FORMWORK EQUIPMENT – ITS DESIGN, MANUFACTURE, ASSEMBLY AND OPERATION

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ABSTRACT: Formwork equipment for tunnels is a key element in the construction of underground structures, especially in the construction of monolithic concrete tunnel linings. Its design, manufacture, assembly and subsequent maintenance require a high degree of technical precision and coordination. The design of the formwork equipment is based on the geometry of the tunnel, technological requirements and the planned construction procedure. The shape of the lining, the length of the stroke, the pressure of fresh concrete and the requirements for surface quality are taken into account. The structure must allow for easy demoulding, movement and reuse. Another important aspect is the integration of working platforms, safety features and concrete vibration systems.

Formwork equipment is usually manufactured in specialised engineering workshops. High-quality steel profiles and sheets are used, which are then welded into the required shape. The surface of the formwork is coated with a special paint. Production also includes hydraulic systems for spreading and demoulding, transport mechanisms and, where appropriate, automated elements to speed up the cycle.

The equipment is assembled directly in the tunnel, often under limited space conditions. After the individual segments have been assembled, calibration and test runs are carried out. Precise levelling and geometry checks are important. Assembly work must be coordinated with other activities on the construction site, such as reinforcement, concreting and material transport.

During the operational phase, the formwork equipment allows for regular concreting of individual sections. Equipment operators must be trained and comply with safety regulations. Efficient operation depends on the correct cycle settings, concrete quality and coordination with construction logistics.

Regular maintenance is essential to maintain the functionality and safety of the equipment. This includes cleaning surfaces, checking hydraulics, lubricating moving parts and inspecting joints. After completion of the project, the equipment is dismantled or reconditioned for further use.

1. INTRODUCTION TO FORMWORK

Formwork as such has been known for its structural essence for decades or even centuries. In this article, I focus primarily on **steel, hydraulically sliding formwork**, which significantly reduces the need for physical labour and enables fast and efficient construction. Thanks to hydraulic control, it is possible to move, remove and adjust individual parts of the equipment with minimal effort on the part of the operator and with maximum precision. This type of formwork thus contributes to speeding up the entire construction process, reducing the time during which the equipment is idle and minimising the costs associated with handling and operation.

Currently, there are also various **system formwork** systems that play an irreplaceable role in underground construction. However, these solutions are generally more dependent on manual labour and require greater physical effort from workers than hydraulically sliding structures with remote control. Steel sliding formwork is therefore a modern and effective alternative where the emphasis is on speed of construction, operator safety and minimisation of manual handling.

In this article, I focus on the entire formwork design process and its specifics. I describe in detail the procedure from the initial conceptual design, through production and control assembly, to testing of individual functions before the equipment is sent to the construction site. I also focus on the actual assembly of the formwork on site, which takes place under the supervision of a supervisor or the entire assembly team, and on how it is operated, serviced and, if necessary, dismantled ( ). A separate and very interesting area is the design of **special formwork** for non-standard profiles or profiles that change over a distance of several tens of metres. The aim of such a design is to create a solution that functions as a construction kit with minimal modifications and does not affect the construction process more than necessary. And if there is any impact on the construction process, it should be as small as possible and easily solvable.

2. FORMWORK DESIGN

The formwork design itself is based on the basic profile of the secondary tunnel lining, and its shape must correspond to this profile, usually with a slight increase in the nominal dimension of approximately 30 mm. This increase reflects the deformation of the formwork that occurs during concreting, which is usually only a few millimetres. The entire conceptual solution must also take into account all specific customer requirements and construction conditions – in particular, space requirements for the passage of concrete mixers or other equipment, access options, safety conditions and operational continuity. Another important aspect of the design is the shape and size of the formwork in the stripped state to ensure easy and safe cleaning and to meet all traffic requirements in this position.

The design also includes the careful placement of working platforms, which must allow comfortable and safe access to the filling windows and the concrete fillers themselves, as well as ergonomic access for cleaning the formwork before concreting. The ergonomic design of the entire system is of fundamental importance, as it affects not only the safety of workers, but also the speed and smoothness of work processes. A separate part of the design is the placement of fillers and filling windows, which are always designed in close cooperation with the construction site and the concrete manufacturer in order to achieve optimal concreting, uniform form filling and safe access for operators.

When creating the concept, it is also necessary to take into account transport conditions, in particular the method of transporting individual parts to the construction site. The sizes and weights of the individual formwork parts must be designed so that they are suitable for normal truck transport and allow safe handling using available technology. This requirement affects not only the overall division of the structure, but also the position of the assembly points, suspension eyes and connection points.

The result of the entire conceptual process is a design or approval drawing of the formwork, which includes a representation of the equipment in the concreting state and in the stripped state, and which serves as the basis for final approval by the customer and subsequent processing of detailed design and production documentation.

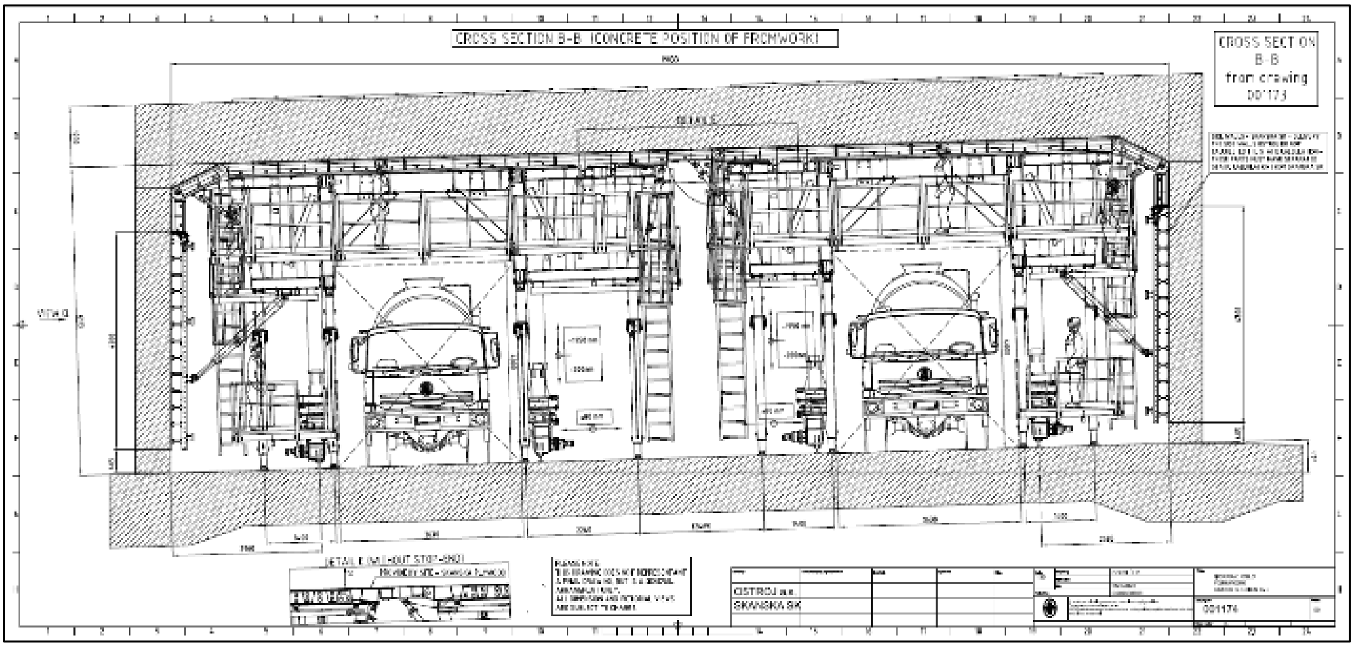


Figure1: Example of an approval drawing for equipment

The time required to process individual formwork designs depends primarily on the specific type of structure and profile shape to be implemented. Construction requirements are often very specific, and the economic viability of the entire solution must always be maintained. For common profiles, typical especially for road or railway tunnels, the design is usually faster because the shape and layout of the elements are similar to those of previously designed structures. On the other hand, for completely new or atypical profiles that have never been processed in the past, the design phase can be more time-consuming, especially in the case of a special shape or structural arrangement where it is necessary to design the form practically "from scratch". An example of this is the formwork for the D metro line, where in one case the segment length is 6 metres and in another 12 metres; in such a situation, it is advantageous to design the structure as a whole, which can then be divided into two separate parts according to the needs of the construction.

An integral part of the design is also the solution for recesses, necks, profile extensions or emergency bays, which have a direct impact on the overall layout of the structure and the placement of individual formwork elements. These specific elements must be taken into account at an early stage of the design so that the equipment can be deployed and operated directly on site without complications. The structural design itself must also take into account all loads that may act on the formwork. The load of fresh concrete alone represents the largest component of the total stress on the structure. However, in the case of equipment located outdoors, other adverse loads such as wind, snow or heavy rain may also act on the formwork, which can significantly affect the behaviour of the entire system in terms of statics. The formwork design must therefore be prepared with all these possible influences in mind to ensure its safety, reliability and long-term service life.

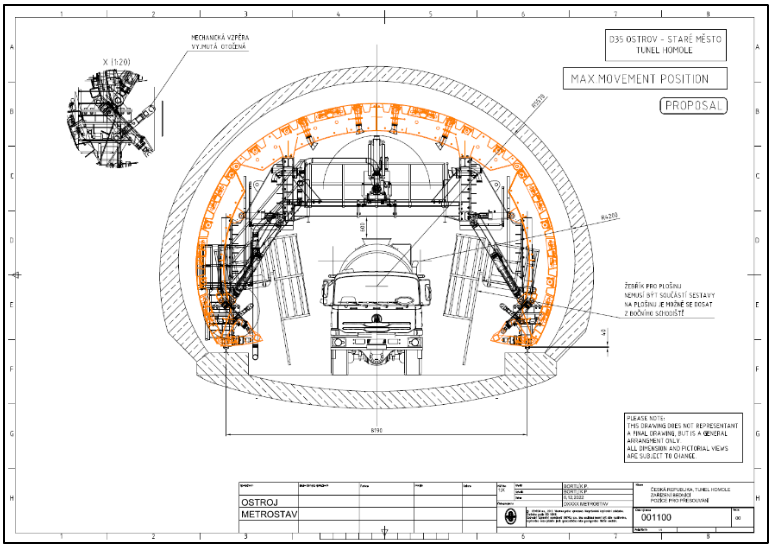


Figure2: Example of an approval drawing for equipment – example of formwork removal

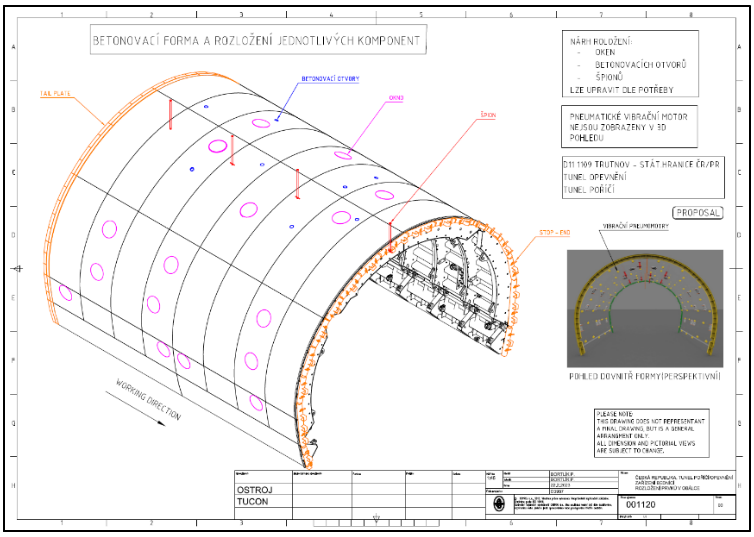


Figure3: Example of an approval drawing for equipment – example of window layout

3. FORMWORK CALCULATION

The formwork calculation consists of several consecutive phases, the aim of which is to correctly determine the boundary conditions of the structure and precisely identify all the influences acting on the formwork. The basic assessment is usually carried out for two main operating conditions:

1. **Concreting state**,
2. **Equipment movement state**.

Neither of these conditions represents a significant advantage for the structure – each of them imposes a different type of load. In addition, formwork intended for outdoor use may also be subject to **special loading conditions**, such as **the effects of wind or snow**, which can have a significant negative impact on the structure and must be taken into account in the overall assessment.

The calculation process also includes **a technological calculation**, the purpose of which is to verify the functional capabilities of the equipment. This includes:

- **dimensioning of hydraulic cylinders**,
- verification that the hydraulics can move individual parts of the structure in the required directions,
- **calculation of the distribution of forces** in individual elements,
- **kinematic calculation of the speeds of** all movements,
- determination of the required power of **the main motor of the hydraulic unit**.

As mentioned above, the key part consists of a pair of main calculation states. In **the concreting state**, the following are primarily evaluated:

- deformation and deflection of the structure,
- stress in all critical elements,
- assessment of the load-bearing capacity of the envelope and supporting frame,
- usually according to the **HMH (von Mises)** analysis for determining equivalent stress.

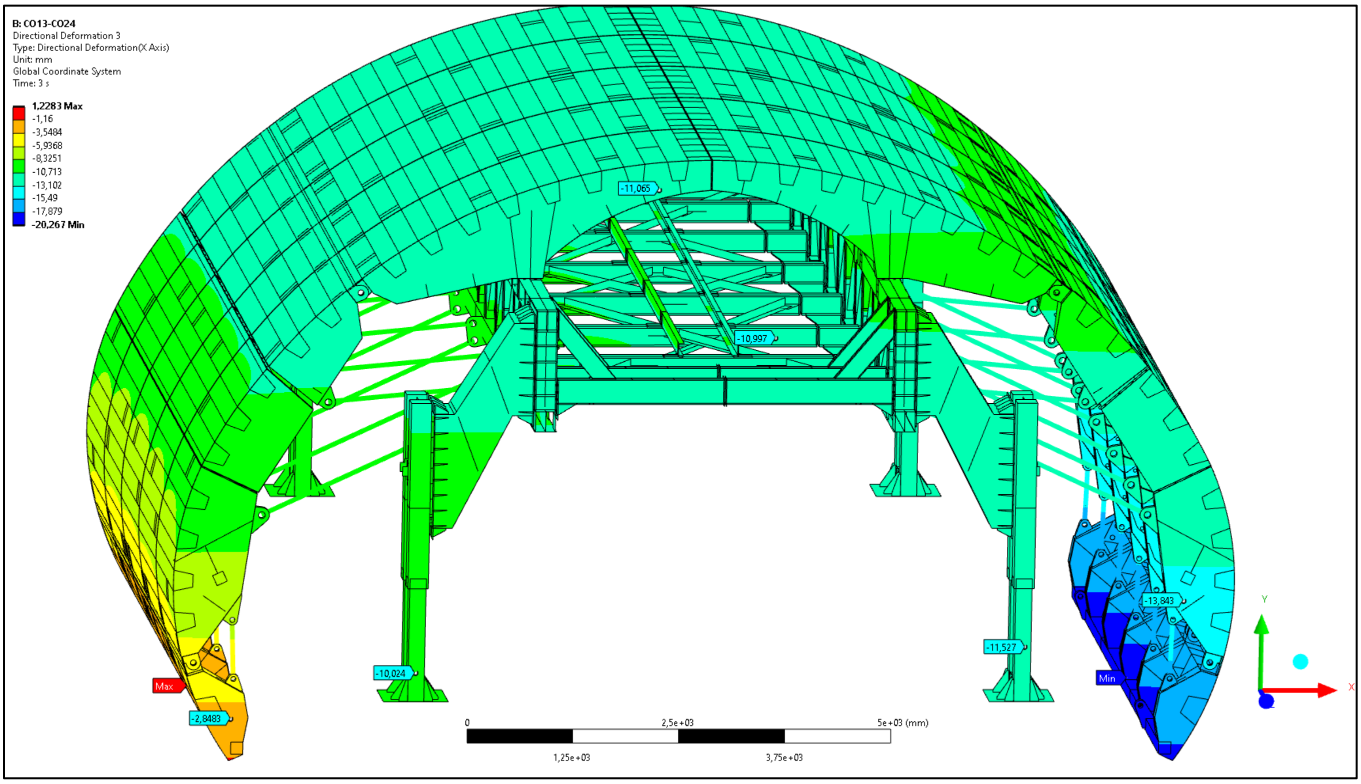


Figure4: Example of deflection calculation during concreting – Prague Metro D

The second state is the state of displacement of the entire structure, where the state of deformation and deflection is also evaluated.

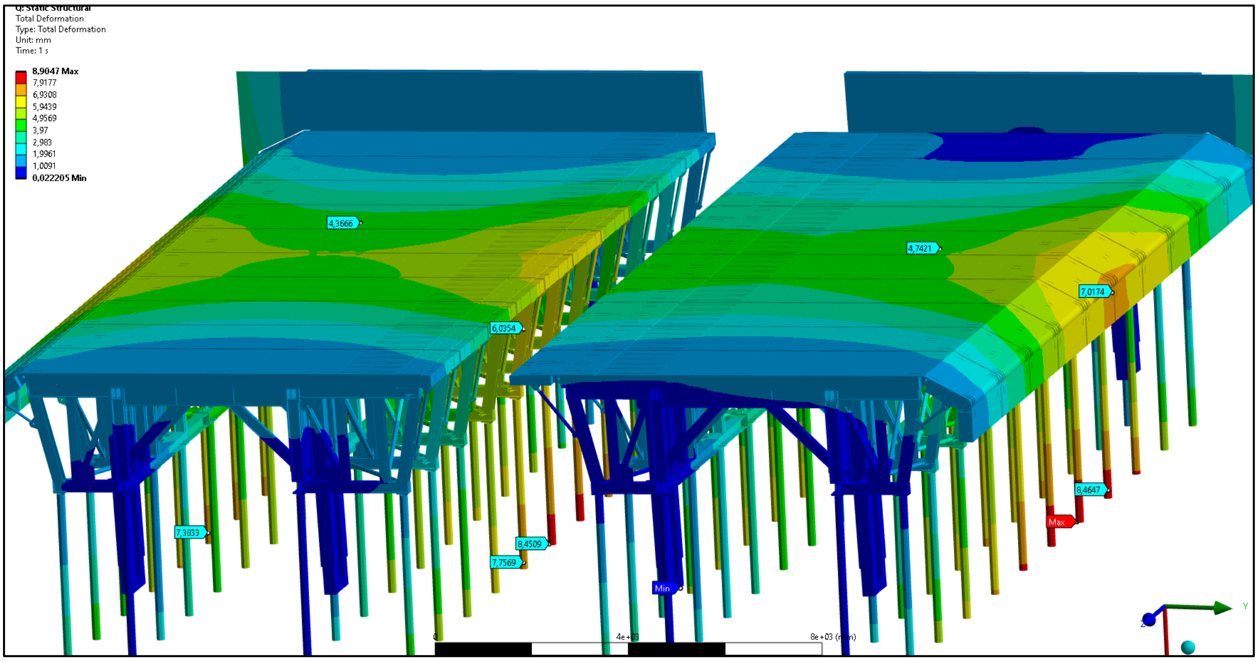


Figure5: Example of deflection calculation during displacement – Norway – Oslo

Specialised software tools are used for structural formwork calculations, which enable the accurate determination of stress, deformation and overall structural response according to applicable or recommended standards. These programmes can simulate load conditions as they actually affect the structure during concreting, movement or due to external climatic conditions.

For **detailed analyses**, especially for complex elements or joints, advanced systems such as **ANSYS** are used, which enable:

- detailed modelling of contacts and local stresses,
- non-linear calculations,
- assessment of critical points with high stress concentrations,
- combination of shell and volume elements similar to classic mechanical engineering calculations.

In most cases, the formwork envelope consists of **trapezoidal sheets** that form the main working shell. The following are evaluated in particular for these elements:

- **stress in individual profile waves**,
- total deflection of the surface,
- local stability of the sheet metal,
- load-bearing capacity and stiffness depending on the choice of profile and material.

The correct choice of trapezoidal sheet type and thickness is crucial, as it significantly affects the resulting stiffness of the shell and its resistance to fresh concrete loads.

In addition to global structural calculations, a number of **detailed engineering calculations** are also performed, including:

- **pin calculations**,
- bearing assessments,
- design of gearing for travel mechanisms,
- screw connection checks,
- weld dimensioning,
- calculation of sliding or rotating guides,

- assessment of structural nodes during the transfer of local forces.

These calculations are necessary to verify the safety and service life of mechanical parts of equipment that transmit significant forces and repeated loads during operation.

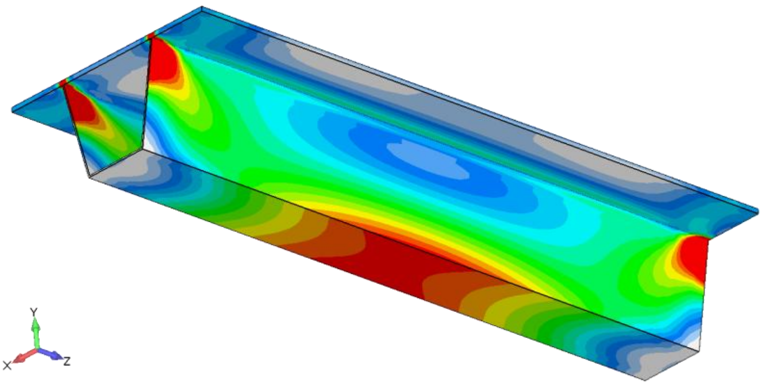
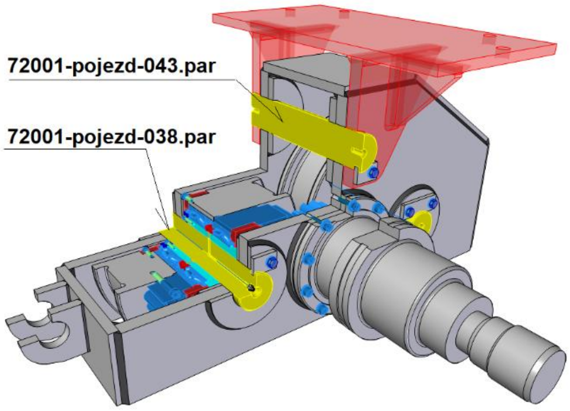



Figure6: Calculation example – special calculations

The assessment may also evaluate **the stability of the equipment during movement on rails** with regard to the effects of crosswinds. The aim was to verify that **the entire structure** would not **overturn** under the proposed load and to assess **the stress on the rail** caused by horizontal forces from the wind.

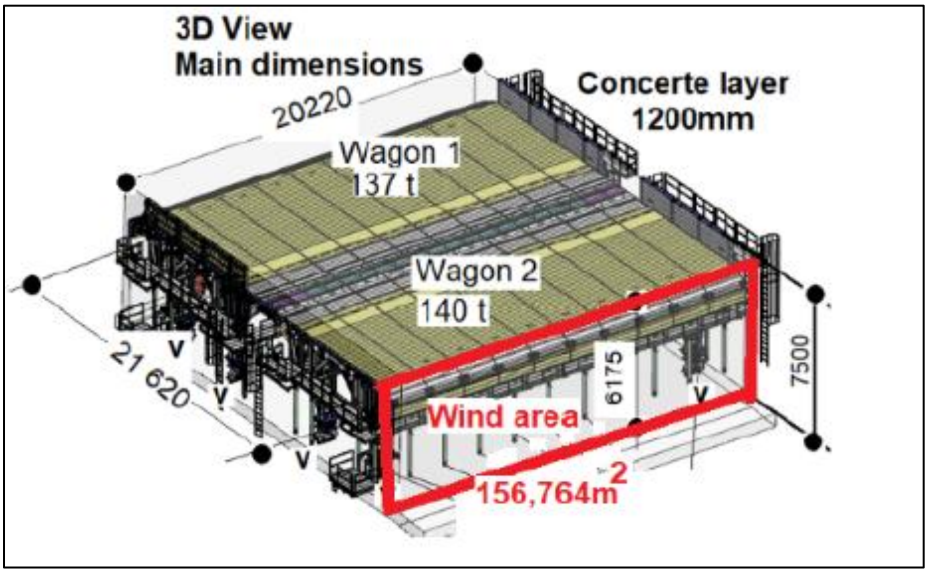
The stability of the structure was analysed by comparing:

- **the overturning moment** caused by the wind,
- with **the restoring moment**, which is formed by the dead weight of the equipment and the position of the centre of gravity.

At the same time, **internal forces, deformations and stresses in the rail** were determined, in particular due to the lateral horizontal force transmitted through the running wheels or guide elements. The evaluation was carried out with regard to:

- **ultimate limit state** (ULS) – checking for exceeding permissible stresses,
- **serviceability limit state** (SLS) – checking for deformations, deflections and contact with the ground.

The result of the assessment is confirmation that the structure, taking into account wind loads, is satisfactory in terms of both **overall stability** and **stress** on **the rail system**.



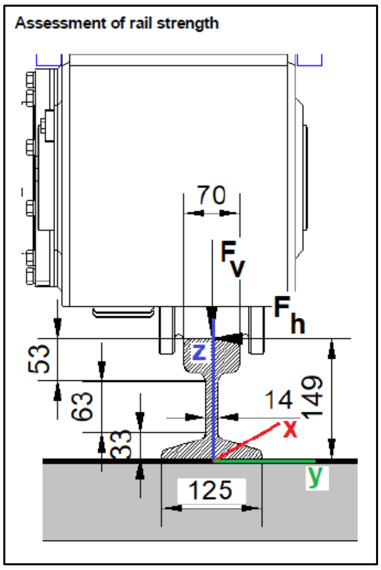


Figure7: Calculation example – special calculations

4. FORMWORK PRODUCTION

The actual manufacture of the equipment must be carried out in accordance with pre-defined standards and, at the same time, the correct execution class EXC1 to EXC4 must be determined according to the method of use of the equipment and the requirements for its safety and reliability. The execution class is determined according to the relevant manufacturing and design standards (e.g. EN 1090).

The production of individual parts is expected to be made from **certified materials** supplied with a certificate in accordance with **EN 10204–3.1**, i.e. with confirmation of the material properties by an independent authorised person. Materials must be traceable and properly marked throughout the entire production process.

After welding, each welded part must undergo at least **a visual inspection** (VT) **of the welds**.

For welds that are subjected to higher stresses or are located in critical nodes of the structure, **non-destructive testing (NDT)** must be performed – for example, capillary (PT), magnetic (MT), ultrasonic (UT) or radiographic (RT) testing according to the required testing level and EXC class.

Weldments, especially **the main envelope of the equipment**, are manufactured in precision jigs that facilitate assembly and ensure correct profile geometry. The jigs must be designed to minimise deformation during welding and guarantee the reproducibility of the dimensions of individual pieces.

For large welds, **visual 3D inspection** using a tablet or scanning device is also used, which allows quick identification of any deviations from the nominal dimensions and comparison of the actual condition with the CAD model.

All parts that undergo further machining (drilling, milling, turning, etc.) are subject to **dimensional inspection**, especially at the connecting and contact surfaces. The purpose is to verify that the specified dimensions according to the drawing documentation will be met after assembly and that there will be no inaccuracies affecting the function of the whole.

Figure8: Formwork production

5. TEST ASSEMBLY OF FORMWORK

The control assembly of formwork is a key step in the process of verifying the assemblability of the equipment and determining the actual speed of assembly of individual units. This procedure is usually performed for newly developed types of formwork, for which completely new drawing documentation is created.

The trial assembly is based on prepared **3D documentation**, which forms the main assembly basis. The advantage of this approach is the **immediate availability of documentation from anywhere**, which allows for the effective resolution of any problems during assembly.

The following checks are performed during assembly:

- function of the hydraulic unit,
- function of all formwork elements,
- verification of limit states:
  - maximum extension,
  - clamping of the envelope,
  - checking for collisions between individual parts of the equipment.

The geometry of the envelope is checked in two operating modes:

- **concrete pouring state**,
- **transfer state (transport position)**.

The geometric parameters are compared with the values in the 3D model and assembly drawings.

The assembly check includes verification of all operating functions, in particular:

- **movement on rails**,
- **lateral corrections**, which are essential for the precise guidance of the equipment during operation.

A functional inspection report is drawn up for all tests, which serves as an official record of the conformity of the assembly with the specifications.

After completion of the test assembly and verification of functionality, the assembled units are **disassembled into individual sub-units**, which are dimensioned so that they can be transported by a standard road truck.

This procedure ensures **quick and trouble-free assembly directly at the installation site**.

Figure9: Test assembly of the device

Figure10: Test assembly of the equipment

6. FORMWORK ASSEMBLY AT THE INSTALLATION SITE

After completion of the test assembly at the factory, **the equipment** is **assembled directly at its future place of operation**. The time required for assembly depends on the specific type of formwork, but with proper organisation of work, it usually takes only a few days. The aim is to minimise the load on the construction handling equipment and ensure the smooth progress of follow-up work.

Assembly takes place in individual units according to **a predetermined schedule**, which is closely coordinated with **the logistics of the arrival of lorries** carrying formwork components. This coordination is essential for:

- minimising storage space on site,
- the effective use of crane and handling equipment,
- ensuring assembly without unnecessary downtime.

After the basic supporting structure has been assembled, the next step is to **assemble the equipment envelope**, which forms the functional working shell.

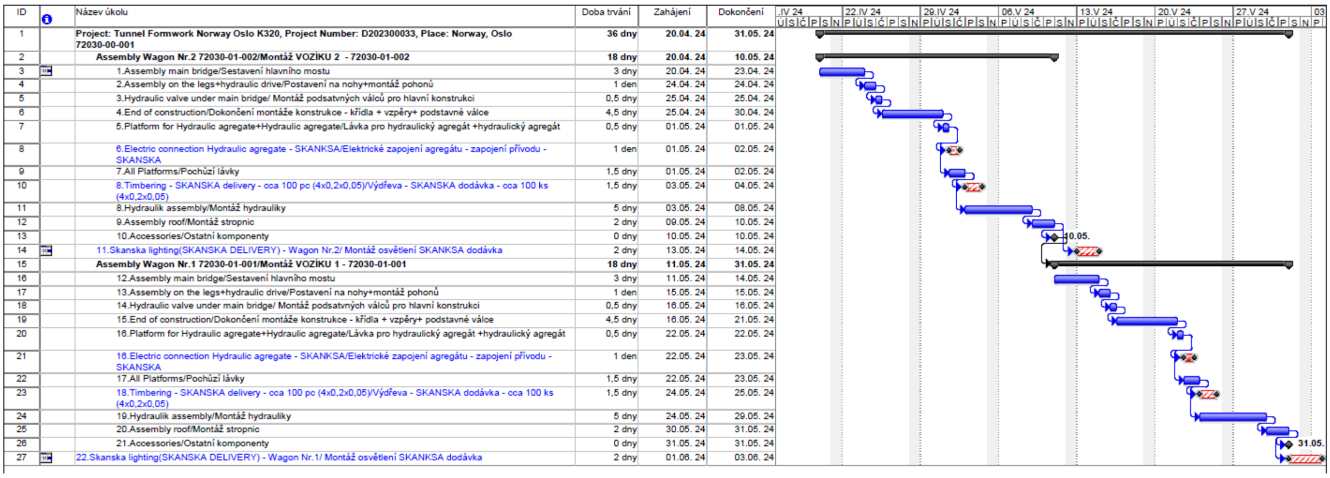
If necessary, some types of equipment can be assembled **outside the tunnel area**. The design allows the drives to be rotated up to **90°**, which provides sufficient space for other construction equipment to pass through or for parallel work in the tunnel. This feature greatly facilitates the organisation of the construction site and minimises construction downtime.

After complete assembly on site, **all functions** are **checked** again, similar to the test assembly at the factory. In particular, the following is verified:

- the operation of hydraulic systems,
- the functionality of all drives and mechanisms,
- movement precision (travel, lateral correction, clamping, extension),
- collision conditions,
- envelope geometry during concreting and movement.

A **report on the commissioning of the equipment** is drawn up based on the inspection.

After successful completion of assembly and functional tests, the equipment is **officially handed over to the customer**, unless another handover scheme is agreed in the contract (e.g. gradual handover, trial operation, or handover in another mode).



ID		Název úkolu	Doba trvání	Zahájení	Dokončení
1		**Project: Tunnel Formwork Norway Oslo K320, Project Number: D202300033, Place: Norway, Oslo 72030-00-001**	**36 dny**	**20.04. 24**	**31.05. 24**
2		**Assembly Wagon Nr.2 72030-01-002/Montáž VOZÍKU 2 - 72030-01-002**	**18 dny**	**20.04. 24**	**10.05. 24**
3		1.Assembly main bridge/Sestavení hlavního mostu	3 dny	20.04. 24	23.04. 24
4		2.Assembly on the legs+hydraulic drive/Postavení na nohy+montáž pohonů	1 den	24.04. 24	24.04. 24
5		3.Hydraulic valve under main bridge/ Montáž podsatvných válců pro hlavní konstrukci	0,5 dny	25.04. 24	25.04. 24
6		4.End of construction/Dokončení montáže konstrukce - křídla + vzpěry+ podstavné válce	4,5 dny	25.04. 24	30.04. 24
7		5.Platform for Hydraulic agregate+Hydraulic agregate/Lávka pro hydraulický agregát +hydraulický agregát	0,5 dny	01.05. 24	01.05. 24
8		6.Electric connection Hydraulic agregate - SKANKSA/Elektrické zapojení agregátu - zapojení přívodu - SKANSKA	1 den	01.05. 24	02.05. 24
9		7.All Platforms/Pochůzí lávky	1,5 dny	01.05. 24	02.05. 24
10		8.Timbering - SKANSKA delivery - cca 100 pc (4x0,2x0,05)/Výdřeva - SKANSKA dodávka - cca 100 ks (4x0,2x0,05)	1,5 dny	03.05. 24	04.05. 24
11		8.Hydraulik assembly/Montáž hydrauliky	5 dny	03.05. 24	08.05. 24
12		9.Assembly roof/Montáž stropnic	2 dny	09.05. 24	10.05. 24
13		10.Accessories/Ostatní komponenty	0 dny	10.05. 24	10.05. 24
14		11.Skanska lighting(SKANSKA DELIVERY) - Wagon Nr.2/ Montáž osvětlení SKANKSA dodávka	2 dny	13.05. 24	14.05. 24
15		**Assembly Wagon Nr.1 72030-01-001/Montáž VOZÍKU 1 - 72030-01-001**	**18 dny**	**11.05. 24**	**31.05. 24**
16		12.Assembly main bridge/Sestavení hlavního mostu	3 dny	11.05. 24	14.05. 24
17		13.Assembly on the legs+hydraulic drive/Postavení na nohy+montáž pohonů	1 den	15.05. 24	15.05. 24
18		14.Hydraulic valve under main bridge/ Montáž podsatvných válců pro hlavní konstrukci	0,5 dny	16.05. 24	16.05. 24
19		15.End of construction/Dokončení montáže konstrukce - křídla + vzpěry+ podstavné válce	4,5 dny	16.05. 24	21.05. 24
20		16.Platform for Hydraulic agregate+Hydraulic agregate/Lávka pro hydraulický agregát +hydraulický agregát	0,5 dny	22.05. 24	22.05. 24
21		16.Electric connection Hydraulic agregate - SKANKSA/Elektrické zapojení agregátu - zapojení přívodu - SKANSKA	1 den	22.05. 24	23.05. 24
22		17.All Platforms/Pochůzí lávky	1,5 dny	22.05. 24	23.05. 24
23		18.Timbering - SKANSKA delivery - cca 100 pc (4x0,2x0,05)/Výdřeva - SKANSKA dodávka - cca 100 ks (4x0,2x0,05)	1,5 dny	24.05. 24	25.05. 24
24		19.Hydraulik assembly/Montáž hydrauliky	5 dny	24.05. 24	29.05. 24
25		20.Assembly roof/Montáž stropnic	2 dny	30.05. 24	31.05. 24
26		21.Accessories/Ostatní komponenty	0 dny	31.05. 24	31.05. 24
27		22.Skanska lighting(SKANSKA DELIVERY) - Wagon Nr.1/ Montáž osvětlení SKANKSA dodávka	2 dny	01.06. 24	03.06. 24

Figure11: Example of an installation schedule

Figure12: Installation with rotated drives

7. FORMWORK OPERATION

The operation of the formwork is designed to be as simple and safe as possible. In most applications, the equipment is controlled by **remote control**, which significantly increases operator comfort and allows for efficient control of all machine functions. Although some installations may use **local control** exclusively, this is a less convenient solution and, from an operational point of view, less efficient. Although local control may initially be perceived as cost-effective, in practical operation, the use of **remote control** clearly pays off.

A very important advantage of remote control is the ability **to parameterise the speeds of individual functions**. The operator (under the supervision of the manufacturer) can set:

- lower speed at maximum control lever deflection,
- higher speed when the lever is partially deflected,
- specific speeds for precise manoeuvring or smooth operation.

This variability allows the equipment to be adapted to specific construction conditions and operating methods.

Another major advantage is the possibility **of** using **the same remote control for the concrete mixer truck**, which greatly simplifies operation and reduces the need for staff training.

All modern systems are equipped with **an LCD display** as standard, which shows key operating data such as:

- operating temperatures,
- oil levels,
- pressures in individual hydraulic circuits,
- power supply status, and more.

Special attention is paid to monitoring **the input voltage of the electrical network**, which often fluctuates on construction sites. Fluctuating or excessive voltage can cause:

- immediate damage to the hydraulic unit motor,
- interruption of operation,
- the risk of construction delays.

Thanks to its integrated protection, the device is able to respond preventively to dangerous voltage values and thus prevent damage to components.

Figure13: Remote control of formwork

Figure14: LCD display with parameters

Modern formwork systems also allow **remote access**, directly from the office or other service location. This makes it possible to monitor the status of the equipment and individual operating functions in real time and to evaluate any malfunctions.

Remote access allows you to monitor, for example:

- current operating parameters (pressures, temperatures, flow rates, voltages),
- the status of individual subsystems,
- history of error messages and operational events,
- records of when the fault was detected and when it was rectified.

This data is stored in the system memory, making it possible to perform **retrospective analysis** of operations.

Thanks to long-term data collection, it is possible to evaluate:

- recurring faults,
- deteriorating parameters of machine parts,
- unusual behaviour of hydraulic or electrical systems.

This greatly facilitates **the prediction of future problems**, service planning and minimisation of downtime. The user can therefore estimate in advance the condition of the equipment and what actions will need to be taken in the near future.

- rapid fault diagnosis without the need for a service technician to be physically present,
- Reduced equipment downtime
- lower service costs,
- the ability to respond immediately to non-standard machine behaviour,
- higher operational safety thanks to continuous monitoring.

For safe and proper operation of the formwork, it is essential that complete **operating documentation** be supplied with the equipment. This documentation is crucial not only for the operation itself, but also for ensuring that the equipment complies with applicable standards and regulations.

The most important part of the documentation supplied is **the Declaration of Conformity**. This document confirms that the equipment meets all relevant safety requirements and has been manufactured in accordance with harmonised standards. The Declaration of Conformity is legally binding and is necessary for the machine to be put into service.

8. CONCLUSION

The development, manufacture and subsequent operation of modern tunnel formwork is a complex process that requires careful coordination of technical, manufacturing and operational procedures. From the initial design, through test assembly and verification of all functions, to final assembly on site, every step must be carried out with the utmost precision. Emphasis on the quality of the materials used, adherence to technological procedures and systematic assembly checks are essential to ensure the long-term reliability of the equipment.

Equally important is properly maintained and complete operational documentation, which ensures safe operation and compliance with legislative requirements. Modern solutions with remote control and online diagnostics also significantly increase the efficiency and safety of the entire process. This digital support not only provides an immediate overview of the machine's status, but also enables predictive maintenance, which minimises downtime and contributes to the smooth progress of construction.

The entire system is a technologically advanced and fully integrated tool that provides construction sites with a reliable, flexible and efficient solution for the construction of tunnel structures. The correct execution of all steps — from design to commissioning — is the key to the safe and successful use of the equipment in demanding construction conditions.

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