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Austroads Guideline to Bridge Assessment: Back to the future

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Abstract

This paper outlines the philosophy and engineering principles underpinning the new Austroads *Guideline to Bridge Assessment*, due to be published in the second half of 2025. Devotees of engineering history will observe that the fundamental engineering principles contained within the Guideline have not changed since Roman times. While our understanding of uncertainties has improved over time, the approach to understanding and managing uncertainties has not. Since engineers are designing and managing structures in the physical environment, using materials with variable properties to carry future unknown loads, and using mathematical models to describe complex structures, uncertainties will always be present.

The focus of bridge assessment in the context of the Guideline, is the management of access to bridges by heavy vehicles. The distinct roles of the road agency and assessor are set out in the Guideline. While an assessor is typically focussed on analysis and calculations, the road agency must consider other issues being managed by the road agency. The Guideline will assist assessors to prepare more reliable bridge assessments and road agencies to understand and manage risk, so encouraging better decision making.

The Guideline adopts risk-informed decision-making as outlined in AS 5104:2017, *General principles on reliability for structures*, as its basis for bridge assessment. While the Guideline utilises much of AS 5100:2017, *Bridge design*, which is familiar to engineers, the standard is unsuitable for bridge assessment due to its design focus and restrictions due to its format as an Australian Standard. Risk-informed decision making provides a richer basis for engineers to understand and manage bridges.

The paper will inform bridge asset owners and assessors about what to expect in the new Guideline and why it is so different to what they may currently be familiar with, despite the timeless underpinning principles.

Keywords: bridge, assessment, reliability, risk, asset

1. Introduction

The Austroads *Guideline to Bridge Assessment* (Guideline) is expected to be published around October this year (2025) and represents the culmination of a four-year program to develop the Guideline. The Guideline has been prepared in response to a need identified by road agencies receiving conservative and sometimes misleading bridge assessments about the capabilities of bridges to carry heavy vehicle loads. At the time of writing, the draft *Guideline to Bridge Assessment* was under review by Austroads.

The Guideline adopts AS 5104:2017[1], *General principles on reliability of structures*, as its basis. The Australian Standard has been reproduced from ISO 2394:2015 and as such, represents an international perspective on structural reliability. The Guideline also draws on USA, Canadian and European practice, which are based on the same principles for structural reliability. This paper outlines the adoption of AS 5104: 2017 in the Guideline and its relationship to AS 5100:2017[2]. While some engineers may view the approach outlined in the Guideline as novel and a departure from practice in Australia and New Zealand, the paper discusses the historical context to show that the approach is not new but is what good engineers have always done for centuries.

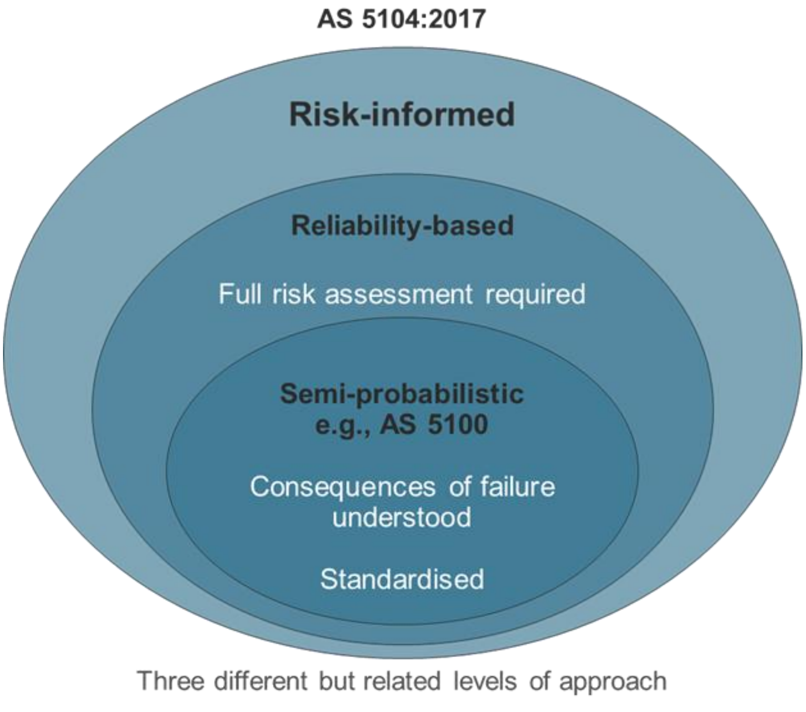
2. Risk-informed decision making

The Guideline has adopted three forms of decision making approaches, namely:

- risk-informed
- reliability-based
- semi-probabilistic

While each approach may be applied independently for design or assessment, they are related as shown in Figure 1.

Figure 1 AS 5104:2017 decision making approaches.



Source: Draft Guideline to Bridge Assessment – Figure 2.1.

The reliability-based approach may be applied after a full risk assessment has been undertaken and the consequences of failure are well understood and in normal ranges. The semi-probabilistic approach, which is the approach embodied in AS 5100:2017, may be adopted when the consequences of failure are well understood, and failure modes can be categorised in a standardised manner. All three approaches relate to decision making and not just the calculation of a rating factor or assessment ratio. Reliability-based and semi-probabilistic decision making must meet the requirements for risk-informed decision making.

Risk-informed decision making considers all the consequences associated with decision making including:

- safety
- economic benefits
- societal benefits
- costs and/or benefits to the environment
- sustainability
- financial implications.

Therefore, the risk-informed approach provides a richer basis for decision making for structures over their life cycles. An important consideration is the robustness of structures and the consequences of their failure. Setting of nominal failure probabilities is based on component failure rather than systems failure. Consequently, the risk-informed approach requires investigation of many scenarios and determining the consequences of component failure. Where collapse occurs following a component failure, a lower target probability of failure is needed. Where there are alternative load paths and sufficient warning is provided, higher target probabilities of failure may be acceptable.

Clause 7.5 of AS 5104:2017 states:

> *'Risk-informed decision making can be applied directly as basis for decisions concerning structures throughout their entire life cycle; however, it can also be applied for the purpose of setting maximum acceptable nominal failure probabilities for structures and thereby support reliability-based approaches, as well the formulation and regulation of semi-probabilistic safety formats.'*

The Guideline does not seek to apply risk-informed decision making directly but has adopted it for the purpose of setting maximum acceptable nominal failure probabilities for reliability-based methods and to calibrate the semi-probabilistic approach.

It should be noted that decision making is the responsibility of the road agency, and that assessors may undertake assessments and investigations to assist road agencies in their decision making.

3. Reliability-based and semi-probabilistic approaches

Clause 2.1.8 of AS 5104 defines reliability as:

> *'ability of a structure or structural member to fulfil the specified requirements, during the working life, for which it has been designed.*
>
> *Note 1 to entry: Reliability is often expressed in terms of probability.*
>
> *Note 2 to entry: Reliability covers safety, serviceability, and durability of a structure.'*

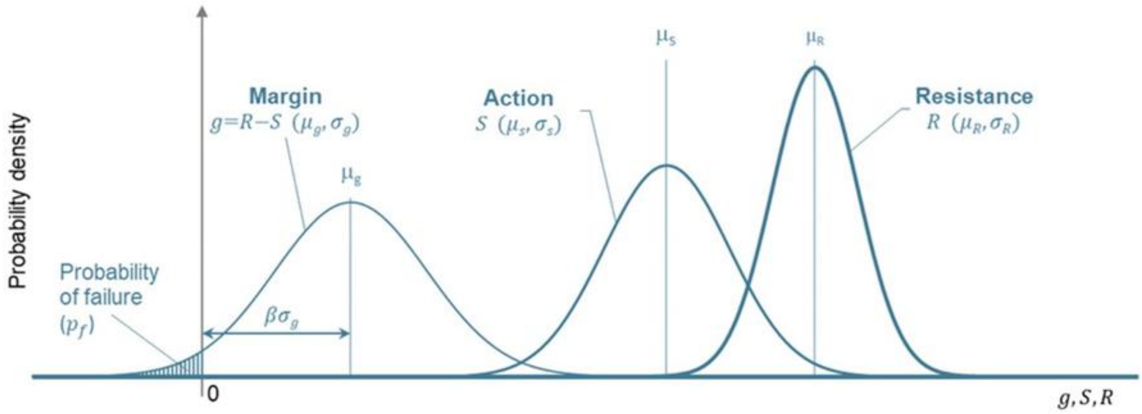
Although this section focusses on reliability in terms of probability of failure, the general definition above, which is similar to the common English definition, should be borne in mind. In other words, the aim of reliability-based decision making should be, how reliable is the structure at meeting the required objectives over its lifetime?

The structural engineer is faced with the problem of managing many uncertainties including:

- uncertainties in loading conditions
- variabilities in material properties
- uncertainty in section properties (dimensions and so on)
- uncertainties associated with modelling real structures.

These uncertainties are described using probability density functions, means and standard deviations usually. These can be aggregated to obtain statistical distributions for actions and resistances as shown in Figure 2. The margin is defined as the difference between the resistance and the action. The area under the distribution where the margin is less than zero is the probability of failure. As the difference between the resistance and the action increases, the distribution of the margin moves to the right and the probability of failure reduces.

Figure 2 Probability distribution functions for reliability-based approach.



Source: Draft Guideline to Bridge Assessment – Figure 5.2.

The probability of failure can also be represented by the reliability index, β, as determined using Equation 1. If the resistance and the action were normally distributed, the mean of the margin would be located β times the standard deviation of the margin from the origin. Hence, the larger the value of the reliability index, the smaller the probability of failure.

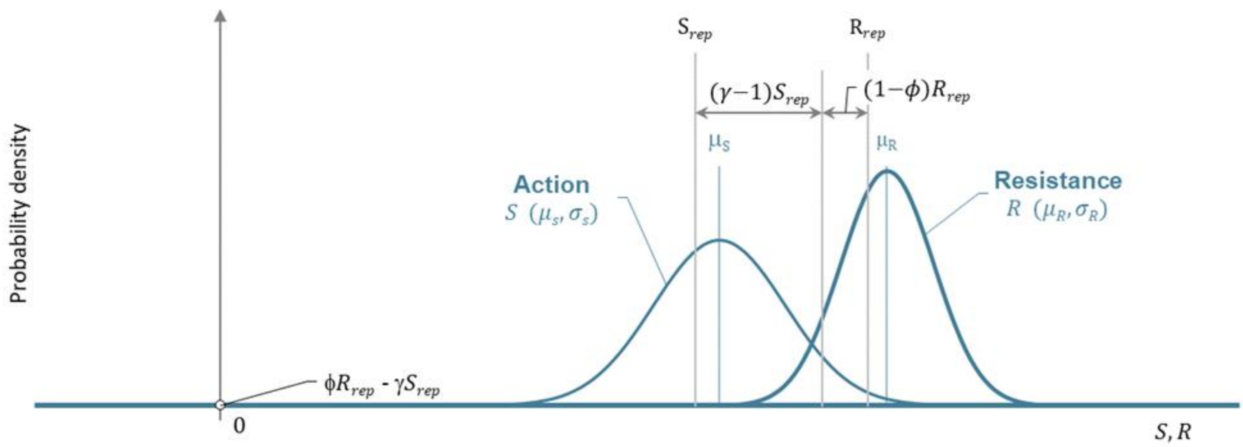
$$\beta = -\Phi^{-1}(p_f) \qquad 1$$

where

β	=	reliability index
Φ^{-1}	=	inverse standard normal probability distribution function
p_f	=	probability of failure

Figure 3 shows the probability distributions in Figure 2, redrawn to show the semi-probabilistic approach.

Figure 3 Semi-probabilistic approach.



Source: Draft Guideline to Bridge Assessment – Figure 5.11.

If the distributions for the resistance and action were to be represented by R_{rep} and S_{rep} respectively as shown in Figure 3, the separation of the two, or margin, could be represented by $(1-\phi)R_{rep} + (\gamma-1)S_{rep}$ where γ is the combined action factor (load) and ϕ is the combined capacity reduction factor. These factors may be chosen so that $\phi R_{rep} - \gamma S_{rep} = 0$ when the margin represents the desired probability of failure or reliability index. The formulation using factors is the basis of the semi-probabilistic method which underpins AS 5100:2017.

The semi-probabilistic decision making approach is calibrated with the reliability-based approach to achieve the same decision making outcome. That is, if the semi-probabilistic approach has been properly calibrated, assessing a bridge using this approach should result in the same outcome as applying the reliability-based approach directly. In reality, calibration is not uniform and some differences will be encountered when applying both methods to a particular bridge.

The reliability-based and semi-probabilistic approaches can be linked to a risk assessment through a target reliability index. Where risks are determined to be high, a high reliability index and hence a higher margin can be adopted. The reverse is true if risks are low consistent with the road agency's risk appetite. Bases on which the target reliability index may be determined are set out in Annex G of AS 5104:2017.

4. Implementation of risk in the guideline

The Guideline adopts the semi-probabilistic decision making approach as its main focus because it will be familiar to most engineers in Australia and New Zealand and is consistent with AS 5100:2017. To meet the requirements for risk-informed decision making, the Guideline requires a risk assessment to be undertaken. The consequence classes set out in Table 1 are adapted from Table F.1 in AS 5104:2017 and are based on the consequences to the community should the bridge fail or collapse.

As well as the consequence class other matters the road agency should consider include but are not limited to:

- potential fatalities and/or harm to people as a consequence of failure
- importance of the structure in the network
- resilience of network
- public aversion to failure
- potential economic benefits
- potential economic consequences of failure
- potential environmental consequences of failure
- potential sustainability benefits
- structural robustness including redundancy and ductility
- post-elastic structural behaviour and advance warning signs of failure (component failure versus system failure)
- ability of the inspection programme and asset management system to identify and track signs of potential failure
- evidence of satisfactory past performance
- risk appetite of road agency
- costs to reduce risks and uncertainties
- evidence of the impact of compliance and/or quality control on reducing uncertainties.

As a result of the risk assessment, the road agency should have an understanding for how much margin should be needed for the structure. Table 2 provides guidance on selecting an appropriate target reliability index (margin) for the risk profile determined from the risk assessment.

Table 1 Consequence classes

Consequences Class	Description of expected consequences
Class 2	Material damages and functionality losses of significance for owners and operators but with little or no societal impact. Damages to the qualities of the environment of an order which can be restored completely in a matter of weeks. Expected number of fatalities and/or serious injuries fewer than 5. Minor bridges may be considered in this class.
Class 3	Material losses and functionality losses of societal significance, causing regional disruptions and delays in important societal services over several weeks. Damages to the qualities of the environment limited to the surroundings of the failure event and which can be restored in a matter of weeks. Expected number of fatalities and serious injuries fewer than 50. Typical bridges may be in this class.
Class 4	Disastrous events causing severe losses of societal services and disruptions and delays at national scale over periods in the order of months. Significant damages to the qualities of the environment contained at national scale but spreading significantly beyond the surroundings of the failure event and which can only be partly restored in a matter of months. Expected number of fatalities and serious injuries fewer than 500. Major bridges usually fall into this class.

Note: Adapted from Table F.1 in AS 5104:2017

Table 2 ULS annual target reliability indices and risk profiles

Annual Target Reliability	Annual Probability of Failure (approx.)	Risk Profile
3.0	1.4×10^{-3} (1 in 740)	Class 2 structures where costs of safety measures are large. Robust structures (ductile and high redundancy) with satisfactory past performance and belonging to a family of bridges with a good track record. Minor structure in network with alternative routes available. Economic and environmental consequences of failure minor. Significant economic benefits anticipated. Inspection programme and asset management system suitable to identify any signs of potential failure.

Annual Target Reliability	Annual Probability of Failure (approx.)	Risk Profile
3.5	2.3×10^{-4} (1 in 4300)	Class 3 structures where costs of safety measures are large or Class 2 structures where costs of safety measures are medium. Potential disruptions to economy and society limited to region. Environmental impact restricted to locality and can be restored in weeks. Structures are robust and inspection programme and asset management system suitable to identify any signs of potential failure. Most bridges will fit into this profile.
4.0	3.2×10^{-5} (1 in 31,500)	Class 4 structures where costs of safety measures are large. Potential economic disruptions on a national scale. Environmental impacts significant and may take years to restore. Also, potentially appropriate for Class 2 structures where costs of safety measures are large and possibly low redundancy present. Structures have satisfactory record of past performance and inspection programme and asset management system suitable to identify any signs of potential failure. Could also apply for Class 3 structures where costs of safety measures are medium.
4.5	3.4×10^{-6} (1 in 294,000)	Equivalent to design of new structures and nominally Class 3 structures where costs of safety measures are small. Costs to mitigate risks and reduce uncertainties are small. Potential economic and environmental consequences of potential failures are large. Little track record of satisfactory past performance. Could also apply to Class 4 structures where costs of safety measures are medium.
5.0	2.9×10^{-7} (1 in 3,500,000)	Class 4 structures where costs of safety measures are small. Special structures of national importance and possessing little robustness. For example, failure of one component resulting in catastrophic collapse of the structure and many casualties. Impact on economy and environment extreme.

Based on the desired target reliability index, the road agency or the assessor will be able to select live and dead load factors which have been calibrated to target reliability indices, for use in the semi-probabilistic assessment approach. The tables have not been reproduced here as at the time of writing, they had not been endorsed by Austroads. It should be noted that the Guideline includes tables for freight vehicles but does not include tables for special heavy vehicles being cranes, low loaders, load platform trailer combinations and so on, because statistics for these vehicles are not available in Australian and New Zealand. The Guideline includes a recommendation that statistics for these vehicles be collected to calibrate factors for these vehicles.

5. Historical context

The Guideline’s approach to decision making may appear novel and perhaps unfamiliar to engineers more acquainted with AS 5100:2017. However, astute engineers will realise that this is not the case. Table 3 lists some notable milestones in engineering achievement including availability of tools, advances in engineering theory and notable bridges. It can be observed from the table that computers are very recent and that Australian standards did not exist before the last century. Research on the strength of materials commenced in the seventeenth century. However, reliable structures were constructed centuries before this enlightenment.

Table 3 Engineering milestones

Year	Milestone
1999	World Wide Web
1985	Desktop structural analysis packages
1977	Apple 2 desktop computer
1953	First Australian Bridge Design Specification
1922	Standards Australia formed
1871	Modern theory of plasticity - Saint-Venant
1833	Poisson
1824	Navier – theory of elastic (working stress)
1779	Iron Bridge, Shropshire U.K.
1744	Euler buckling
1687	Newton’s laws of motion
1678	Hooke’s law
1638	Strength of bodies - Galileo Galilei
18 BC	Pont du Gard, France

Noting that risk-informed decision making is applicable to design as well as assessment, consider the hypothetical building of a bridge by Romans two millennia ago. The first step would be to define the needs and objectives for the crossing which could include the following:

- to facilitate the temporary crossing by the Roman legion as part of campaign of conquest
- to facilitate rapid responses to civil unrest in the empire, by Roman legions
- to facilitate economic trade with remote parts of the empire
- to demonstrate the engineering prowess and might of the empire.

In this case, the last three objectives are established by Rome (road manager) as required. Options for the site of the crossing including possible structural form, would be developed. Uncertainties to be considered would have included materials (properties and availability), available skills and labour, potential for flooding and earthquake and foundation conditions. Potential structural forms include timber, pontoon or stone arch.

A preliminary risk assessment is undertaken and timber and pontoon bridges are discounted as being unlikely to meet the objectives. The stone arch is selected as the most reliable structural form to achieve the required objectives. A detailed design is prepared noting the geometry of the crossing, foundational conditions and the semi-circular nature of the arch design at the time. The structural design of the structure is based on empirical relationships including that (O'Connor[3]):

- the ratio of the rib thickness to the span should be about 1/10, however thicknesses as thin as 1/20 are possible, particularly for longer spans
- stone depths greater than 5 Roman feet are to be avoided.

O'Connor (p.186) noted that:

> *'The Romans were practitioners. Although they were no doubt incapable of describing behaviour in the terms mentioned here, yet one should not be hasty in underestimating their ability to judge the real behaviour of the arches they built for so many years.'*

The 'terms mentioned here' by O"Connor, referred to structural behaviour as we understand it today.

Construction proceeds under the watchful gaze of centurions to ensure good quality control, and the bridge is completed. The result is a reliable structure (which outlasts the empire) conceived and executed based on risk-informed decision making to address the many uncertainties faced by Romans.

6. Risk-informed decision making for assessment in the guideline

Risk-informed decision making for assessment of existing bridges to carry vehicle loads, is illustrated in Figure 4. The steps are discussed in detail below.

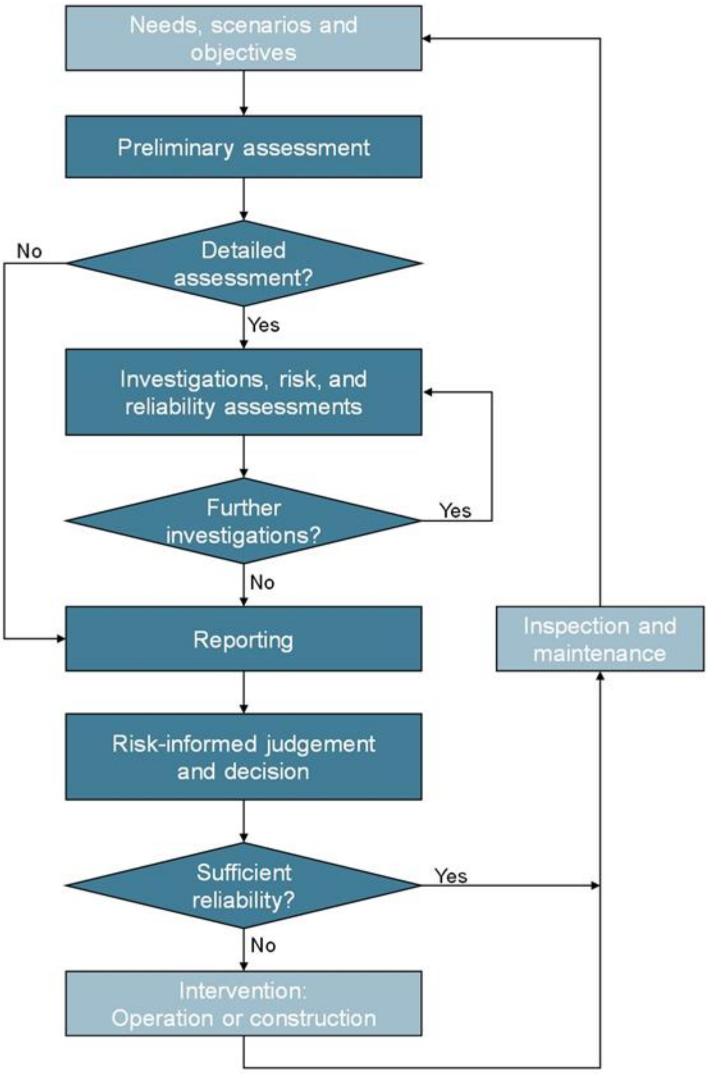
Needs scenarios and objectives – The road agency should set out the needs, objectives and possible scenarios for the assessment. Needs may arise from concerns about the bridge performance under current traffic, a desire to increase loading limits on the bridge or to provide a benchmark for assessing applications for access. Objectives may include a short time horizon before the bridge is replaced, long term performance, post disaster function and facilitating new industry. Scenarios may include enhanced maintenance or management, changes in land use, possible changes in operation of the bridge, fatigue and so on.

Data collection – Relevant available data may include project and standard drawings, as built drawings, specifications and contract records, construction records such as test results, diaries and quality records, maintenance records, past reports, inspection reports, detailed surveys including scour, historical material and section properties and so on.

Inspection and observations – The bridge should be inspected to gain information specifically relevant to the assessment. Observations may include the structural form, straightness of members, discrepancies with drawings, missing data, taking photographs, scour, condition of foundations, condition of components likely to influence strength calculations and usage of the bridge by heavy vehicles during inspection.

Reference vehicles – The main purpose of reference vehicles is to establish the relationships between the global positioning of the vehicle on the bridge and bridge components. Therefore, the reference vehicles should approximate the various vehicles of interest particularly with the same ground contact width. The results of assessments based on reference vehicles can be post-processed to obtain assessment results for application vehicles (those applying for access or representing a family of vehicles).

Figure 4 Flowchart for assessment – AS ISO 13822-2005.



Source: Draft Guideline to Bridge Assessment – Figure 2.1.

Permanent and time dependent actions – Permanent actions such as self-weight and variable (superimposed) dead and actions such as dynamic effects should be determined. If a dynamic load allowance is assumed, it may be modified later if all action contributions are recorded separately.

Preliminary risk assessment – The preliminary check will require a review of all available information and may involve some high-level calculations to determine whether the bridge presents any immediate unacceptable risks or whether a detailed investigation is required. As a result of the preliminary risk assessment, the road agency will be able to determine what margin it is prepared to accept and select a target reliability index, should a detailed assessment be needed.

Load factors – If undertaking a semi-probabilistic assessment, the assessor will need to choose load factors and capacity reduction factors which are consistent with the risk profile determined for the bridge.

Analysis and calculations – Computer modelling and analysis should be approached cautiously to ensure that they represent realistic structural behaviour. It is likely that multiple models and assumptions will be necessary to explore structural behaviour. The Guideline contains advice about computer modelling as well as more refined resistance calculations such as concrete beam shear.

Plausibility check – The results of the assessment should be reviewed against observations of the structural performance of the bridge. If the assessment indicates that the bridge should show signs of distress and it does not, further investigation is required. Assumptions made during the assessment should be reviewed and amended as needed to explore the impact of those assumptions on the assessment outcome.

Bridge specific investigations – As a result of the assessment, the road agency will have potentially become aware of assumptions which may be able to be better understood through bridge specific investigations. Investigations may include material testing, more accurate dead weight assessment, usage of the bridge by heavy vehicles including driveline, dynamic effects and live load variability, and proof load testing. Bayesian updating should be applied to test results.

Judgement and decision making – Judgement and decision making may be required for the management of the asset and/or for determining access to the asset. Judgement requires consideration of all the evidence based on skills and experience. Risk needs to be considered through the lens of SFAIRP (so far as is reasonably practicable) as judged by a reasonable person. Based on the findings from the assessment, the road agency may wish to adjust the risk profile and hence the target reliability index up or down compared to the preliminary risk assessment. The judgement and the reasons underpinning the judgement should be documented in a logical manner. Risk mitigation may involve changes to the asset management system.

Documentation – It is essential that the assessment, assumptions underpinning the assessment and the findings, be documented in such a way that a third party could repeat the assessment and obtain similar results. Documentation must be clear, transparent and comprehensive. The rationale behind decisions taken and how risk has been assessed and is to be managed, must also be documented. The asset management system must also be updated to include the documentation, any further investigations to confirm assumptions (close the loop), changes to inspection and maintenance procedures as a result of the assessment, how access for heavy vehicles is to be managed and the date for review of the assessment and efficacy of risk mitigation measures.

The above approach will lead to a better understanding of structural performance and risk, and ultimately to better decision making. Better decision making leads to better management of the asset and better outcomes from the asset for society. Further information on the Guideline is provided by Shaw[4] et al.

7. Conclusion

It is concluded that:

- Risk-informed decision making is a more holistic basis for managing structures over their life cycles, than simply calculating rating factors or assessment ratios.
- The risk-informed decision making approach is not new and is what has been adopted by good engineers for centuries.
- The adoption of risk-informed decision making in the Austroads *Guideline to Bridge Assessment* will assist road agencies to make more informed decisions about managing their assets and access to them.

8. References

1. AS 5104:2017, (ISO 2394: 2015), *General principles on reliability for structures*, Standards Australia.
2. AS 5100:2017, *Bridge design*, Standards Australia.
3. O'Connor, C. (1993), *Roman Bridges*, Cambridge University Press, Great Britain.
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Acknowledgments

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