and a good correlation is obtained. A reasonable agreement with test results from the literature is also demonstrated. Therefore, both the simplified finite element model and the classical sandwich beam theory are recommended to be used by engineers for the elastic structural analysis and for estimating the degree of composite action in serviceability.

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Numerical investigation on shear capacity of truss connectors for precast concrete sandwich panels

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Monitor Session 1.2F Precast concrete, November 11, 2024, 1:30 PM - 3:30 PM

Abstract. The precast concrete sandwich panels (PCSPs) consist of two concrete wythes, insulation layer and connectors, offering advantages such as energy conservation, thermal insulation and decorative integration. Compared with other connectors, truss connectors are applied widely due to light weight, high strength, easy to install. Based on test results, this paper conducted numerical simulation to investigate shear capacity of truss connectors. The simulation results showed that the Finite Element (FE) models were verified by test results. The truss connectors experienced diagonal bar rupturing subsequent to compressed bar buckling. According to AC 320, the characteristic point corresponding to 2.54 mm slip between concrete wythes was proposed to evaluate the shear capacity of connectors. Generally, the shear capacity of truss connectors decreased with increasing of thickness of insulation layer significantly. While the diameter of diagonal bar and pitch had a positive correlation with the shear capacity of truss connectors.

Keywords: Precast concrete sandwich panels, Truss connectors, Numerical investigation, Shear capacity

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Decreasing environmental and increasing economic impact within the prefabricated industry – Automated design and production of structurally optimised concrete components

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Monitor Session 1.2F Precast concrete, November 11, 2024, 1:30 PM - 3:30 PM

The concrete construction industry plays a pivotal role in shaping the modern urban landscape, with concrete being one of the most used materials worldwide. Within the production, one differentiates between offsite and onsite construction, with the former being directly linked to precast elements. To counteract the high material utilisation and waste production while simultaneously increasing the currently low productivity of the concrete construction industry, the authors present a new automated design and production approach focusing on increasing the resource efficiency of the prefabrication sector in various aspects of the entire workflow. For one, the design process is digitalised offering easy automated structure optimisation of concrete components applicable by not only the designers but also the manufacturing companies themselves. Based on the designs, the components are mass-produced in newly developed production cells using a revolutionised shuttering concept which presents a high versatility of the to-be-shuttered elements. Through the elimination of disposable formwork and optimisation of the material usage within the structural component, a clear decrease of the environmental impact can be noted. In conjunction with the development of a modular component kit, that allows for a reuse of the elements, this offers the industry the possibility of a higher value circular economy. First preliminary experiments as well as close collaboration with the industry demonstrate the feasibility and potential of the strategy and clearly define further research demand.

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Buckling of prestressed concrete bridge girders

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Monitor Session 1.2F Precast concrete, November 11, 2024, 1:30 PM - 3:30 PM

In India in the recent past many segmentally constructed precast prestressed concrete bridges are collapsing during the construction. In spine & wing span by span construction of bridges, the deck width has been increasing up to 34.0m while for the extradosed bridges , the free cantilever during construction has increased up 125m. The indiscriminate increase in the slenderness where tried and tested designs with the protective cover of experience is overstepped, has led to what author calls as dimensional scale effects. The secondary effects which were not significant hitherto in the design as such neglected, start governing the design in dimensional scale effects.

In the paper, author synthesizes as to how buckling can prove to be a dimensional scale effect leading to failure during construction of precast prestressed segmental bridges.

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Ultimate Load Capacity of Unbonded Prestressed Concrete Beams Reinforced with Enlarged Section Considering Secondary Stress

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In order to reveal the limit state of the unbonded prestressed continuous beams reinforced with enlarged sections on both sides considering secondary stress, Abaqus software was used to simulate some two-span reinforced beams. The Model Change function could realize the secondary stress analysis, and the load processes of the unreinforced beam (URB) and reinforced beam (RB) were compared. In Addition, the influence of parameters such as concrete strength, reinforcement ratio, area and effective prestress of prestressed tendons, and linetype on the static performance of URBs were investigated. The ultimate load capacity formula based on the mechanical characteristics and equilibrium relations was proposed. The results show that the ultimate load capacity of the URB has increased to 159% compared to the UB. In the URB, the tensile steel bars stress and concrete compression strain in reinforced zone were smaller than those in unreinforced zone, and it made the structure safer to consider secondary stress. The concrete strength and reinforcement ratio had significant effect on the ultimate load capacity. What is more, the formula has high accuracy with the value error within 1% compared to the simulate results. The research results provide a theoretical basis for researching unbonded prestressed beams reinforced with enlarged section on both sides.

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Enhancing Impact Resistance in Nuclear Power Plant Structures: A Comprehensive Study on Reinforced Concrete Panels

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Monitor Session 1.2G Structural performance, November 11, 2024, 1:30 PM - 3:30 PM

Nuclear power plant (NPP) structures are intricately designed to prioritize safety during extreme events like earthquakes, tsunamis, and potential terrorist attacks. This entails specific considerations, including limits on reinforcing steel yield strength, containment liner plate (CLP) design, and integration of impact-resistant elements. Historically, constraints on reinforcing steel yield strength have challenged efficient NPP design, leading to increased construction costs and compromised concrete quality due to reinforcement congestion. Research has explored reducing rebar amount with high-strength alternatives. Additionally, the CLP, preventing radiation leakage, doubles as permanent formwork from construction's outset. Following recent catastrophic incidents, the U.S. Nuclear Regulatory Commission has revised regulations, now mandating assessments of potential impacts from large commercial aircraft on newly designed NPPs. Design codes like ACI349-13, DOE-STD-3014-2006, and NEI 07-13 recommend empirical formulas based on impact tests for NPP-related structures. However, they mostly overlook the effect of reinforcement, hindering efficient NPP structure designs. This study investigates impact resistance of reinforced concrete (RC) panels under hard impacts, exploring rebar spacing, impact conditions, and steel liner presence. Impact tests, varying in yield strength, steel liner presence, impact velocity, and conditions, simulate an aircraft engine shaft impact on NPP walls. Criteria include perforation resistance, failure modes, projectile residual velocity, and surface damages on RC panels. Results show wider rebar spacing decreases perforation resistance, exhibiting a critical failure mode with greater projectile residual velocity. A larger damaged area is induced on both panel faces under the same applied impact force. However, a rear steel liner significantly enhances impact resistance, preventing scabbing failure and reducing projectile residual velocity. In rebar collision cases, direct collisions remarkably enhance perforation resistance, with minimal or no projectile residual velocity. However, scabbing areas on panel rear sides exceed those without direct rebar collision. Based on these results, a proposal suggests a quantitative assessment method for each factor.

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Bending response of the GFRP-reinforced concrete pontoon deck with cutout

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Monitor Session 1.2G Structural performance, November 11, 2024, 1:30 PM - 3:30 PM

The study investigated the flexural behaviour of concrete pontoon decks reinforced with GFRP bars under a four-point bending test, particularly considering the effect of a cutout in the edge of the deck that accommodates the pile. The pontoon decks are reinforced with non-corrosive GFRP rebar, ensuring sustainability and resilience in the marine environment. The investigation focuses on two large-scale concrete pontoon decks, one measuring 2400×1500×125 mm with an edge cutout of 300×300 mm. The first specimen contains internal reinforcement at mid-depth, spaced longitudinally at 150 mm intervals, while the second specimen incorporates a double layer of GFRP reinforcement spaced at 250 mm intervals. The specimen with the double layer shows improved flexural performance in both pre- and post-crack stages due to increased effective section depth. Finite element analyses were also implemented, incorporating the elastoplastic behaviour of concrete and its post-crack stiffness degradation using the concrete damage plasticity (CDP) model. Meanwhile, the GFRP bars are assumed to exhibit linear elastic behaviour. Calibrating the FE model based on experimental results, a parametric study is conducted to assess how concrete strength and span-to-depth ratio influence the flexural strength of GFRP-reinforced concrete decks with a cutout.

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Improved design by synergized soil-structure interaction

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Monitor Session 1.2G Structural performance, November 11, 2024, 1:30 PM - 3:30 PM

Analyzing soil-structure-interaction from a structural engineering perspective involves the deformations caused by soil settlement. For example, a building must settle in a trough or an anchored retaining wall must absorb the deformations of the subsoil. Conventionally, this correlation is represented by inserting subgrade reaction moduli at the contact surface of the structure with the soil body. The subgrade reaction moduli are hereby derived from geotechnical analysis using a settlement-relevant load combination with simplified regard of the structure stiffness. However, this conventional approach leads to various errors. One problem is the insufficient regard of the structure stiffness in the geotechnical analysis. Another problem arises in the context of the common practice in structural analysis and design, when calculating individual load cases using the subgrade reaction moduli and then combining them for design. By doing so, the related load combination for structural analysis does not comply with the load combination for geotechnical analysis anymore. In addition, the application of partial safety factors for the determined forces in the structure do not correctly distinguish between forces due to loads and forces due to imposed deformations by the ground deformation. The result is an overly conservative design that does not reflect the actual internal forces and safety level.

The main objective of this paper is to derive a reasonable approach for the consideration of soil-structure-interaction in simple structures. In order to achieve a more realistic representation of the soil-structure-interaction, the static model is therefore superimposed with a geotechnical model. By closing the gap between static and geotechnical models, the proposed methodology should enable a more accurate representation of realistic soil-structure-interaction and thus contribute to a more efficient and reliable design process.

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Effect and mechanism of diaphragms on girder performance of simply supported T-girder bridge

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Monitor Session 1.2G Structural performance, November 11, 2024, 1:30 PM - 3:30 PM

Prefabricated simply supported T-girder bridge is a popular system in accelerated bridge construction. But the cast-in-place diaphragms restrict the convenience and efficiency of its construction and the practice of diaphragms is still controversial. In the traditional design concept, the necessity of setting the diaphragms is reflected in its effect on enhancing the structural integrity and reducing the design loads of the main girders, while an opposite view is proposed in this paper. A spatial grillage (SG) model was first verified by the finite element method to ensure its accuracy. Subsequently, the SG models of T-girder bridges with different diaphragm layouts were built to evaluate the effect of diaphragms on the girder performance. The results show that the presence of intermediate diaphragms indeed enhances the structural integrity but also increases the bending moment of the exterior girders which usually control the girder design. The mechanism of this uncommon phenomenon and the possibility of removing the diaphragm is discussed in detail in the paper.

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Evaluating Seismic Inertia Demand of Precast Concrete Diaphragms: A US-NZ Comparison

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Monitor Session 1.2G Structural performance, November 11, 2024, 1:30 PM - 3:30 PM

Precast concrete diaphragms play a critical role on the seismic performance of structures, and increasing attention is being paid to strengthen these structural elements in the aftermath of the 2010/2011 Canterbury earthquakes. However, a significant gap remains in our understanding of the seismic forces that diaphragm elements should be assessed or designed for. Various key parameters affecting the seismic demands of diaphragms such as higher mode effects, plan and vertical irregularities and the role of over-strength capacity of the lateral resisting elements are not comprehensively addressed in current design and assessment documents. These missing aspects have raised questions about the adequacy of the simplistic design methods commonly used in national documents. The New Zealand loading standard NZS 1170.5 specifies a pseudo-Equivalent Static Analysis (pESA) approach for calculating diaphragm forces, taking into account Peak Ground Acceleration (PGA) and structural overstrength. Conversely, the US loading standard ASCE 7-22 introduces an alternative method for precast concrete diaphragms, utilizing a diaphragm design force reduction factor, Rs, while also including considerations for higher mode effects and structural overstrength. These aspects often lead to higher force demands compared to the general method in ASCE 7-22, used for other diaphragm types, but the accuracy of these methods in estimating diaphragm demands remains an open question. This study aims to bridge this gap by conducting a comparative analysis of the NZS1170.5 and US approaches to determine seismic forces demand in the diaphragm. The various documents are brought to a comparable framework by aligning key seismic design parameters such as response spectra, ductility and overstrength. The diaphragm forces were calculated using both standards and on a representative New Zealand building archetype to assess the efficacy of each standard's approach. The findings of the study offer critical insights into the calculation of diaphragm forces under US and NZ standards. This research contributes significantly to the field by aiding engineers in making informed decisions regarding the seismic design and assessment of buildings, ultimately enhancing structural resilience in earthquake-prone areas.

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Experimental investigation on seismic performance of prefabricated pile-slab bridge bent

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Monitor Session 2.1E Structural testing, Bealey 4 & 5, November 11, 2024, 4:00 PM - 6:00 PM

To investigate the seismic performance of pile-slab bridges and promote their application in earthquake-prone regions, a half-scale specimen is designed and constructed based on a three-pile bridge bent with prestressed and reinforced high-strength concrete (PRC) piles of an actual pile-slab bridge and then tested under quasi-static cyclic loading. The progressive damage, hysteretic behavior, lateral resistance and displacement and ductility capacity are discussed. The experimental results indicate that the bent exhibits satisfactory energy-dissipation and ductility capacity, along with moderate self-centering features. The failure mode of the bent is brittle fracture of the prestressing rebars at the bottom of piles, accompanied by severe spalling of cover concrete. However, the pocket connections between the piles and the bent cap remain functional throughout the test.

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Experimental Investigation on Shear Behaviour of Prestressed Bridge Girders

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Monitor Session 2.1E Structural testing, Bealey 4 & 5, November 11, 2024, 4:00 PM - 6:00 PM

When assessing existing prestressed concrete bridges, we encounter cases where the webs are reinforced with only a minimum and constant amount of shear reinforcement. This causes problems with the determination of the load capacity of the bridge when shear resistance is considered according to current standards - Eurocodes. The reason is the influence of the normal force on the shear resistance in the old design models used in Czechoslovakia.

The article provides a description of the experimental campaign of prestressed beams with shear reinforcement, which was focused on the effect of axial force. Shear resistance was determined on I-shaped beams with a height of 0.6 m. Identically reinforced elements were tested at different levels of prestressing force. The experimentally obtained results were compared with the prediction according to Eurocode 2 and its second generation as well as according to Model Code 2020. According to current design predictions, the influence of the axial force does not play such a significant role as it was in the past.

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Tests on Special Anchors for RC Frames With Structural as Well as Non-Structural Masonry Infills to Resist Seismic Load

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Monitor Session 2.1E Structural testing, Bealey 4 & 5, November 11, 2024, 4:00 PM - 6:00 PM

Reinforced concrete (RC) frame structures are usually treated as moment resisting frames, with different design options depending on environmental conditions. The bearing capacity of such frames can be significantly increased by installing masonry infill walls that act as shear walls.

The greatest supporting effect of the wall on the frame is expected in the in-plane (IP) direction. The IP loads usually are introduced into the wall as compressive forces, whereas the Out-of-plane (OoP) loads generate shear forces at the joints between the frame and infill.

The interaction between the RC frame, the (integral) infill and their joints is critical to the overall performance of the structure and needs a specific consideration during the design of the structure. Even though infill walls are classified as non-structural elements by most of the building codes worldwide, they can be designed as load bearing - acting like shear walls - in IP direction. For both considerations, they must withstand OoP loads, particularly in the case of earthquakes to prevent failure, which can endanger people and block escape routes and to assure they are still suitable for important actions especially for later upcoming loads in IP direction.

A good opportunity to improve the OoP performance is to place special ties in the joints between the frame and infill. The action on these ties can be determined from the load bearing capacity and deformation behaviour of the frame structure or by calculation according to EN 1998 or similar.
For this purpose, not only the load-bearing capacity but also the deformation behaviour must be investigated, which can best be achieved by tests in different scales.

In this paper, the technical background is explained, and the various experimental results are illustrated and compared.

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Experimental study on beam-column-slit slab joint to achieve proper failure mode of existing RC frame structures

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Monitor Session 2.1E Structural testing, Bealey 4 & 5, November 11, 2024, 4:00 PM - 6:00 PM

The “strong beam-weak column” failure mode for RC frame structures can be frequently observed in post-earthquake fields, partially due to the inadequate seismic design consideration that ignoring the participation of slabs in beam flexure. Thus, it is of critical importance to achieve proper failure mode of “strong column-weak beam” in the existing reinforced concrete structures. For this purpose, the authors developed a novel method to cutting a slit between the slab and primary beam in the zone of the beam-column joint. The slit with a specific length was used to weaken the strengthening effect of the floor slab on the primary beam. Two 1:2 scale beam-column-slab joints were tested under pseudo-static loading to investigate their seismic performance. One specimen was constructed with intact slabs and the other with a slit length of 420 mm at the beam-slab juncture. Test results indicated that column-end plastic hinge first occurred in the beam-column-slab joint with intact slabs, while beam-end plastic hinge earlier appear in the specimen with slit slabs. As a result, the proper failure mode of “strong column-weak beam” was accomplished. The ultimate resistance of the specimen with slit slabs was 7.7% lower than that of the specimen with intact slabs.

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Design and Implementation of an UHPC Post Tensioning Anchorage Blister using Full Scale Prototype Testing.

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Monitor Session 2.1E Structural testing, Bealey 4 & 5, November 11, 2024, 4:00 PM - 6:00 PM

As part of the Brisbane Metro Project, strengthening of Victoria Bridge was required to ensure that it has capacity to carry increased loading beyond its intended purpose. A key part of the strengthening solution involves an external post-tensioning system that is anchored to the bridge using a combination of an in-situ concrete multi-tendon anchorage, steel deviators, and precast ultra high-performance fibre reinforced concrete (UHPFRC) anchorage blisters, a first in Australia.

At the time of design, there were no Australian Standards available for the design of structural components comprised of UHPFRC, and limited standards available internationally. It was therefore proposed to base the design on full scale prototype testing to be undertaken in accordance with AS5100.5:2017 Appendix A.

The selection of UHPFRC over more common construction materials such as reinforced concrete or steel allowed for a significant reduction in the blister size and weight. Unlike currently available external PT anchorage methods, the UHPFRC blisters present an innovative solution for the anchoring of medium to large multistrand tendons to existing structures using a pre-fabricated component that relies on a friction connection to resist the longitudinal loads induced by the tendon. The minimalistic nature of the blisters also ensures that they provide a highly sustainable solution to growing infrastructure needs and that works undertaken on infrastructure within urban environments are less likely to affect public perception, both game-changers in the approvals process.

This paper provides insight into the design process including an overview of the full-scale prototype testing, highlights the detailing used to overcome the significant loading requirements of a medium to large multistrand tendon, and presents the benefits of using this type of system on an existing medium to large span bridge.

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Comparative Experimental Investigation on Mechanical Properties of Innovative Ultra Lightweight Structural Concrete

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Monitor Session 2.1F Concrete mixes, November 11, 2024, 4:00 PM - 6:00 PM

For the last decade, Structural Lightweight Concrete (SLC) has grown distinctive popularity be-tween scholars due to reduction in over-all dead-load, its structural characteristics accompanied with its varieties in materials to produce. Thus lots of attempts have been made to refine such properties including modifications in lightweight aggregates, mix design, pozzolanic materials and etc. In this paper, an innovative mix design of Ultra Lightweight Structural Concrete (ULSC) comprising with lightweight expanded clay aggregate (LECA) as course aggregates, Expanded Perlite (EP) as fine aggregates, cement and silica fume as cementitious materials, has been presented and a comparative study has been conducted to determine the mechanical properties of ULSC. ULSC is a novel type of concrete with 28-day compressive strength of approximately 33.5 MPa and diminished dry unit weight of about 1200 kg/m3, which can significantly reduce the overall dead loads of structures then results in seismic resistance and financial benefits. For comparison, compressive, flexural and elastic modulus of ULSC, Structural Lightweight Concrete (SLC) and Conventional Concrete (CC) have been tested in different ages. It has been found that the 28-day dry unit weight of ULSC is considerably diminished up approximately to 87 and 40 percent in comparison with CC and SLC, respectively, where its strength properties are in conformity with definition of structural lightweight concrete based on different standards.

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Influence of Mechanically Treated Recycled Concrete Aggregates and Curing Method on Recycled Aggregate Concrete

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Monitor Session 2.1F Concrete mixes, November 11, 2024, 4:00 PM - 6:00 PM

The implementation of a circular economy model for all EU member states aims to valorize and create value from waste streams that would otherwise be considered a burden. At the same time, it strives to protect natural resources from continuous depletion. Hence, the construction industry should modify its practices to meet these requirements. The use of crushed concrete in the form of Recycled Concrete Aggregates (RCA), generated from Construction and Demolition Waste (CDW), can be incorporated into convectional concrete. However, the mortar adhered to the surface of RCA leads to poor mechanical and durability properties of Recycled Aggregate Concrete (RAC). The main objective of this research is to independently investigate the effects of an Internal Curing (IC) method and the incorporation of mechanically treated RCA on the mechanical and durability performance of RAC. Overall, 32 RCA-based mixtures were cast and examined for their mechanical (compressive and splitting tensile strength) and durability (chloride penetration and drying shrinkage) properties at both 0.25 and 0.50 w/c ratio, implementing untreated or treated quantities of RCA (0%, 25%, 50% or 100%). IC mixtures with 25% treated aggregates yielded compressive strengths nearest to their equivalent reference mixture compressive strength, while the incorporation of recycled sand significantly improved tensile strength. Regardless of w/c ratio, type and percentage of RCA, all chloride resistance values decreased, while shrinkage strain measurements indicated a clear reduction compared to reference values, for all IC RAC mixtures.

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The Improvement of Permeable Concrete Mix Design Method with regards to Void Ratio

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Monitor Session 2.1F Concrete mixes, November 11, 2024, 4:00 PM - 6:00 PM

Permeable concrete is expected to be innovative solutions against ongoing problems such as heat island phenomena and urban flooding with its features of permeability and greenability. However, it has difficulties in controlling its void ratio during the casting, which significantly affects the performance of it, or the permeability coefficient and the vegetation ratio. To solve this problem, this study focuses on the change of aggregate amount in design and construction and clarifies it theoretically to find the actual distribution of void, paste and aggregate. Specifically, the aggregate distance is calculated by modeling the process of making permeable concrete, then the systematic method which tells change of aggregate amount (correcting modulus) is constructed with the calculated aggregate distance. In addition, several verification experiments are conducted with important parameters. From these results, it is found that this model reproduces the correcting modulus corresponding to the paste stiffness well including the maximum limitation value of correcting modulus when paste is soft. On the other hand, other parameters have different results in calculation from the model and the experiment. These differences are caused from experimental phenomena which is not taken into account in the model. Therefore, by considering it in the model, it is possible to reproduce the actual correcting modulus on construction from the suggested method. To sum up, the new systematic method can be the basis of improved mix design method in the perspective of the void ratio, which enables us to get required performance of permeable concrete constantly.

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Use of Finite Element Thermal Modelling to Verify CIRIA 766 Requirements on Complex Structures

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The accurate prediction of temperature rise in concrete due to heat of hydration is crucial in preventing structural issues such as cracking and delayed ettringite formation, especially in complex shapes like wind turbine bases and Super-T end blocks. Traditional modelling methods, like those in CIRIA C766, often fall short in these structures where heat flow occurs in multiple dimensions, and peak temperature and temperature differential limits for control of crack widths are critical. The use of local cements with varying thermal properties necessitates advanced analysis techniques, such as finite element thermal modelling.

Finite element thermal modelling, gaining popularity, emerges as a solution, offering a detailed approach to simulate multi-directional heat flow in complex geometries. This modelling technique not only provides the most accurate method to predict in-situ temperatures in complex shapes but also enables the modelling of post-cooling methods, such as the use of cooling pipes. This is particularly crucial in scenarios where maintaining low concrete placement temperatures to achieve target temperature limits is challenging yet essential. The historical reluctance of contractors to adopt techniques like cooling pipes is now being overcome by a growing recognition of their importance in effective temperature control.

The paper presents case studies employing finite element analysis for cooling pipe design in complex structures, discussing the efficacy of these methods in thermal management and guideline compliance, promising enhanced accuracy and efficiency. The aim of the paper is to bridge the current knowledge gap in the thermal management of concrete by advocating for the integration of advanced modelling techniques, such as finite element analysis, in construction practices.

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Evaluation on bond splitting failure of reinforced concrete with 3D image analysis for aggregate spatial distribution

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Monitor Session 2.1F Concrete mixes, November 11, 2024, 4:00 PM - 6:00 PM

It is important to evaluate spatial arrangement of coarse aggregate, as for crack propagation behavior in concrete when the reinforcement is subjected to tensile force, which affects the concrete-to-steel bar bond strength due to formation of interfacial surfaces between aggregate and cement paste. Visually extracting the position of coarse aggregate in concrete by X-ray CT in this study, the image data process which quantifies the coarse aggregate location as three-dimensional array was introduced for the cross-sectional continuous images. In addition, the fracture property with bond splitting failure, which is a brittle failure mode of reinforced concrete, was evaluated based on AE (Acoustic Emission) behavior. In particular, this paper focused on the development and propagation of cracks at the interface between reinforcing bar and concrete as well as that between cement paste and aggregate under the pull-out test of reinforcing bar from cylindrical specimens. The specimens were prepared in consideration of maximum aggregate size and water to cement ration in the mix proportion, fabricating the spatially inhomogeneous distribution of course aggregate in concrete according to the distance from the reinforcing bar. As the results, the crack propagation behavior around the reinforcement and the aggregate was confirmed in the cross-sectional images acquired using X-ray CT method. Moreover, it was clarified that the size and the location of coarse aggregate in reinforced concrete affect the fracture mechanism when bond splitting failure in reinforced concrete. In addition, the characteristics of fracture morphology were identified using AE parameters such as number of hits, frequency, amplitude and so forth including RA value (rise time/amplitude of AE signal) with identification of fracture region based on AE source location result.

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Tailored fiber placement for load path oriented reinforcements in textile reinforced concrete

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Monitor Session 2.1G Alternative reinforcing, November 11, 2024, 4:00 PM - 6:00 PM

Textile-reinforced concrete (TRC) is considered an innovative building material enabling lightweight and high strength concrete construction. This is mainly due to the non-corrosive nature of the textile reinforcement and its high tensile strength combined with a low weight. The most commonly used textile reinforcements in the industry are biaxial grid-like textile structures impregnated with polymers to increase the load bearing capacity of the composite. These grid-like textile reinforcements merely substitute steel reinforcement imitating its biaxial reinforcement structure. However, to achieve a high material-efficiency and resource minimization, the reinforcement should meet the requirements of the end product in terms of maximum loads and load paths. The textile production process of Tailor-Fibre-Placement (TFP) enables the placement of reinforcement systems in almost any geometry. This study demonstrates the mechanical performance of such Tailor-Fibre-Placement textiles in comparison to conventional textile reinforcements. Results shown that with the same material utilization efficiency in the textile of 1400 MPa, TFP can reduce the amount of reinforcement by 50 % while reaching a higher mechanical strength by 40 % in the composite. This makes TFP a potential alternative for the realization of textile reinforcement systems in components with complex geometries and load path systems.

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Lime-based Textile Reinforced Mortar with natural fibers: experimental tests and mechanical characterization

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Monitor Session 2.1G Alternative reinforcing, November 11, 2024, 4:00 PM - 6:00 PM

Sustainability is a common challenge in all modern human activities and industrial sections. In this context, civil engineering is not an exception: new materials, possibly obtained from renewable and locally available resources, are being developed and their potential for real-World application is currently investigated. As part of this common effort, special attention is being paid to an emerging class of materials, generally referred to as bio-based composite systems.

This study investigates the mechanical properties of a Textile-Reinforced Mortar (TRM) system produced by utilising either Flax or Jute textiles as the internal reinforcement embedded within a hydraulic lime-based mortar representing the matrix of the composite system. This research also aims at analysing the cracking patterns exhibited by the Natural TRM systems as well as the bond behaviour of the natural textile embedded in the produced mortar. The proposed analyses highlight the relevant mechanical response observed on both Flax- and Jute-TRM specimens, and allows to gain a comprehensive understanding of their mechanical behaviour, in view of their possible use in seismic strengthening of existing masonry structures.

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Effect of Age on Reverse-Cycle Performance of Hybrid Fibre Reinforced Concrete Beam-Columns

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Monitor Session 2.1G Alternative reinforcing, November 11, 2024, 4:00 PM - 6:00 PM

The post-crack properties of Fibre Reinforced Concrete (FRC) are known to change with aging. The bond between concrete and steel reinforcement is also known to change as concrete ages, and the strength and elastic modulus of the concrete itself will steadily increase. Given that so many characteristics of both concrete and FRC change as a member ages, it is valid to question whether the reverse-cycle load resistance of Reinforced Concrete (RC) and RC/FRC hybrid members also changes with the passage of time. Although the effects of environmental exposure, including chloride ion ingress, carbonation, and concrete cracking on the seismic resistance of RC members has been examined extensively, the effect of inherent age-related changes in the properties of concrete and FRC on reverse-cycle load resistance has not received much attention.

To address this short-coming, the present investigation has examined how age-related changes in the properties of macro-synthetic fibre reinforced concrete (MSFRC) influences the reverse-cycle flexural performance of RC/FRC members. Laboratory testing was performed on conventionally reinforced beam-column members (structural members subject to simultaneous bending and compression) made with plain concrete and macro-synthetic fibre reinforced concrete. A total of 40 beam-columns were tested at ages of 3, 6, 12, 24, and 60 months after casting. The tests indicate that there is a small increase in peak flexural capacity under reverse-cycle loading for both plain and FRC with aging, but that there is no deterioration in post-crack performance with age at least for the MSFRC mixture presently examined. The data also suggest that, when used at practical dosage rates, embossed macro-synthetic fibres can reduce the requirement for confining stirrups by permitting an increase in stirrup spacing.

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Characterisation of the Alkaline Resistance of Fibre Reinforcement Strands Produced in a Dynamic Fibre Winding Process for 3D Concrete Printing

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Monitor Session 2.1G Alternative reinforcing, November 11, 2024, 4:00 PM - 6:00 PM

It is imperative that the construction industry becomes more sustainable if global climate targets are to be achieved. There are various ways in which this can be achieved, one of which is the establishment of additive manufacturing concepts. Free-form design, efficient use of materials and digital processes can make buildings significantly more sustainable in the future. The research presented here focuses on the development of reinforcement strategies for large and thus load-bearing, additively manufactured concrete structures. The reinforcement of additively manufactured components is very challenging due to their layer-by-layer construction. One approach for this is the robotic integration of glass fibre reinforcement strands by winding. Previous works have already presented a Dynamic Winding Process that can be used to implement various reinforcement concepts for different additive manufacturing methods. It is important to know the exact mechanical properties of the reinforcement structures that can be produced with this process to use them as efficiently and purposively as possible.

In this paper, the alkaline resistance according to ISO 10406-1 for reinforcement bars made of E-glass and ECR-glass as primary fibre material is presented. Detailed knowledge of load transfer and the long-term durability of the reinforcement strands that can be produced is important to increase the service life and thus the sustainability of the structures produced.

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Numerical investigation of the bond-slip behavior between ultra-high-performance concrete and titanium alloy bars

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Monitor Session 2.1G Alternative reinforcing, November 11, 2024, 4:00 PM - 6:00 PM

Conventional reinforced concrete (RC) structures (composed of steel and concrete) are usually designed for a service life of around 50 years, but they are susceptible to corrosion from various environmental agents (salts, chlorides, carbonation, humidity, etc.) which overtime may compromise their expected service life. Recently, the use of titanium alloy bars (TiABs) in place of traditional steel rebars for reinforcing and ultra-high performance concrete (UHPC) has been proposed as an attractive construction method (namely, TARUHPC) to increase the durability of RC structures in seismic regions. Although some element and sub-assembly tests on TARUHPC have been conducted, its bond behavior is still not fully characterized. This paper extends previous experimental efforts by investigating numerically the bond behavior between TiABs and UHPC. Detailed nonlinear Finite element (FE) models were used to assess the pull-out strength of TARUHPC specimens. For comparison, the pull-out strength of specimens with normal concrete (NC) and TiABs was also evaluated. In order to consider realistic assumptions, the interaction and bond between concrete and rebar was simulated using the cohesive zone modeling method, whose parameters were obtained by model-updating between the FE models and the experimental pull-out test results. The FE models were validated against the experimental pull-out tests and the models were able to capture adequately the bond-slip behavior, bond strength, and failure modes of test specimens. A parametric analysis was conducted for some parameters such as bar diameter, embedment length. Based on the results, some design recommendations for TARUHPC are provided.

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Incorporation of Excavation Soil Sands in Self-Compacting Concrete (SCC) for the Precasting industry : Using the Equivalent Mortar Method

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Monitor Session 2.2E Sustainable design, Bealey 4 & 5, November 11, 2024, 4:00 PM - 6:00 PM

This work investigates the effects of substituting natural sand with excavation soil sands (ESS) in the formulation of self-compacting concrete (SCC) designed for precasting industry. Four sand ESS deposits from different sites and a natural rive sand were studied. As part of the preliminary phase, a comprehensive characterization of the geometric and physicochemical properties of four different sand was carried out. Using the concrete equivalent mortar approach, the reference mortar (RM) was developed from a self compacting concrete with a C30/37 strength class. Subsequently, a substitution of natural river sand (NRS) with 30% of each ESS are explored. The research considers two moisture conditions of sand : the natural state of sand in storage and the dry state of sand. A comprehensive series of experimental tests, including spread tests for flowability at initial mixing (T0), 15 minutes (T15), and 30 minutes (T30) to assess the temporal evolution of spread characteristics, flexural tests and compression tests at different time points for overall mechanical performance, are conducted for each formulation. Results from spread tests indicate that, for the RM, the flow of mortar made with sand in its natural state is greater than that made with sand in its dry state. In all conditions, it is observed that all mortars lose their fluidity over time. Overall, when sand is used in a dry state, the maintenance of spread after 15 and 30 minutes proves superior compared to its natural state of storage and the results for mortars with 30% ESS are close to RM. For mechanical properties, the reference mortar made with natural sand in its natural state showed higher compressive strength than in the dry state. The compressive strength of the various mortars with 30% ESS was on average comparable to that of the RM when the sand was used in its dry state. The results also indicate that the water status of the sand did not significantly affect the compressive strength of the different mortars with 30% ESS.

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Improving the quality of Recycled Concrete Aggregate (RCA) using Thermo mechanical treatment

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Monitor Session 2.2E Sustainable design, Bealey 4 & 5, November 11, 2024, 4:00 PM - 6:00 PM

In pursuit of advancing towards a circular economy, there is a significant requirement to optimize the utilization of waste materials in construction activities. Among the abundant waste resources available, Recycled Concrete Aggregates (RCA) represent a significant opportunity. Over the past few decades, numerous methodologies have been introduced to enhance the quality of RCA. Notably, Thermo-Mechanical Treatment (TMT) in concrete recycling has gained widespread attention in global research circles due to its potential to yield high-quality RCA.

This study aims to investigate the effects of varying temperatures, residence times, and moisture conditions on the quality of recycled concrete aggregate (RCA) through a Thermal-Mechanical Treatment (TMT) process. The results indicate that thermal treatment (TT) at a temperature of 500°C enhances the removal of adhered mortar (AM) in RCA, particularly when combined with water saturation. The proposed three-step TMT method, involving pretreated RCA soaked in water and heated at 500°C for 2 hours, demonstrates notable improvements in RCA quality compared to thermal treatment alone. Additionally, concrete fabricated with W-TMT-RCA-500°C exhibits promising compressive strength, exceeding 80%, which is comparable to that of concrete made with natural aggregates. Furthermore, microstructural analysis confirms the effective removal of AM, contributing to improved aggregate quality.

Keywords: Construction and demolition waste, recycled concrete aggregate, Thermal-mechanical treatment, Recycled Aggregate Concrete

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Embodied carbon over the life cycle of reinforcing steels: Carbon emissions associated with Modules A1-A3 Product and A4-A5 Construction stages

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The buildings and construction sector accounted for 36% of final energy use and 39% of energy and process-related carbon dioxide (CO2) emissions in 2018, 11% of which resulted from manufacturing building materials and products such as steel, cement and glass. Design and structural engineers need to understand the environmental impact of their designs and in particular, the upfront 'embodied' carbon emissions – measured as its Global Warming Potential (GWP) in CO2 equivalent (CO2e) per tonne of product.

fib has incorporated sustainability into the Model Code (MC) since MC2010. With sustainability and performance-based design at its core, MC2020 is the MC for future thinking. The fib platform for CO2 Inventory Data is aiming to accelerate the shift to low embodied carbon materials in all projects.

Embodied carbon can be defined as Greenhouse Gas (GHG) emissions from the extraction of raw materials, processing and manufacturing, in-use maintenance and replacement, end of life demolition, disassembly and disposal including transport relating to all three.

This paper outlines how embodied carbon data is accurately calculated for specific steel producers, reinforcing steel products and fabrication, transport and construction life cycle stages. It explains how 3rd party verification can provide confidence in the data and limited comparability. It concludes with how an innovative collaboration is developing a solution to digitise the reinforcing steel supply chain so this information can be used by fib platform and other construction stakeholders to help drive down emissions.

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Functions of green roofs in sustainable urban environment

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Monitor Session 2.2E Sustainable design, Bealey 4 & 5, November 11, 2024, 4:00 PM - 6:00 PM

In recent years, the concept of sustainable urban living has gained prominence as cities worldwide grapple with the challenges of rapid urbanization, climate change, and environmental degradation. One innovative and multifaceted approach towards creating a sustainable urban environment involves the development of green roofs. These eco-friendly rooftops serve several crucial functions that contribute to the overall well-being of urban ecosystems. The paper explores the various roles played by green roofs in fostering sustainability in urban environments. It is also described how they can significantly contribute to urban regeneration and sustainable communities on different levels: reducing air pollution, increasing energy efficiency of buildings, managing storm water systems, increasing urban biodiversity and local food production or creating of social spaces for community engagement.

The paper presents, among other things, a brief history of green roofs engineering in Europe and the phases of their design in view of the functions they are to perform in a sustainable urban environment. It also analyses the trends in the development of these structures due to climate changes, especially in countries in which such rooftops were previously unknown.
It was highlighted in the paper that the growing popularity of green roofs in the future is not just a matter of environmental responsibility - it also aligns with the broader goals of creating sustainable, resilient, and liveable urban environments. As awareness of these benefits increases and technological advancements continue, green roofs are poised to become integral components of the urban landscapes of tomorrow.

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Characterising the behaviour of Hybrid Fibre-Reinforced Concrete

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Conventional concrete is a brittle material, typically characterised by low strength and toughness in tension. Distributed fibres can be added to the matrix to enhance the performance of concrete. The overall behaviour of the resulting cementitious composite is greatly affected by the characteristics of the fibres, such as the type, material, geometry and amount. Moreover, different types of fibre can be combined in the same composite, obtaining property enhancements that can be greater than the sum of those due to individual types of fibres. Nonetheless, these synergistic effects are not well understood, and the change in material properties due to all the possible combinations is difficult to predict. In this study, different fibre-reinforced concretes were characterised experimentally in compression and tension. The effects of different types of fibres were investigated, specifically hooked steel fibres of two different lengths and polypropylene fibres. The progressive change in flexural be-haviour was studied on prismatic notched specimens in three-point bending. The results indicated that hybrid fibre-reinforced concretes exhibited increased flexural strength and ductility, and longer steel fibres were more effective in enhancing the flexural behaviour of both steel and hybrid fibre reinforced concretes.

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Evaluation of the shear-effective area according to Model Code 2020 for non-rectangular cross-sections of reinforced concrete elements

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Monitor Session 2.2F Design codes, November 11, 2024, 4:00 PM - 6:00 PM

In both buildings and infrastructural structures, planar elements with recesses or linear elements with an I-shaped or T-shaped cross-section are often used. The 2020 Model Code assumes for such cross-sections that the shear force is carried by a rectangular shear-effective area, defined by the minimum width of the cross-section multiplied with an effective shear depth. Whether this is a logical assumption has been investigated with the non-linear cross-sectional analysis program Response 2000. With this software the distribution of the shear stresses over the cracked and uncracked zones can be determined. A selection of hypothetic T-shaped beams, I-shaped beams and beams representing a hollow core slab were examined, all with-out shear reinforcement and without prestressing. The study shows that the presence of flanges has a significant influence on not only the shear stress distribution over the cracked and uncracked zones but also the maximum shear stress that can be resisted. However, all effects which increases or decreases the shear resistance appear to compensate each other. Assuming a shear-effective area of 0.9 times the effective height multiplied by the minimum width of the cross section turns out to be suitable simplification. Assuming that the effective shear depth is equal to the maximum lever arm, which could be considered as an alternative, appears to be not suit-able because it leads to an overestimation of the shear resistance.

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Review of NZ code modelling and deemed to satisfy provision based on Full Probabilistic Analysis (FPA)

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Monitor Session 2.2F Design codes, November 11, 2024, 4:00 PM - 6:00 PM

A growing emphasis is being placed on design for concrete durability, particularly in the context of sustainability and reliability based design. In New Zealand, the close proximity of the ocean to all structures means chloride induced corrosion has always been a concern. In 2006, a model for chloride ingress based on research of the preceding decade was published in FIB Model Code for Service Life Design. NZ3101-2006 was the first national code to adopt chloride modelling for determining minimum cover requirements and was developed on the same decade of research and local experience. Nearly 20 years on, there has been a considerable amount of research on chloride ingress and significant modelling experience of NZ structures. It would be appropriate for any revision to NZ3101 to consider that research and experience in determining appropriate requirements for durability.

This paper reviews the requirements in NZ3101-2 in respect to chloride modelling and provides comments based on the current understanding from FIB COM8 and CIA Durability Committee activities. The key topics covered consider how to implement models for chloride initiation and propagation, target reliability, critical chloride level, diffusivity with time, and surface chloride level. Subsequently, a full probabilistic analysis is employed to assess the deemed to satisfy requirements of NZ3101. Examples of modelling of new NZ marine structures for design life are also provided.

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Analysis of fastenings in concrete using spring models: Requirements for finite-element based modelling

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Monitor Session 2.2F Design codes, November 11, 2024, 4:00 PM - 6:00 PM

In structural engineering applications fasteners are used for connecting structural and non-structural elements to structural components for example: steel beams to concrete column connection, handrail connected to the concrete base etc. Since, fasteners transmit the actions on the element to the structural member. They are important for the safety of the structure and occupants. In recent years, for designing these connections the concepts of fastening technology are being integrated into the design concept of the component method for steel and composite structures.

The design of fasteners is governed by EN1992-4 which is limited to certain fastening configurations and are valid only for stiff anchor plates. Since, in practice configurations other than those covered in design guidelines are often needed and a quantitative definition for stiff anchor plates is not available. The spring-based models for fasteners are gaining attention. Finite Element (FE) analysis using spring models for fasteners are performed with two objectives: 1) compute the actual load distribution (actions) on different fasteners in a group considering the actual stiffness of anchor plate, profile, stiffeners etc and 2) to analyse the ultimate load carrying capacity (resistance) of a connection considering actual conditions.

The designer has the flexibility to decide on the complexity of the FE model, which would depend on the aim of simulation (local analysis of the connection, effect of connections on structural response etc) and the limitations of the software used. Depending on the limitations of the software, different modelling approaches are possible. The paper presents a numerical investigation conducted using general purpose FE program ANSYS®, with an objective to compare different modelling approaches (solid elements, shell elements, beam elements and their combination). Furthermore, the sensitivity of each modelling approach to input parameters is also investigated. Based on the presented results requirements for an objective FE model are outlined.

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The limitations of the Concrete Capacity Design (CCD) Method in calculating the breakout area

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Monitor Session 2.2F Design codes, November 11, 2024, 4:00 PM - 6:00 PM

Anchors and headed studs are the basis of structural connection in the field of fastening and strengthening technology. But this kind of fastenings require an accurate engineering model to design them with the required safety for the ultimate limit state. Since more than 20 years, the Concrete Capacity Method (CCD) has been established for the design of fastenings failing with a concrete cone. In this model, the projected areas of the developing cones are determined and used to calculate the anchor capacity. Influences on the capacity are considered if the projected area is reduced by, e.g., small edge distances and small spacings. In this case, the projected areas are reduced compared to the reference area of a single anchor placed in the middle of a concrete block. In this concept, factors like holes in the concrete, multi-leveled edges, and any other cut-outs in the breakout area are not considered in the design since the projected area does not change. The results presented in this work show the limitations of the CCD-Method and the necessary research requirements. Therefore, in the future, a design method should be developed that standardizes special cases, thus eliminating the need for different interpretations of scenarios due to technical judgment.

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A Comparative Assessment Of The Accuracy Of The Hong Kong (HKBD) And Japanese (JSCE) Concrete Code Shrinkage Prediction Models

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Shrinkage of hardened concrete is due to the moisture-related time-dependent volume reduction, which is independent of any external stresses. The magnitude of concrete shrinkage is important, as shrinkage may result in cracking, warping and deflection (and even loss of serviceability) of concrete structures.

For many reinforced and prestressed concrete applications, a reasonably accurate prediction of the magnitude and rate of shrinkage strain is an important requirement of the design process. Ideally laboratory tests may be undertaken to quantify the shrinkage of concrete proposed for a structure. However, such tests as these are generally not a practical option. Hence, empirical code-type prediction models are relied upon to predict total shrinkage strain with time.

This investigation assessed the accuracy of the Hong Kong Code of Practice Model (HKBD, 2013) and the two Japanese Code of Practice Models (JSCE, 2007). In the case of the JSCE, the two models considered were the one applicable to normal strength concretes (referred to as JSCE) and the subsequently introduced model which is applicable to high strength concretes (> 55 MPa), referred to as JSCE HS. The models were evaluated when compared with actual shrinkage strains, measured over a period of approximately six months, on a range of concretes under laboratory-controlled conditions, for six mixes (comprising three aggregate types and two water cement ratios).

The HKBD was the most accurate model in the case of all the mixes, with an overall coefficient of variation (ωall) of 43,1 %. This model generally over-predicted shrinkage in the relatively lower strength mixes and over-predicted in the relatively higher strength mixes. Both the JSCE models over-predicted shrinkage, at all ages, in the case of all the mixes. The JSCE HS model was more accurate (with a ωall of 109,7 %) than the JSCE model (with a ωall of 123,2 %).

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Studies on Characteristics of Natural Frequency of Deteriorated Bridges Using Microtremor Measurement

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Monitor Session 2.2G Structural health monitoring, November 11, 2024, 4:00 PM - 6:00 PM

Recently, there is a serious problem that the maintenance of bridges which were built for the rapid economic growth period in Japan, so it is required that nondestructive methods of evaluating structural performance methods which does not give load to structures.

We practiced survey on structural performance of aging bridges and microtremor measurement to establish structural performance evaluation methods of bridges using on microtremor measurement. As the survey on structural performance, in addition to the proximity visual inspection, the loading examination of bridges and the observation of PC steel wires in girder after removal were conducted. At the loading examination, the deflection and the strain of girders by the load of the dump truck (200kN) were measured to evaluate the loading capacity of bridges. At the observation of PC steel wires in girder after removal, the quantity of rusted PC steel wires from the girder which received salt damage were counted. As the survey of vibration characteristic, microtremor measurements of vertical acceleration at the center of the bridge span were conducted. Measurement data from several data of bridges showed that natural frequency becomes smaller when bridge span becomes longer. Then, by referring to the Fourier spectrum which was calculated by fast Fourier transform using wave pattern of time history, the natural frequency of the bridge was estimated from predominant frequency. Also, we tried to elucidate the influence on natural frequency degree of the pre-stress that was introduced into a girder experimentally. As a result of these survey, the relationship between judgement classification for soundness of aging bridges and natural frequency was recognized while the relationship of the proximity visual inspection was not recognized.

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A Computer Vision and Infrared Thermography Based Debonding Damage Inspection Method for Building Facades

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Monitor Session 2.2G Structural health monitoring, November 11, 2024, 4:00 PM - 6:00 PM

The exterior facades of the buildings are frequently adorned with ceramic tiles which are subjected to continuous exposure to the natural environment. Hence, delamination beneath the tiles is prone to occur. Over time, these damages may escalate to debonding from the substrate material and spalling from the façade, thereby posing a threat to the safety of individuals. Infrared thermography (IRT) is an extensively employed non-destructive testing (NDT) technique for detecting delamination on building surfaces, owing to its convenience and accuracy. Nevertheless, much of the research about the application of infrared thermography for detecting tiles debonding primarily focus on identifying the location of the damage, lacking in-depth information regarding physical scale parameters, such as dimensional size. And this information is of great value in guiding the risk assessment of the probability of falling tiles.

In this paper, a computer vision and infrared thermography based inspection method is proposed for extracting the area information from the infrared data of tiles debonding. During the testing process, semantic segmentation is employed to distinguish between debonding and normal regions. After the inspection on the laboratory walls with artificial debonding and walls of buildings in service, the new method demonstrated its effectiveness to measure the area of tiles debonding in building facades.

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Management of Prestressed Concrete Bridges Damaged by Salt Attack with Severe Corrosion of PC Cables

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Monitor Session 2.2G Structural health monitoring, November 11, 2024, 4:00 PM - 6:00 PM

In order to maintain and manage PC structures rationally while ensuring their safety, it is necessary to select an appropriate evaluation method according to the deterioration mechanism and the extent of deterioration. From the results of our previous research, it was shown that the appropriate limit for application of the design formula in evaluating the safety of PC structures damaged by salt attack is considered to be a corrosion rate of 5%. When deterioration is above this level, it is necessary to apply nonlinear FEM or some other means of evaluation that can take into account the decline in mechanical properties associated with pitting. However, there is little example of discussing the ideal maintenance planning considering the decline in mechanical properties of PC tendons. In this study, requirements for maintenance plans and examples of practical inspection methods for estimating the corrosion rate of PC tendons from the occurrence of stirrup rebar corrosion cracking are shown. Then this paper describes examples of maintenance and management of PC bridges damaged by salt attack in accordance with the PC tendon corrosion rate.

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Characterizing Bridge Distress with Advanced Computer Vision Methods

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Monitor Session 2.2G Structural health monitoring, November 11, 2024, 4:00 PM - 6:00 PM

In the U.S., the escalating weight of vehicles presents considerable challenges for maintaining in-service bridges. This trend in vehicle weight is influenced by factors such as economic advantages of transporting goods and the increasing prevalence of electric vehicles. While states are mandated to adhere to standard federal weight limits for interstate highways, federal law permits higher weight limits for interstate travel under specific conditions, such as for containerized vehicles heading to ports. Moreover, certain states have established their own bridge formulas for non-interstate highways. This study investigates the effects of such deviations from standard weight limitations. It encompasses the monitoring of main bridge types, including steel and reinforced concrete superstructures. Additionally, finite element analysis models are employed to conduct nonlinear analyses of the bridges. Wireless strain and crack width gauges are strategically installed on specific bridge elements to measure the impact of passing trucks. These gauges provide quantitative data on strain in bridge girders, allowing for an assessment of how vehicles influence strain levels based on their weights. It is concluded that strain measures observed in the field align with damage characterized in analytical nonlinear FEA models. This correlation arises not necessarily from the computational aspect being more sensitive in all prototype bridges, but from its effectiveness in characterizing crack strains in reinforced concrete elements, determined through more cost-effective crack width gauges. Furthermore, the study aims to empirically and analytically investigate the sensitivity of changes in mode shapes to identify localized distress caused by heavy vehicles, leveraging state-of-the-art technologies.

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Investigation the Damage Causes of a Prestressed Concrete Box Girder Bridge

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Monitor Session 2.2G Structural health monitoring, November 11, 2024, 4:00 PM - 6:00 PM

Extensive spalling of the concrete and exposure of the reinforcement were found on both surfaces of the web near the segmental joints of the pre-stressed concrete box girder bridge constructed by the segment method on the Hanshin Expressway. The results of the detailed investigation showed that the concrete was damaged to the extent that the tendons in the web could be seen from the outer surface of the web, and significant corrosion of the tendons was observed to the extent that they were lost. It seemed that the damage was caused by penetration of anti-freezing agent water through the segmental joints, the inadequate filling of the grout in the sheath, and the remained grout hose. From the above, this study investigated; 1) the corrosion condition of the tendons and the grout filling condition in the sheath using a CCD camera, 2) the water penetration pathway from the remaining grout hoses in the sheath, and 3) the distribution of salt content in the concrete. The results revealed the followings: 1) the most of the tendons were suffered only minor rust and filled with grout except where the loss of tendon occurred, 2) the water penetration through segmental joint is dominant because the grout hose had been filled with, 3) the higher salt values were identified near the segment joints and the lower values were found as it moved away from the joints. The results of the above investigation revealed that the water penetration through the segmental joints is a major factor. Therefore, the damaged area will be repaired by the materials with Lithium nitrite and the waterproofing the bridge deck surface to prevent water penetration from the segmental for improving durability.

Poster Presentation

Abstracts

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A Case Study of Sustainability Certification for Constructional Steels

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Poster Session, Exhibition Hall, November 12, 2024, 12:00 PM - 1:00 PM

Governments are increasingly requiring major projects to specify product conformity and carbon performance. For example, the UK governments procurement guidance note PPN 06/21 requires suppliers bidding for major government contracts to commit to achieving Net Zero by 2050 and publish a Carbon Reduction Plan and its PPN 04/23 requires the tracking of steel origins.

The expectations of stakeholders across the construction industry value chain have increased significantly because of new legislation, a growing body of scientific evidence and a greater understanding of sustainability impacts. Designers and specifiers are demanding transparent, reliable data and comparable sustainability management and performance information about competing construction materials.

Constructional steel forms a significant part of any major construction project. The supply chain for constructional steel: raw materials, production, distribution, processing, and delivery to a construction site, is complex. Constructional steel manufacturers and processors are coming under increasing pressure to take proactive steps which reflect the environmental, social, ethical and economic impacts of their operations and products. Buyers' purchasing decisions are increasingly driven by efforts to ensure positive impacts and reduce any negative social, environmental, and economic impacts.

The CARES approach relies on responsible sourcing of raw materials, full product traceability and a digital record, providing a 'chain of custody,' as well as the sustainability principles of inclusivity, integrity, stewardship and transparency across the entire process from manufacturer to the end-user. It provides confidence to client's procurement teams, specifiers, and construction consultants that the certification process has verified a broad range of requirements without them having to repeat any part of the process. Certified performance data is available to them to inform their decision making.

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A review of methodologies relating to Shrinkage, Tensile Strength and Young's Modulus development comparison in early age cementitious concrete curing

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Poster Session, Exhibition Hall, November 12, 2024, 12:00 PM - 1:00 PM

Concrete subjected to tensile strains during an early age poses a cracking risk, especially when subjected to restrained shrinkage such as in precast construction. These cracks pose a durability, maintenance and aesthetic problem, the causes of which can be difficult to assess or correct. By comparison of major codes worldwide and selected research, we can show the relationship between the compressive strength development and other properties such as tensile stiffness. This allows a model of the major strains on the concrete during this stage.

Review of research papers show modelling of tensile strength properties during early age is directly proportional to the compressive strength, however Young's modulus development is not. Major codes, AASHTO, ACI 318R-14 and NZS 3101 do not give guidance on how to derive concrete properties prior to 28-day strength development. However, EN 1992-1 provides separate relationships between each property. AS 5100.5 eludes to the Young's modulus relationships, however the provided equations do not contain allowance for time. The approaches given within these codes are not universal and comparison to research suggests that Eurocodes provide closer relationships to that shown in the research. From other codes, we assume a compressive development curve and apply a directly proportional relationship between compressive strength, tensile strength and stiffness.

The Eurocode approach allows for a faster stiffness gain within the concrete, when compared to the compressive and tensile strengths, leading to a phase in which movements within the concrete take up larger stresses and low rupture strengths. This phase is crucial to understanding to the reasons for rupture in early age, shrinkage induced cracking and the best ways in which to mitigate this problem.

Precast construction during curing, where shrinkage combined with precast unit restraint creates tensile strains in the in-situ concrete, often leads to cracking. By reviewing the ratios of derived Young's modulus, tensile strength and restrained shrinkage development curves, we can plot critical shrinkage points in our concrete curing cycle and show theoretical maximum cracking risk points and any deficiencies in codes. Other factors also contribute to these development times, such as concrete additives, curing methodology and mix design, which will also be discussed.

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Ageing Concrete Hydraulic Structures in a Seismically Active Environment

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Poster Session, Exhibition Hall, November 12, 2024, 12:00 PM - 1:00 PM

This paper explores the critical issue of managing safety and resilience of ageing concrete dams and hydraulic structures in seismically active environments, with a particular focus on New Zealand. The country's unique geological setting, characterized by frequent seismic activities, presents significant challenges for dam safety management of ageing concrete dams and hydraulic infrastructures in New Zealand, some of which date to the early 20th century.

The authors of this paper will discuss recent dam safety evaluations and engineering assessments of concrete appurtenant structures, contributing to the broader discourse on dam safety management in seismically active regions, with a focus on ageing infrastructure. This would likely be helpful to the wider engineering community faced with similar problems of managing the seismic safety of ageing concrete hydraulic structures.

The paper introduces the active seismic environment of New Zealand, highlighting the inherent risks posed to ageing structures that were not designed to modern standards for earthquake performance, or without any earthquake considerations. It includes appurtenances and components (e.g., intakes, penstocks, powerhouses, gates, valves, etc.). The concrete design and construction practices for these structures and components have significantly evolved since then, highlighting the need for complex assessments and investigations to accurately establish likely structural behaviour under such loadings. It examines the principles of seismic analysis and design in the context of dam safety, and the urgent need for rehabilitation of ageing concrete hydraulic structures vulnerable to seismic damage. Key challenges in this context include significant remediation requirements and cost impacts, and feasibility of replacement structures.

The paper also emphasizes the importance of comprehensive risk assessment strategies that consider the probability of seismic events, likelihood of fault ruptures, and consequences of structural failures. It argues for a holistic approach to structural safety management that integrates best engineering practices, technological solutions, and risk management strategies.

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An Experimental Study on Internal Curing of Ultra High Performance Concrete Using Lightweight Scoria Sand

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Poster Session, Exhibition Hall, November 12, 2024, 12:00 PM - 1:00 PM

Today, the construction of tall buildings and the increase of structures of high importance have caused fundamental changes in concrete with normal behavior and the creation of concrete with improved strength properties. Ultra-high performance concrete (UHPC) is a new class of cementitious composite with very high strength and improved durability, which is usually made with the optimized gradation of granular constituents, lower water-to-cement ratio, and high percentage of cementitious materials and fiber reinforcement. Having superior mechanical properties, including compressive and tensile strengths, toughness, and impact resistance, as well as very high durability, distinguishes the UHPC from conventional concrete. However, UHPC has considerable autogenous shrinkage due to the use of large amounts of cement and a very low water-to-cement ratio. To control and reduce autogenous shrinkage of ultra-high performance concrete, various strategies can be used such as internal curing, replacement of cement with pozzolanic materials, application of shrinkage-reducing agents, etc. Internal curing is one of the successful and useful methods to reduce the shrinkage of UHPC. Therefore, in this study, we have used lightweight scoria sand in different percentages for internal curing of UHPC. For this purpose, after the preparation of experimental specimens, tests were conducted to determine autogenous shrinkage and compressive and flexural strengths of UHPC. Considering the experimental results, it has been found that by increasing the lightweight scoria sand content in the mixes, UHPC's autogenous shrinkage was successfully reduced as well as a decrease in strength properties. The optimum content of lightweight scoria sand as an internal curing agent can be attained to reduce the autogenous shrinkage with lower impacts on strength properties.

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An Experimental Study on Interpretation of Core Test Results for Assessment of Concrete In-Situ Strength

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In existing concrete structures, concrete cores may be extracted to assess the current condition of the structure. This is often done when there are concerns about the structural integrity or if the structure is undergoing renovations or modifications and to determine its ability to carry additional loads. This is generally done by taking cores at representative locations in the structure, to give a good overall indication of the strength. This helps ensure that the concrete meets the required strength and durability standards.

Core testing is therefore introduced in most local and international codes such as British, European and ACI Codes. The core test results should be carefully interpreted taking into account a number influencing factors such as diameter, aspect ratio (l/d), moisture condition of the core specimen, direction of drilling, etc. The factors considered in different standards and codes provisions for interpretation of the core results and influence of above factors are different.

In New Zealand, the technical standards NZS 3112:2 and NZS3109, have detailed how these tests should be carried out and the results analysed. In the New Zealand concrete construction standard NZS3109, the evaluation of core test results is determined by Technical Report No. 11 (TR11) from the UK Concrete Society. However, this document was withdrawn and replaced in the UK by Concrete Advice No. 68 (CA68), which is a summary of BS EN 13791.

In this research, an experimental study was undertaken to examine different factors affecting the interpretation of core test results, in particular comparing the methods described in TR11 and CA68. The experimental program involves four concrete test blocks. In total 24 concrete cores were taken with different length/diameter ratios in vertical and horizontal directions.

The compressive test results obtained from the cores are analysed and the influence of different factors are discussed. The results are evaluated in accordance with TR11 and CA68 codes, to compare and identify possible differences between the two methods in assessment of Concrete In-Situ Strength from core test results.

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Application of +/-45 Degree Bidirectional FRP to Improve Shear Transfer Capacity Across Slab-to-Wall Concrete Connections

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Many structures designed according to outdated code lacks sufficient reinforcement and aggregate interlocking capacity along their connection, which are essential for effective shear transfer. Recognizing the limitations of traditional retrofitting methods such as concrete jacketing and adding steel reinforcement - particularly in configurations with complex joint accessibility- this study explores the application of bidirectional +/-45-degree fiber reinforced polymer (FRP) wrapping at these intersections. Shear transfer capacities of four slab-to-wall connection samples with smooth cold-joint concrete interface models were assessed. These cold-joint interfaces were provided with a bond-breaker. Out of these four samples, three were retrofitted with various layouts of externally bonded glass and carbon FRP, incorporating carbon anchors and one was considered as a benchmark specimen to compare its results with retrofitted model. The experiment involves subjecting a wall to quasi-static loading in the in-plane direction, specifically at the cold joint interface. The finding from this experimental program revealed that the carbon fabric, glass fabric, and carbon anchor retrofitting techniques along the connection can efficiently improve shear transfer capacity from the wall member to slab. Notably, incorporating the carbon anchors outperformed two other retrofit layouts in terms of overall strength gain when compared with benchmark specimen.

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Application to the Danish test of a bond law deduced from a short RC tie

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The analysis of the variations in the steel and concrete stresses obtained from a test on a short RC tie allows the corresponding bond law to be deduced. This avoids passing through the analysis of the experimental data based on pull-out tests, where bond is substantially influenced by the state of stress, deformation and cracking of the concrete. The deduced bond stress - slip diagram clearly shows two distinct branches: a first approximately linear branch in which, starting from the zero slip section, the bond stress and the slip both increase; a second branch in which the bond stress decreases when the slip continues to increase. What happens is not just a local phenomenon and has to be considered as preponderant in service conditions in case of stresses close to the maximum values. Here, the proposed bond law is applied to the case of a Danish test, where two bars of equal lengths, embedded into a concrete prismatic specimen, are put in tension and put end to end. The separation of the two bars permits to eliminate any interaction of forces between them. If one applies the fib bond law as it is, from the ascending distribution of the slip that occurs from the embedded end of the bar to the end of the concrete specimen, an ascending distribution of the bond stress would be obtained. This result is not confirmed if one applies the proposed bond law as the bond stress is null at both ends of each bar.

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Blind simulation competitions on the assessment of the predictive performance of FEM-based approaches for the design of FRC structures

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The fib WP 2.4.1 is a technical committee of the fib organization (https://www.fib-international.org/commissions/com2-analysis-design.html) dedicated to the development of methodologies for the design of fibre reinforced concrete (FRC) structures using computer programs based, mainly, on the finite element method (FEM). For taking advantage of the fiber reinforcement, these computer programs should simulate the relevant fiber resisting mechanisms, mainly the ones that increase the post-cracking tensile capacity of cement-based materials. Several challenges are, however, faced for assuring reliable simulations, namely: 1) the knowledge of the stress-crack opening simulating correctly the post-cracking tensile behavior of the FRC of the structure to be designed; 2) modelling the contribution of fiber reinforcement in structures failing in shear, punching or torsion; 3) level of accuracy of these models on performing the serviceability and ultimate limit state design verifications; 4) guarantee results independent of the refinement of the finite element mesh; 5) design format (characteristic, average or design values for the material properties). To contribute for a proper handling of some of these challenges, the fib WP 2.4.1 has been coordinating a series of blind simulation competitions (BSC), whose relevant objectives and results are described in this work. All the structures of the BSC include steel fibers and conventional steel reinforcements, herein designated by R/SFRC.

Regarding the 1st BSC, despite the provided experimental data for the definition of the relevant model parameters, inac-curacies on the load capacity, deflection and strain at peak load have attained 40%, 113% and 600%, respectively. Furthermore, inadequate failure modes have been estimated, and simulations with the same commercial software have pro-vided very different results. Regarding the 2nd BSC, it was concluded the larger difference in terms of predictive performance of the Lattice Discrete Particle Models and Discrete Crack Models versus smeared crack models and Concrete Damage Plasticity was mainly on the strains in the steel reinforcements and average crack width. The analysis of the results of the 3rd BSC is being executed.

The vison on the use of this information for deriving information useful in the design of R/FRC structures is also provided.

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Comparative Lifecycle Assessment of SFRC and Conventional RC Structural Slabs

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Concrete has a very low tensile strength despite having a high compressive strength. As a result, it is unable to transfer stress independently when loaded, making it brittle. To increase the mechanical and durability features of reinforced concrete structures, a variety of materials, including fibres (made of steel, glass, carbon, and polymer), have been utilised over the years. In certain situations, these fibres have completely replaced conventional steel rebars. Fibres in concrete have proven to enhance its structural and durability performance. However, as a material that presents enhanced performance, its potential to reduce carbon emissions must be analyzed to reflect these advantages. The investigated literature showed that most life cycle assessments of reinforced concrete members with varying material constituents analyzed their environmental impacts based on their physical properties, and this approach does not give a realistic picture of the carbon footprint where alternative materials such as steel fibres with improved performance are utilized.

With a life cycle assessment that considers the structural performance of slabs, this paper compares the whole-life embodied carbon of two-way suspended slabs reinforced with steel fibres and/or conventional steel rebars. Variables included span, concrete strength, and imposed load. A finite element analysis and design were performed for a number of slabs and also assessed for their carbon emissions using a cradle-to-grave approach.

The results from the life cycle assessment were normalised based on the structural functionality of the slabs. This showed that the use of steel fibres can potentially reduce the average area of steel required in a reinforced two-way concrete slab by about 68% and also reduce the whole-life embodied carbon by 32%.

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Conformity Assessment Model for the Supply and Installation of Post-Tensioning Systems in Concrete Structures in Australia and New Zealand

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Conformity Assessment models continue to develop and the need for such models has never been so great in recent years due to the product scandals, structural failures, and collapse of conventional structures. The cost of incidents may well end up far greater than the loss of market for manufacturers. It could take years to repair the damage to reputations and customer trust.

The Australasian certification scheme, developed by CARES for the Supply and Installation of Post-Tensioning (PT) Systems in Concrete Structures, was launched in May 2021. CARES developed its new scheme following an approach from the Post Tensioning Institute of Australasia (PTIA), which represents a significant number of specialist contractors and suppliers locally. As a result of its long-standing relationship with the Australasian Certification Authority for Reinforcing and Structural Steels (ACRS), CARES was able to work closely with a range of stakeholders to develop the post-tensioning scheme for Australia and New Zealand.

The objective of the Scheme is to give confidence to purchasers of post-tensioned concrete structures that products comply with the appropriate specification - without the need to undertake separate verification. It involves the application of quality assurance principles to assess individual supplier's systems and, as appropriate, product testing to ensure their conformity with requirements set out in this Scheme and as appropriate, National or International product standards.

This paper describes a unique, approach to conformity assessment modelling for the entire supply chain from PT kit, duct, grout and strand production to onsite installation of complete PT systems ensuring best practice is adopted.

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Contemporary Design and Construction of Post Tensioned Structures

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Post-tensioned concrete is a terminology heard with increasing frequency in the NZ construction industry. It has been used as a construction method in building structures over the last 50 years. New Zealand has seen significant growth in the use of post-tensioned flooring systems for buildings since the late 1990s, particularly for slab on grade applications. More recently, the benefits of post-tensioning for suspended slab construction have been recognised by consultants and contractors with a number of high rise projects both under construction and in the design phase.

The method of reinforcing concrete with post-tensioning allows designers to take advantage of the benefits provided by prestressed concrete and at the same retaining the flexibility associated with the cast-in-situ concrete. Post-tensioning offers significant flexibility as a construction solution in numerous building types and a limiting factor in its use is a lack of exposure amongst designers and constructors.

This paper provides an introduction to post-tensioning, looks at the key benefits of using post-tensioning and presents examples of post-tensioned floor construction with specific reference to the New Zealand market.

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Cracking Assessment Methodologies for RC Walls Analysis

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Assessing the extent of cracking in Reinforced Concrete (RC) structures, particularly for major members such as structural walls, is critical in the design process. The occurrence of flexural cracking directly influences the effective stiffness of the walls, impacting the structures' computed periods of vibration, lateral deflections, and design seismic demand significantly.

This study evaluates walls' effective stiffness through nonlinear static pushover analysis and compares cracking assessment methodologies and requirements provided by NZS3101 Amd.3[1], ACI 318-19(22)[2], and the latest SESOC interim design guidance [3]. This study aims to provide clarity on conflicting recommendations and their implications for RC walls. The study conducts a series of nonlinear analyses on individual RC walls with different shapes and heights.

The investigation outcomes demonstrate that SESOC's recommendation to apply the effective section properties over the full wall height is inappropriate for RC walls, under-estimates the walls' effective stiffness, and may result in unconservative design demands.

This study emphasizes the need for careful consideration in cracking assessment to ensure the safety and reliability of RC wall structures.

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Design for deconstruction of concrete hollow core slabs, an experimental study.

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Poster Session, Exhibition Hall, November 12, 2024, 12:00 PM - 1:00 PM

For reasons of sustainable construction, it is becoming increasingly important to extend the service life of buildings and, if this is not possible, of the elements that form part of the building. In order to anticipate future deconstruction possibilities, an experimental study was carried out to test different types of joint filling material for longitudinal joints. This contribution focuses on the resistance of the horizontal shear to ensure that the floor acts as a diaphragm. At least as important in achieving the diaphragm effect are, of course, the tie arrangements, which should also be easily removable. In this study, tests have been carried out with three types of weak joint fillings, ranging from an easily removable sand-cement mixture, through an insulating mortar, to a C12/15 concrete quality. A 1.8×3.6 m² floor test area was constructed, loads were applied in alternate directions by three vessels, and at the end, a test specimen was also loaded to failure. Depending on the mechanical properties of the grout, more pronounced deformations and activation of the peripherical tie (through lost and smooth falsework) were observed. The results are compared at a theoretical level with the results of linear elastic finite element analysis, and the dismantling effort is also monitored at a practical level. Finally, design considerations are formulated and knowledge gaps are identified.

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Design of buried arch structures for earthquake effects, to Australian and New Zealand codes

Mr Doug Jenkins

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The design of concrete buried arch structures may be governed by bridge design codes or by the general building codes. In both cases, different codes are applicable in Australia and New Zealand, with different requirements for earthquake related loads, due to the very different seismic conditions in the two countries. The codes are focused on above ground structures and provide little guidance on seismic design of buried structures, and in some cases reference to partially buried structures such as bridge abutments may be misleading.

In this paper the analysis and design of precast concrete buried arches for recent projects in Australia and New Zealand is investigated. Static and response spectrum analyses of the structures are compared with time-history analyses and displacement based design, and the effects of different code requirements on design outcomes are discussed. Recommendations are presented for suitable earthquake design parameters for this class of structures.

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Elimination of Tilts in Multi-Story Buildings Using an Experimental Information-Analytical System and Digital Twins

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In the technological process of the foundation tilts elimination the following measuring transducers and sensors are used to assess the main parameters of the base stress-strain state: an inductive sensor for the continuous control of the strip foundation settlements in the range of up to 500 mm; a measuring inductive transducer for the settlements control conversion into inductance; a local inductive sensor with a measuring transducer for shifts control; an inductive sensor with autonomous operation for the main stresses magnitude and direction control in the strip foundation based on the magnetoelastic effect use; an inductive sensor for the remote control of the magnitude and direction changes in the strip foundation inclination in the range up to the limit value. To monitor the above-mentioned parameters, a structural scheme of their automated control has been developed. The generalized structural diagram includes a unit for the continuous calculation of the soil stress-strain state during the technological process of the foundation tilt elimination in the multi-storey building and a unit for the current managerial commands generation. This allows determining the local soil areas that require managerial influence based, for example, on the technological settlements correction under the strip foundation bottom. During the above-standard tilts elimination in buildings and structures some discrepancies often occur in the values of such actual and predicted parameters as the construction object technological settlement or tilt. Therefore, the additional engineering measures shall be envisaged in the projects, for instance, real-time monitoring, technological methods of settlements control according to the calculation diagram, etc. They must ensure the system predicted and actual deformations equality with tilts at all stages of the building tilt elimination works. The report contains more than 18 examples of successful leveling of the multi-storey buildings in the city of Zaporizhzhia, Ukraine.

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Enhancement of hydration and stabilization of cement clinkers using chemically modified TiB2 nanosheets

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Increasing the proportion of dicalcium silicate (C2S) in Portland cement has proven to be an effective strategy for mitigating the environmental impact of cement production. However, the challenge lies in the relatively insignificant early age strength development of C2S compared to tricalcium silicate (C3S). The addition of stabilizing agents during C2S synthesis has been recognized as a method to enhance its hydration behaviour. A recent focus has emerged on integrating graphene, a pioneering 2D nanomaterial, as a sustainable additive in concrete. Graphene's exceptional mechanical and catalytic properties not only reinforce the composite but also impact the stabilization and hydration behaviour of C2S.

In this study, we explore the potential of a novel class of nanosheets derived from Titanium diboride (TiB2), a 2D material recently discovered by our research group, as cement additives. Our findings indicate that the inclusion of 3% chemically modified TiB2 nanosheets results in ~4 times increment in the formation of the β-C2S polymorph. Isothermal calorimetry analysis of the stabilized C2S demonstrates heightened peak heat and cumulative heat evolution during early age hydration (24 hours), suggesting that TiB2-based nanosheets enhance the rate of C2S hydration. Long-term hydraulic characterization (28 days) further reveals a higher degree of hydration in the nano-modified samples. TiB2 derived nanosheets also enhanced the carbon sequestration efficiency of the dicalcium silicate. Nano-modified C2S showed 3 times more carbon capture than the pure C2S samples.

This unconventional approach, exemplified by TiB2-derived nanosheets, underscores the promising potential of 2D materials in the development of robust cement additives. The unique properties of TiB2 nanosheets offer a rich avenue for innovation in enhancing the performance of cementitious materials.

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Evaluation Method of Shear Capacity at Slab-Web Interface in Hybrid Beam System

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In Japan, keywords such as rational, economical and efficiency, led to a shift from the conventional steel structure to a mixture of reinforced concrete column and steel beam structure (hybrid structure). This was considered ideal to construct large span buildings, such as logistic terminals and shopping malls. However, the detail of the beam column joint was very complicated, and fabrication was time consuming and labor consuming. Moreover, with the fabrication cost of steel soaring and labor shortage on the rise, there is a concerted effort to reduce the construction cost and at the same time increase the productivity.

Therefore, research investigations are being carried out and one of the methods is using an innovative hybrid system where the columns are reinforced concrete and, the beams are hybrid beams. The hybrid beam system consists of a wide flange steel beam in the midspan and, the wide flange steel beam is embedded in the reinforced concrete on both ends. The wide flange steel beam does not penetrate through the beam-column joint which reduces the fabrication cost and saves labor when compared to the typical hybrid structure.

In ordinary construction for the hybrid beam system, concrete is cast for slabs and beams at the same time with the same concrete strength. However, the required concrete strength for slabs is lower than that of beams from the structural behavior viewpoint and designers prefer different strengths for webs and slabs from economical viewpoint. Previous researchers discussed the seismic performance of hybrid beams with monolithic concrete, but no researchers have clarified the shear-slip behavior at the slab-web interface of the hybrid beams. Therefore, hybrid beam specimens with slab-web interface were designed to examine the shear-slip behavior at the slab-web interface and a method to evaluate the interface shear capacity was proposed in this paper.

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Evaluation of areal corrosion rate distribution for reinforced concrete plane members using non-invasive polarization resistance method

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In the investigation on soundness of existing reinforced concrete structures, it is necessary to efficiently select locations where destructive tests such as coring are to be performed on large concrete surfaces, i.e., locations where corrosion is significant. For this purpose, the use of nondestructive testing methods is important. Therefore, the purpose of this study was to evaluate the areal corrosion rate distribution. We prepared flat members that had been damaged beforehand and then subjected to salt spray to accelerate corrosion. The nondestructive polarization resistance method, which we have already developed, was applied to a number of locations. This method can evaluate the corrosion rate by measuring impedance using electrodes placed on the surface. On the other hand, one specimen was dismantled to determine the actual presence and extent of corrosion. As a result, the corrosion rate evaluated by the nondestructive methods were consistent with the actual amount of corrosion. Therefore, this experiment revealed that the proposed method is applicable to areal corrosion assessment. In addition, it was found that the corrosion rate was not the highest at the point where cracks were introduced, and that the corrosion rate could be reduced by repairing the cracks.

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Evaluation of Building Height Effect on RC Wall Systems' Response

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Reinforced Concrete (RC) walls are one of the popular structural lateral load-resisting systems that are widely used in major cities worldwide. While the structural walls have demonstrated satisfactory seismic performance in low to medium-rise structures, the appropriateness of their use in tall buildings in NZ under major seismic loads has yet to be tested. The American design load standard, ASCE 7-22 [1] imposes strict criteria on RC shear wall systems in buildings with high seismic design categories, by restricting their height. In contrast, NZ standards, notably NZS1170.5[2] and NZS3101 Amd3 [3] do not have any height limitations. This raises the question of whether building height influences the behavior and ductility of wall structures, an aspect that has not been considered by NZ Standards. This study aims to look into this matter by analyzing the impact of shear wall height on buildings' response through a series of nonlinear static pushover analyses (NSP) and assessing their seismic performance as per the TGEA [4] approach. This research demonstrated that, although the results of the NSP analyses and the TGEA assessment are consistent, their achieved ductility is significantly lower than the maximum available ductility recommended by NZS3101. The findings revealed that increasing the height of the walls leads to a linear increase in the achieved ductility, which contradicts the height restrictions established by ASCE7-22. The investigation also identified a significant disparity between the calculated drift capacity of the wall buildings using the TGEA/NSP approaches and the maximum allowable drift specified by NZS1170.5 and ASCE41-17[9].
The study underscores the critical importance of comparing New Zealand standards with each other and with international good practices to ensure compatibility, structural safety, and seismic resilience in building design.

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Experimental study on mechanical properties of reinforced concrete transfer beam with openings

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The reinforced concrete transfer beam with web openings is one of the effective ways to decrease the self-weight and lay the pipeline and equipment. To study the mechanical behavior of this transfer beam, a 1/4 scale static test of the reinforced concrete transfer beam with web openings under vertical load was carried out. The crack process, failure mode, deformation and ductility were studied. The results show that the transfer beam with web openings exhibited bending failure. The longitudinal bars at the bottom of the beam yielded and the concrete at the top of the beam was crushed. The ductility coefficient was 3.54. The transfer beam showed a good integrity and ductility.

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Experimental Study on the Anchorage Designs' Influence on the Shear Capacity of Looped Wire Rope Connections between Perpendicular Wall-Elements

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The so-called looped wire rope connection is increasingly used as connection between precast concrete wall elements due to its benefits in the installation process.

When concrete wall elements are placed perpendicular to each other, i.e. in corners, there exist no experimental evidence of the shear capacity of loop wire rope connections. Here, the practical approach is to place the wire ropes similar to wire ropes in connections between wall elements in the same plane and assume similar shear capacity. However, this approach requires the wire rope to be bent in the wall element and may affect both the failure mechanism and the shear capacity. Hence the authors have start-ed a process of experimental investigations on the anchorage (tensile) capacity of a single looped wire rope that is bent in the anchorage zone. These experiments represent a situation where a looped wire rope is pulled out of the side of a wall element, and the influence of the anchorage conditions and failure mechanisms are investigated. Further studies on the shear capacity of the entire perpendicularly placed looped wire rope connections will provide a better understanding of the failure mechanism and clarify the influence of the anchoring conditions. Therefore, this paper presents an extensive experimental programme on the shear capacity of looped wire rope connections between perpendicular-placed wall elements. The programme varies the distance from the end of the wall element, such that both L- and T-connections are tested. The experimental programme investigates the influence of the anchorage design of the looped wire ropes by varying the reinforcement in the anchorage zone and the direction of the shear forces in relation to the bent direction (negative or positive). In addition, failure mechanisms, crack widths and wire forces are studied with digital image correlation.

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Fire Performance of Hybrid Fiber Reinforced Self-Consolidating Concrete with Recycled Ground Glass Pozzolan

Dr Nur Yazdani

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Fiber hybridization is an emerging technology where concrete is reinforced using macro and micro-fibers. The former imparts mechanical strength while the latter provides fire protection and minimizes early and late age cracking. The current study investigated the fire performance of hybrid fiber reinforced self-consolidating concrete (HFRSCC) blended with steel and polypropylene fibers. The research also investigated recycled glass pozzolan as a partial cement replacement option to limit cement usage and reducing the carbon footprint. The combination of self-consolidating concrete (SCC) with hybrid fibers and glass pozzolan has not been explored previously. Thus, the current research attempted to bridge this knowledge gap by conducting pre-, during- and post-fire investigations on smalls beams and cylinders made with HFRSCC. It was found that mixes with hybrid fibers resulted in higher residual splitting tensile and flexural strength than the control mix with no fibers. The combination of steel and polypropylene fibers in the concrete mix successfully mitigated fire-induced explosive spalling and enhanced ductility but reduced the workability of fresh concrete. Mixes with recycled ground glass pozzolan experienced significant fire damage and reduction in strength since glass pozzolan acted as a thermal conductor.

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First application of use of prestressed CFRP lamellas to strengthen roof slab of building in Slovakia

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Currently, it is very important to use Green solutions in the civil engineering and building industry. It means using new types of materials and new technologies that reduce the carbon footprint, reduce CO2 (decarbonation) and reduce the amount of waste.

One of such modern materials and technologies is the use of CFRP lamellas for strengthening existing reinforced concrete (RC) structures. In many cases, however, it is not enough to just glue the lamellas, as is already often used in practice, but it is also necessary to prestressed them in order to use them more and better efficiency. The use of prestressed CFRP lamellas is not yet so widespread in the world. This article will present the first application of strengthening the roof beam-slab structure of a building (family house) not only in Slovakia, but probably also in Central Europe. It is a building with dimensions of 15.0 x 11.8 m without internal load-bearing walls or columns. One edge side is considered to be completely glazed (non-load-bearing), above which is a load-bearing reinforced concrete (RC) beam supported at the edges on RC walls and in the middle it is supported by a steel column (2-span beam). During the building realization, there was a request to remove this column. It meant changing the static scheme of the beam from a two-span beam to a simple supported beam. For this reason, it was necessary to strengthen the RC beam to transfer the entire load up to the edges into the RC walls. The use of prestressed CFRP lamellas proved to be the most advantageous, since this solution does not take up much space under the slab and the edge steel deviators are not so massive.

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Fracture Mechanism Evaluation of Lap Splice under Tension Utilizing 3D-RBSM

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This study aims to elucidate load-bearing mechanisms and fracture mechanisms of lap splices under tension. Three-Dimensional Rigid Body Spring Method, 3D-RBSM, a discrete analytical model, was employed to assess crack propagation and stress distribution in lap splices. Concrete specimens were represented as rigid bodies with a random Voronoi mesh, and steel bars were modeled using a series of beam elements. The interaction between concrete and steel bars was incorporated using springs with bond stress-slip relations. The bond stress-slip model proposed by Usman et al. [1] was adopted to quantitatively simulate bond behavior without precise modeling of the steel bars' geometry.

Simulations were conducted on the concrete specimens having two-lap splices. The tensile loads were applied at the end of the steel bars. Influences of splice length, clear space, and lateral rebars on the splice strength were evaluated focusing on internal cracks and stress distribution of concrete.

As a result, the bearing mechanisms were visibly revealed; compressive stresses, such as struts, appeared between splice bars, and they bore against the tensile forces. And, it was confirmed that the strength of the lap splice depended on the magnitude of the stress in those struts and their distribution. Fractures in the lap splice occurred due to crack propagation from rebars to the concrete surface. Lateral rebars could prevent those cracks from opening rapidly and confine the concrete, leading to an increase in the strut strength, that is, the bearing capacity of lap splices.

References

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Implementation of a Low Carbon Approach For Hydraulic Concretes

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Poster Session, Exhibition Hall, November 12, 2024, 12:00 PM - 1:00 PM

The CIH (Centre d'Ingénierie Hydraulique / Hydraulic Engineering Center) is one of the EDF Group's integrated engineering centers. We design projects and supervise construction works in the hydropower field.

For the past two years, the CIH has been working on the integration of eco-design principles into its projects with one clear objective, to "Work on our materials and projects to reduce their environmental footprint and preserve natural resources".

This article illustrates how an engineering center of a large company operating in the energy sector (specifically in hydropower) can understand, organize and develop a low carbon strategy. The focus of this article will be on concrete.

We will recall the specificities of concrete used in hydraulic constructions compared to the one used in other, more common structures.

We will detail the life cycle analyses carried out on our recent construction projects and highlight the reduction of impact which can be expected from concrete.
Next, we will summarize our roadmap to reduce the impacts of concrete in the hydraulic sector:

- In the short term: the removal of metal reinforcement (rebar) in massive structures and their replacement by fibre-reinforced concrete,
- In the medium-term: the qualification of low carbon concrete to chemical and environmental aggressions specific to the field of hydraulics,

Lastly, we will develop the practical actions implemented on an ongoing project:

- During the design phase, the structural optimization exercise to minimize GHG (Greenhouse Gas Emissions).
- During the drafting of the tender, solutions to encourage companies to reduce the environmental footprint of construction: GHG emission thresholds in tender documents, technical and economic criteria to take into account efforts in the low carbon field, bonuses and penalties.

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Incremental sequentially linear analysis to trace post-peak snap-backs for concrete

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Poster Session, Exhibition Hall, November 12, 2024, 12:00 PM - 1:00 PM

The Newton-Raphson method (N-R) has been widely used in nonlinear FEM analysis of quasi brittle materials, such as masonry, concrete and reinforced and prestressed concrete. However, the robustness of the N-R method is still a serious issue when bifurcation, snap-back or divergence problems arise. In order to enhance the robustness of solving non-linear problems, incremental sequentially linear analysis (ISLA) has been proposed, which is based on a combination of the N-R method and SLA. The solution search path follows damage cycles sequentially with secant stiffness corresponding to local damage increments, which traces both damage history (explicit) and displacement history (implicit). The objective of this paper is to demonstrate that ISLA can robustly trace post-peak behavior of concrete, especially for snap-backs. A concrete beam was analyzed for a four-point bending test. Stable post-peak results were computed for snap-backs, and localized crack propagation was computed robustly and correctly.

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Innovative structural instrumentation solutions for the monitoring of remote New Zealand civil infrastructure

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Poster Session, Exhibition Hall, November 12, 2024, 12:00 PM - 1:00 PM

New Zealand's aging concrete infrastructure, challenges asset owners to monitor, maintain, repair and strengthen existing structures to meet the constant need for service life and/or load capacity increases. The inherent seismic risk present in New Zealand combined with aging infrastructure, escalating infrastructure cost, the increasing frequency of extreme weather events due to climate change and the concentration of the infrastructure near the coastline and rivers requires sophisticated approaches in structural monitoring. To manage this complex environment, while attempting to extend the life of the asset, minimize loss of service or prevent sudden failure of infrastructure there is a need to understand the performance of the asset. This calls for innovative design, maintenance and repair methodologies that need to be informed by the best possible asset performance data. WSP have applied advanced monitoring techniques to a range of infrastructure assets which has led to changes in design and maintenance processes and procedures, and more informed investment decisions as accurate and reliable data validates theoretical modelling techniques. The paper will explore the latest monitoring technologies and how these have been applied to infrastructure around New Zealand. This will include a case study on an approach for a structure that was viewed as being beyond design life and capacity and was required to accommodate heavier loading. A further case study looks at a transport corridor severely affected by cyclone damage and how instrumentation has informed the repair process from both a construction and health and safety perspective.

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Mass transport properties of recycled aggregate concrete under the coupling effect of chloride ion erosion and freeze-thaw cycles

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Poster Session, Exhibition Hall, November 12, 2024, 12:00 PM - 1:00 PM

In cold coastal regions, reinforced concrete structures are commonly subjected to the synergistic effects of chloride salt erosion and freeze-thaw cycles, leading to decreased concrete strength and accelerated corrosion of reinforcement bars. In this study, the effects of different recycled coarse aggregate (RCA) replacement rates (0%, 50%, and 100%), namely R0, R50, and R100, and the number of freeze-thaw cycles, including water freeze-thaw (WFT) cycles and salty freeze-thaw (SFT) cycles, on the capillary water absorption and chloride ion content in concrete were assessed. The experimental results indicated that the coupling action of chloride ion erosion and frost damage significantly affect the mass transport properties of concrete. Notably, both the initial sorptivity and the chloride ion concrete of concrete increased with higher RCA replacement rates. Specifically, before the freeze-thaw cycles, the concentrations of free chloride ion at a 2mm depth from the surface in R100 and R50 were 54.5% and 218.2% higher, respectively, that in R0. Moreover, after SFT cycles, both the amount of water absorption and the initial sorptivity of recycled aggregate concrete (RAC) were significantly higher than those observed following WFT cycles. For instance, after 55 WFT cycles, the initial sorptivity for R0, R50, and R100 were 0.965, 1.160, and 1.855 (×10^-3 m/h^0.5), respectively. Under 55 SFT cycles, the initial sorptivity for R0, R50, and R100 increased to 1.099, 2.273, and 2.808 (×10^-3 m/h^0.5), representing increases of 13.9%, 95.9%, and 51.4% compared to undergoing 55 WFT cycles. The investigated the mass transport properties of RAC under the combined effects of chloride ion erosion and freeze-thaw cycles, provider valuable data for predicting the service life of RAC in harsh environments.

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Maximum Foreseeable Loss Assessment of Bridge Assets in Eastern Canada

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Poster Session, Exhibition Hall, November 12, 2024, 12:00 PM - 1:00 PM

Route 1 Highway is located in the Eastern part of Canada, in the province of New Brunswick. The assets under consideration, distributed over a total of about 240km, include bridges, retaining walls, overhead signs, pavements, and drainage. This paper presents the methodology adopted for the evaluation of the Maximum Foreseeable Loss (or MFL) in case of a seismic event affecting the region. The 2475-year return period Peak Ground Acceleration (PGA) at firm ground from the 5th generation seismic hazard in the 2019 edition of the Canadian Highway Bridge Design Code (CHBDC) is used as a ground motion intensity indicator, and the extent of structural damage is related to the PGA. The estimated MFL is then identified on a probabilistic basis, in accordance with the procedure endorsed by FEMA (Mander and Basöz, 1999; HAZUS, 2003. For a given hazard level at the site, indicated through the PGA, the probability of damage is obtained and multiplied by the Repair Cost Ratio (RCR, repair cost as fraction of replacement value). The process is repeated to cover the potential for none, minor, moderate, major damage and collapse, and these contributions summed to obtain the cumulative repair cost for the asset. A lower probability of damage is attributed to bridges constructed from 2010 onwards, as comprehensive seismic design provisions were implemented in the 2006 edition of CHBDC. The repair cost estimate obtained for each bridge along the monitored segments reveals a concentration of damage/costs in proximity of larger PGA demands, and complex/older bridges. The seismic induced damage and repair/restoration cost associated to retaining walls, overhead signs, drainage and pavement, is evaluated on the basis of the real data recorded in previous major events, such as Loma Prieta (1989) and Northridge (1994), as provided in the MCEER report (MCEER, 2008). The loss assessment resulted in an estimated MFL in the order of 3-6% of the total replacement cost of the assets.

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Numerical study on assembled monolithic subway station sidewall joints with pre-grouted section steel insertion

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Poster Session, Exhibition Hall, November 12, 2024, 12:00 PM - 1:00 PM

Pre-grouted section steel insertion connection is a new assembly method for the sidewall joints of prefabricated subway stations. It has advantages such as convenient construction and easy control of engineering quality, making it suitable for large-diameter and densely reinforced structures. Currently, there is limited research on this type of sidewall joints. In order to investigate the influence of concrete strength, the haunch height, axial compression ratio, and the connection zone height on the mechanical performance of this joint, a nonlinear finite element (FE) analysis model was established using ABAQUS software. Static behavior analyses were conducted separately on nine sidewall joints with pre-grouted section steel insertion in both positive and negative directions. The results indicate that the failure mode of all nine joints is bending failure at the end of the side wall. As the haunch height, concrete strength, and axial compression ratio of the joints increase, the bearing capacity also increases, but ductility decreases. As the connection zone height of the joints decreases, the bearing capacity increases, and reverse ductility improves.

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Propagation of Errors in Post-crack Performance Assessment of FRC Using the ASTM C1609/C1609M Beam Test

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Poster Session, Exhibition Hall, November 12, 2024, 12:00 PM - 1:00 PM

The post-crack performance of Fibre Reinforced Concrete (FRC) is commonly determined using beam tests such as ASTM C1609/C1609M. Experience has demonstrated that within-batch variability in post-crack performance measured for FRC using this test can be very high. This has led to concerns over the reliability of results both for research and Quality Control purposes. The current investigation has examined variability in the performance of ASTM C1609/C1609M beam specimens and the relationship and inter-dependency between the magnitude of uncertainty in each parameter that affects the overall uncertainty in test results. This has been undertaken using a variance-covariance analysis based on a deterministic functional model of specimen behaviour.

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Properties of concrete containing graphite at high temperatures for thermal energy storage

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Poster Session, Exhibition Hall, November 12, 2024, 12:00 PM - 1:00 PM

An experimental study on the thermal properties and heat transfer characteristics of concrete under high-temperature conditions was conducted for application in the heat transfer medium of thermal energy storage. For efficient thermal energy storage, compared with conventional concrete, graphite with high thermal conductivity was used as a binder and the thermal properties of the concrete subjected to different graphite contents at room temperature and high-temperature of 450 ℃ were investigated. When just one thermal cycle with high-temperature of 450 ℃ was applied, the unit weight and thermal conductivity of concrete significantly decreased and they are almost constant after applying the second thermal cycle. The thermal conductivity of concrete with graphite was 22% greater than that of conventional concrete.

In addition, concrete blocks through which heat transfer fluid was flowed was manufactured and heat transfer performance test of the blocks was measured at different graphite contents. Temperature distributions and thermal energy of each concrete block were analyzed for thermal cycles at elevated temperature. The temperature of the concrete block increased when graphite contents increased. The thermal energy of the concrete block with a graphite content of 10% was highest compared with conventional concrete.

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Seismic behavior of masonry buildings with or without rigid reinforced concrete floor diaphragms

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Poster Session, Exhibition Hall, November 12, 2024, 12:00 PM - 1:00 PM

A severe earthquake hit Zagreb, Croatia, on the March 22, 2020 (ML = 5.5, epicenter 7 km north of the city center) which caused significant damage to the built environment. In historical center of the city, unreinforced masonry structures prevail. Majority of those structures date from the end of 19th and the beginning of 20th century. Structurally, buildings are made primarily of brick masonry and lime mortar with floors made of timber beams and planks. This means that floor diaphragms are flexible compared to the vertical load resisting system. The rest of masonry buildings which had some reinforced concrete elements (tie beams and columns), or rigid reinforced concrete diaphragms suffered much less damage. Seismic behavior of the structure depends significantly on the rigidity of a diaphragm. The aim of this paper is the analysis of typical masonry building in Zagreb city center with either flexible timber floor diaphragm or rigid reinforced concrete floor diaphragm. The numerical models of buildings are developed and analyzed in 3Muri software, and the main results are presented in the paper. Mode shapes of the structure change with the rigidity of the diaphragm. Also, design of reinforced concrete floor diaphragm is analyzed and discussed since that is often neglected in retrofitting projects but may be significant if plan shape of the building is irregular. Connection of diaphragm with the vertical wall elements needs to be adequately calculated and built for the assumption of rigid diaphragm to be valid. Usual connection details used in retrofitting are presented and comments are made on the possible problems that may arise when implementing such details. Since details of connection and the shape of the floor plan significantly influence the behavior of the structure and are usually neglected, a discussion is presented on the possible errors or problems that may arise.

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Seismic Capacities of Prestressed Concrete Beam with Circular Openings

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Poster Session, Exhibition Hall, November 12, 2024, 12:00 PM - 1:00 PM

Prestressed concrete (PC) buildings often have circular openings in the beams for equipment when building heights is restricted. The current PC codes of the Architectural Institute of Japan (AIJ) indicate that circular openings should be regarded as rectangular openings. And the beam with opening shear design should be carried out as the assumed feeler-dieel beams of above and below. The strength of PC beam with opening is calculated by the sum of above and below beams strength. On the other hand, shear design of reinforced concrete (RC) beams with circular openings is considering diagonal rebars and transverse rebars near openings. There is a strong demand that PC beams with circular openings could be able to be designed and evaluated with diagonal and transverse rebars in the same way as RC beams.

Therefore, shear tests were carried out on a total of half-scaled 27 specimens of unbonded and bonded PC beams with circular openings, focusing mainly on shear strength verification. All specimens were designed as shear failure prior to bending failure.
The shear crack initiation load around the openings tended to be bigger than that of RC opening beams due to the effect of prestressing forces, and the maximum shear strength was also higher. The diagonal rebars and the transverse rebars near openings were found to be generally effective for shear resisting from their attached strain gage value.

The long-term shear strength and ultimate shear strength used in the structural design are investigated. Shear crack strength and shear strength are evaluated by the effect of prestressing force, using an evaluation equation in which 10% of the axial force was added to the shear strength of existed RC beams evaluation formula, and the experimental results are corresponded well. This trend is the same for both unbonded and bonded PC specimens.

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The Influence of Concrete Modulus of Elasticity on Integral Bridge Behaviour

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Poster Session, Exhibition Hall, November 12, 2024, 12:00 PM - 1:00 PM

Integral bridges are defined as a single-span, or continuous multiple span bridge structures which are constructed without moveable transverse deck joints at the piers or abutments. Any deck deformation is therefore transferred to the sub-structure, and visa-versa. Deformation in the sub or superstructure could result from concrete shrinkage, concrete creep, deck temperature changes, deflection from dead or live loads, as well as lateral earth pressure. The two most important properties governing the deformation magnitude, other than the load, are the structure stiffness (i.e. moment of inertia) and the material stiffness (i.e. modulus of elasticity).

Reinforced concrete integral bridges are typically constructed with concrete made with locally sourced aggregate. Aggregate type can significantly influence the magnitude of the concrete modulus of elasticity (E value). For the same mix design, concrete made with Andesite aggregate can have an E value approximately 30% high that concrete made with Granite aggregate. This variability of E value would affect the deformation of an integral bridge and thus should be considered at design stage if possible. In this paper the influence of concrete modulus of elasticity on the behaviour of integral bridges will be investigated.

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Victoria Bridge Strengthening and Refurbishment

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Poster Session, Exhibition Hall, November 12, 2024, 12:00 PM - 1:00 PM

The Victoria Bridge has been a key crossing of the Brisbane River for public transport, private vehicles and pedestrians/cyclists since its opening in 1969. As part of the Brisbane Metro project, the structure was closed to general traffic in January 2021 to prioritise public and active transport by increasing the busway corridor and adding a dedicated cycleway to the bridge.

In order to accommodate the expanded busway and the increased vehicle mass from the electric vehicles, the 50-year-old post-tensioned precast box-girder bridge was assessed for strength and was found to have flexural and shear deficiencies in isolated locations on the approach spans as well as local weaknesses at the halving joints at mid-span.

The bridge structure presented numerous constraints including a dense array of utility services housed within the bridge, the presence of previous bridge modifications, maintaining traffic on the structure for the duration of the works and an aesthetic requirement to maintain is current elegant appearance within its prominent inner-city location. A unique strengthening design was developed which recognised these constraints while ensuring constructable detailing of the works.

The strengthening design developed incorporates flexural strengthening using external post-tensioning directly fixed to the webs of the bridge using an ultra-high-performance fibre-reinforced concrete (UHPFCR) blister. Shear strengthening of box-girder webs using prestressed hot-rolled bars was also designed along with a carbon fibre reinforced polymer (CFRP) strengthening solution at the half joints. The works also utilise near surface mounted (NSM) stainless steel reinforcement to provide additional strength where thickening of sections is not possible.

This paper provides an overview of the bridge refurbishment along with the key areas of the strengthening works. It also describes how the design and detailing was carefully planned in order to ensure effectiveness while minimising the risk of damage during installation.