MAÚT30 INTERNATIONAL SCIENTIFIC SYMPOSIUM

MAÚT30
30 ÉVES A MAGYAR ÚT- ÉS VASÚTÜGYI TÁRSASÁG

1-2 | OCTOBER | 2024

Budapest
Hotel Helia

MAÚT30 INTERNATIONAL SCIENTIFIC SYMPOSIUM
Budapest, 1–2 October 2024

Edited by:
Dr. György L. BALÁZS, Dr. Kálmán KORIS

Scientific and Organizing Committee:
Dr. György L. BALÁZS, János BÉLI, Zsófia BERÉNYI, Péter FÜLEKI, Tamás KIS, Gyula KOLOZSI, Dr. Kálmán KORIS, Mónika NÉMETH, Szabolcs NYIRI, Zoltán PÁSZTOR, Zoltán PUCHARD, András RÉTHÁTI, Szabolcs SZINVAI

Organized by:

MAÚT
MAGYAR ÚT- ÉS VASÚTÜGYI TÁRSASÁG

MAÚT Hungarian Road and Rail Society
Szabolcs NYIRI, Chairman

In cooperation with:

fib CEB • FIP Hungary

Featured sponsor:

DUNA ASZFALT

Sponsors:

STRABAG

COLAS WE OPEN THE WAY

SWIETELSKY

ISBN 978-615-82475-2-8

MAÚT30

30 ÉVES A MAGYAR ÚT- ÉS VASÚTÜGYI TÁRSASÁG

Contents

ISBN 978-615-82475-2-8

CLIMATE CHECK – DECARBONIZATION IN AUSTRIAN ROAD GUIDELINES

Martin Fellendorf
Graz University of Technology, Inst. Transport Planning and Traffic Engineering & Austrian Research Association for Roads, Railways and Transport (FSV)
Karlsgasse 5, 1040 Vienna, Austria

SUMMARY

On the recommendation of the FSV Monitoring Group "Climate Agreement and Transport", all 326 RVS and RVE guidelines were examined for their climate relevance. Those guidelines were identified which could lead to a large GHG (greenhouse gas) contribution. There is a consensus in the FSV that future guidelines should contribute to keeping the CO2 footprint of road construction and operation as low as possible. GHG contributions can be caused by the construction materials used and the required energy input or by the operation of the infrastructure facility due to traffic. A total of 37 guidelines were prioritized in terms of climate relevance. This article summarizes the findings of the original study which was written in German.

1. INTRODUCTION

The majority of the FSV members agree that the aspect of GHG emissions should also be reflected in the guidelines RVS/RVE. Heck&Partner was commissioned by FSV to review the existing guidelines for roads (RVS) and rail infrastructure (RVE) for climate compatibility. The FSV monitoring group Climate Agreement and Transport had recommended in advance that the climate relevance of guidelines should be reviewed in a two-stage process (Fig. 1), namely in stage A with an examination of whether the application of the respective guideline has a direct or indirect impact on GHG emissions. In stage B, the level of GHG-Emissions is to be classified in five categories from "not taken into account at all" to "GHG-E are reduced by the directive" to "the directive overcompensates for the GHG".

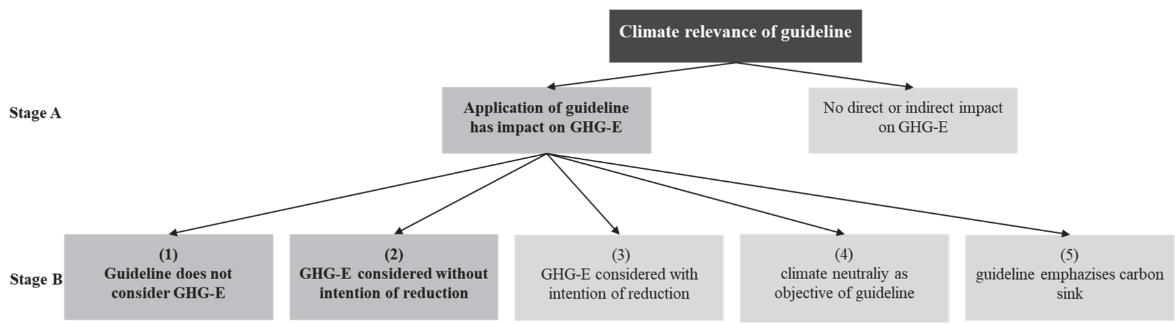


Fig. 1. Two-stage process to evaluate climate relevance as recommended by FSV Monitoring group, 2022

In this study (Fellendorf et al., 2023), assessment criteria for climate relevance are first defined. Subsequently, each of the currently valid 309 road guidelines RVS and 17 rail infrastructure guidelines RVE are examined with respect of climate relevance criteria. Each guideline in which at least one climate-relevant criterion has not yet been considered is classified in terms of its effectiveness. Guidelines with a high level of effectiveness are either applied frequently or used in particularly large projects. From a combination of the high effectiveness of the guideline and climate-relevant criteria that are not yet sufficiently considered, a total of 37 guidelines were identified that need to be revised with high priority due to their climate-relevant significance. Initial implementation steps have already been taken in the working groups since the study was published. Asfinag, the highway operator responsible for the federal road network, is strongly represented in the FSV committees and has already launched several projects aimed at reducing GHG emissions. These are pilot projects from which findings can be incorporated into future guideline work.

2. CRITERIA OF CLIMATE RELEVANCE FOR TRANSPORT INFRASTRUCTURE

The following criteria were identified to check the climate readiness of a transport infrastructure project in any phase of its life cycle (Fig. 2).

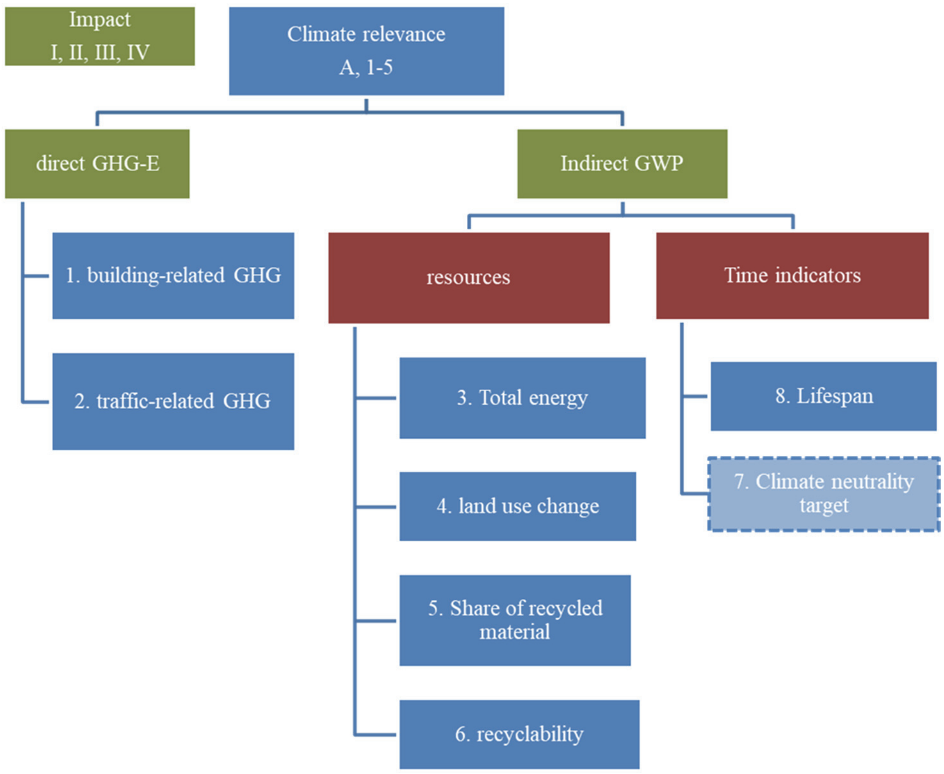


Fig. 2. Criteria to evaluate the climate relevance of transport infrastructure

2.1. Greenhouse gas emissions (GHG-E)

GHG-E of various greenhouse gases are scaled uniformly based on their respective GWP (global warming potential) in accordance with ISO 14064-1 and ISO 14067. The GWP is given in CO_2 equivalents [CO_2eq] and is related to a functional unit. Various quantities can be considered as functional units, such as CO_2eq per unit of fossil fuel [kg CO_2eq/kg], per vehicle kilometre [kg CO_2eq/Vehkm] or per building material used [kg CO_2eq/t or m^3] as well as per unit area of built-up building surface [kg CO_2eq/m^2]. The GWP as an environmental impact of a process, product or building can be determined using the life cycle assessment method in accordance with EN ISO 14040.

Since the RVS guidelines are applied in the planning phase of infrastructure measures such as alternative road or railway corridors as well as building specific roads or railway infrastructure, a differentiation is made between:

i. building-related GHG-E and
ii. traffic-related GHG emissions.

(i) includes GWP related to new constructions caused by the production of building materials and the construction of a building (construction measures, transportation, construction operations, etc.) in life cycle phases A1 up to A5. It is referred to as embodied emissions. On the other hand, the GWP resulting from maintenance, repair and renewal measures in the use phase (life cycle phases B1 to B7) and GWP at the end of life of a building due to dismantling, demolition and disposal (life cycle phases C1 to C4) also count as construction-related GWP. In the ideal case of a circular economy, GWP from reused or recycled materials can be credited in a second building life cycle to reduce emissions, provided that the system boundaries or the period under consideration are extended (life cycle module D). (ii) refers to the GWP caused by traffic. Each vehicle produces some GHG-E per distance travelled. An infrastructure which will lead to higher Vehkm will generate more GHG-E. When determining the GHG-E caused by the infrastructure and traffic, the definition of the study area and the observation period is of decisive importance.

2.2. Life cycle assessment

Life cycle assessment (LCA) is a systematic analysis of several ecological indicators of products, processes, services and buildings in their entire life cycle or in declared parts of the life cycle and is standardized in EN ISO 14040/44. In addition to GWP [t CO_2eq] and primary energy demand [J], other indicators (e.g. ODP ozone depletion potential, AP acidification potential of soil and water, PERT = total renewable primary energy; PENRT = total non-renewable primary energy) are also specified as indicators in an LCA.

The life cycle of a building describes the period between its construction and demolition. According to the LCA method, the entire life cycle of a building comprises the production phase (modules A1–A3 of raw material extraction, transportation to the manufacturer, production) and the erection phase (A4: transportation to the construction site, A5: installation), the use phase (B1–B7), the disposal phase (C1–C4) and the benefits and loads outside the system boundary (module D, informative). The entire life cycle is cradle to grave or ideally takes place in a circular economy (cradle to cradle). Construction products are often only declared for parts of their life cycle.

The life cycle assessment data of construction products is made available to users by environmental product declarations (EPDs) in free or paid databases, for example: ÖKOBAUDAT (https://www.oekobaudat.de), GaBi (https://gabi.sphera.com) and the Life Cycle Inventory (http://www.ecoinvent.org/database). Austrian research projects such as Decarbonization First VIF/FFG (2023) and LZinfra are also currently developing tools for the life cycle assessment of transport infrastructure.

A distinction is made between generic data, i.e. non-specific data from a group of products, association-specific data sets, i.e. industry EPDs, and company-specific data, i.e. product EPDs from individual manufacturers. The databases use both generic data from the literature and specific data in the form of industry EPDs or manufacturer EPDs as a basis. To create the EPDs, the production data for one year is usually recorded for each manufacturer or the entire industry. The EPD creators describe the data as a representative average, but no information is provided on fluctuation ranges in the declaration of environmental impacts. The EPDs are generally valid for 5 years. The declaration of ecological indicators is based on rules for product categories, for example for construction products in accordance with EN 15804. EPDs can be verified by an independent body. The assessment is carried out within declared system boundaries and can also be limited to certain life cycle phases, which seems particularly useful for building materials whose place of use is still unknown (e.g. phases A1–A3 of production – cradle to gate).

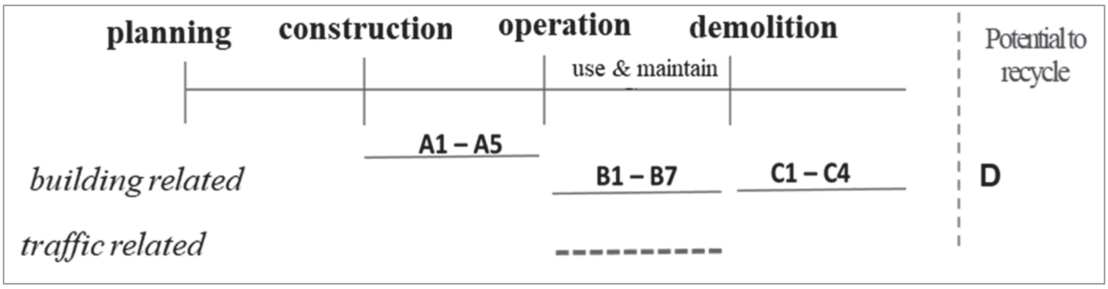


Fig. 3. GHG-E is distributed over life-cycle of an infrastructure project

The specification of ecological indicators of specific building materials (e.g. different types of cement, aggregates, asphalt types, steel types, etc.) enables the differentiated calculation of the GWP of different material mixtures (e.g. concrete types and asphalt types) as well as building types, construction and building methods. Their GWP can vary greatly. There is also a wide range of variation in the data for some building materials due to the different sources, balance limits and specificity.

Note: The analysis of climate-relevant indicators can be part of a more comprehensive sustainability assessment. Impacts of the construction and operation of buildings on sustainable development are assessed using quantitative indicators for (i) environmental, (ii) social and (iii) economic aspects. The sustainability assessment can be applied to all types of construction works according to EN 15643 or EN 17472. This goes beyond the climate relevance of GHG-E as being considered in future RVS guidelines.

2.3. Total energy

Energy consumption correlates with the (structural) production, construction and maintenance as well as with the traffic-related use of transportation structures. As the total energy demand is still largely covered by fossil (non-renewable) energy sources, it indirectly causes GHG emissions. Future energy demand depends on the success of the industrial transformation. Even in the event of a transition to renewable energy sources, the lowest possible use of primary energy for the construction and operation of road infrastructure as well as for the provision of transport services is a key objective.

2.4. Land use change

In the present analysis, land use change is understood as the use of previously undeveloped areas (green spaces, undeveloped or agricultural areas) for transport infrastructure. In a narrower sense, this refers only to areas which were previously biologically productive land.

2.5. Proportion of recycled material

The proportion of recycled material used, i.e. material or building material components that are recovered, processed and recycled for a second life cycle, should be as high as possible in terms of resource conservation in a circular economy under the premise of reducing GHG emissions to relieve the burden on landfills. The term recycled material refers to recyclable material in general and is broader than the specific term recycled building materials, which are defined in accordance with the Recycled Building Materials Ordinance. It also includes metals and wood, for example.

2.6. Recyclability

Recyclability refers to the ability of products, building components and structures to be returned to technical (or possibly organic) material cycles at the end of their life cycle, separated by type of material or usable element or to be reused as whole elements (reusability of entire components) instead of having to be disposed of. In particular, recyclability as a subset means that a component can be broken down into its basic materials, which are then reused as building materials.

The prerequisite for recyclability is that products or structures are designed and constructed in such a way that they can be easily separated and dismantled in a recycling-oriented manner (i.e. sorted and carefully dismantled in the course of demolition). The recycled material can also be used to manufacture new products, building materials or structures. The aim is to achieve a functioning circular economy under the premise of climate targets.

In addition to recycling within a specific sector, such as the construction sector, it also makes sense in terms of the cross-sectoral circular economy to design products or buildings in such a way that they can be recycled in an area that does not correspond to their original use. In the context of recycling-oriented deconstruction (disposal of materials obtained from products or buildings), emphasis should also be placed on increasing this proportion. Qualitative downcycling should be avoided.

2.7. Climate neutrality target

At the various political levels, the climate targets define dates by which net-zero GHG emissions are to be achieved. Austria aims to achieve climate neutrality by 2040. Fig. 4 illustrates the problematic nature of a specific time target for climate neutrality. Assuming two alternative infrastructure measures exist to solve a traffic problem; one construction-intensive with low traffic-related GHG-E (e.g. tunnel connecting two settlements directly) and a second scenario with low construction-related GHG-E at the start of construction but shorter maintenance intervals and significantly higher traffic-related GHG-E (e.g. a longer road between the settlements). Up to time t1, Scenario 2 is more favourable in terms of GHG-E, although scenario 1 performs better over the lifetime of the structures. If the time target of climate neutrality lies before time t1, scenario 2 is given preference over a complete life cycle assessment. Alternatively, only GHG compensation measures beyond the system boundaries could be taken together with scenario 2 in order to reduce GHG-E in the long term.

2.8. Lifespan

The service life of a building or product is the period between its construction or production and its demolition (dismantling) or disposal. The lifespan corresponds to the actual duration over which the infrastructure is used and may differ from the economic lifetime of an infrastructure represented by the depreciation period of a building. The lifespan of transport infrastructure varies widely between 30 years for roads and 100 years for tunnels disregarding maintenance efforts which may extend these periods.

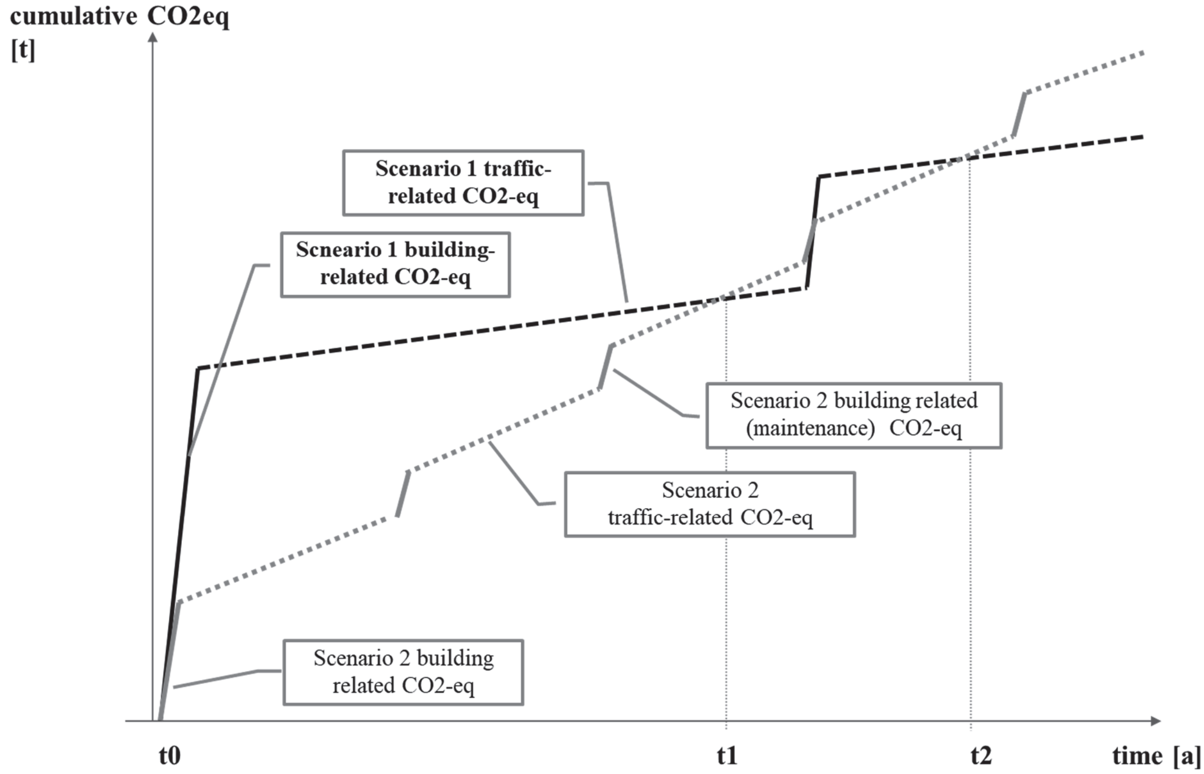


Fig. 4. Accumulated building and traffic related GHG-E for two scenarios during the lifespan of a transport infrastructure

3. EVALUATION OF RVS AND RVE GUIDELINES

Each RVS and RVE has been evaluated subject to the climate criteria (Fig. 2). Each criteria was classified from 1 to 5, if the topic is addressed in the particular guideline; otherwise it was classified as A (not relevant) according to Fig. 1. About half of the RVS guidelines (162 out of 309) have no climate relevance such as guidelines on traffic counts or traffic information.

The importance of the remaining guidelines was classified by an impact value ranging from I (very high impact) to IV (very low impact). The impact value describes how often the guideline is applied and the typical project size. Guidelines with climate relevant criteria (value 1 or 2) and noticeable impact (value I or II) were identified as priority guidelines. Tab. 1 contains all 37 guidelines which are recommended to be addressed in the near future. Most of these guidelines are currently only available in German. However, guidelines with requests from other countries will be translated to English.

Three examples of the prioritized guidelines will illustrate the findings. The RVS 03.08.63 is frequently applied for all pavement designs since it gives guidelines about the constructive details of superstructures. It defines material properties (asphalt, concrete, stabilized base layers) and layer thickness as a function of load classes.

Tab. 1. 37 RVS road guidelines were identified to incorporate the GWP in the next future

RVS_No	German Title	English Title
RVS 01.03.11	Gestaltung und Aufbau einer RVS	
RVS 02.01.11	Grundsätze der Verkehrsplanung	
RVS 02.01.22	Nutzen-Kosten-Untersuchung im Verkehrswesen	
RVS 03.01.11	Beurteilung des Verkehrsablaufs auf Straßen	
RVS 03.03.23	Linienführung und Trassierung	
RVS 03.03.31	Querschnittselemente sowie Verkehrs- und Lichtraum von Freilandstraßen	Cross-section Elements and Envelopes of Clearance of Rural Roads
RVS 03.03.81	Ländliche Straßen und Güterwege	
RVS 03.04.12	Planung und Entwurf von Innerortsstraßen	
RVS 03.05.13	Gemischte und planfreie Knoten	
RVS 03.08.63	Oberbaubemessung	
RVS 04.01.11	Umweltuntersuchung	Environmental Assessment
RVS 04.01.12	Umweltmaßnahmen	
RVS 04.02.12	Ausbreitung von Luftschadstoffen und Tunnelportalen	Dispersion of Airborne Pollutants from Transport Routes and Tunnel Portals
RVS 05.02.11	Anforderungen und Aufstellung	
RVS 05.04.31	Einsatzkriterien Verkehrslichtsignalanlagen	
RVS 05.04.32	Planen von Verkehrslichtsignalanlagen	
RVS 07	Leistungsbeschreibung	
RVS 08.03.01	Erdarbeiten	Earthworks
RVS 08.06.01	Beton und Stahlbeton	
RVS 08.06.02	Bewehrung	
RVS 08.08.01	Stahltragwerke	
RVS 08.15.01	Ungebundene Tragschichten	
RVS 08.15.02	Ungebundene Tragschichten an Asphaltschichten	
RVS 08.16.01	Anforderungen an Asphaltschichten	
RVS 08.17.02	Deckenherstellung	
RVS 08.43.01	Stützmaßnahmen UT	
RVS 08.97.05	Anforderungen an Asphaltmischgut	
RVS 08.97.06	Anforderungen an Asphaltmischgut – Gebrauchsverhaltensorientierter Ansatz	
RVS 09.01.41	Offene Bauweise	
RVS 09.01.42	Geschlossene Bauweise im Lockergestein unter Bebauung	
RVS 10.02.12	Zuschlagskriterien für Bauaufträge im Verkehrswegebau	
RVS 10.02.13	Value Engineering für Infrastrukturbauten	Value Engineering for Infrastructure
RVS 10.02.14	Alternativangebote für Infrastrukturbauten	
RVS 13.04.01	Allgemeiner Teil	
RVS 13.05.11	Lebenszykluskostenermittlung für Brücken	Calculation of Life-Cycle-Costs for Bridges
RVS 15.01.11	Qualitätskriterien für die Planung von Brücken	

The load class is defined by measured or forecasted traffic volumes and shares of truck volumes. Different forecasted traffic volumes will impact traffic related GHG-E and may influence the load class. Land use is not a topic within this guideline and as such marked with A (not relevant). Recycled material and lifespan are already addressed to a small extent in the current guideline and marked with 2. All other climate relevant criteria are not addressed in this guideline and marked as 1 (Tab 2).

Tab. 2. Climate criteria evaluated for RVS 03.08.63 dimensioning of road superstructure (Oberbaubemessung)

Building related GHG-E	Traffic related GHG-E	Total energy	Land use change	Recycled material	Recyclability	Lifespan
1	1	1	A	2	1	2

The RVS 08.08.01 looks at concrete as one specific materials used in road constructions. Therefore, traffic related GHG-E are not relevant (A not relevant) but all other climate criteria are relevant and not yet addressed in this guideline (Tab 3).

Tab. 3. Climate criteria evaluated for RVS 08.08.01 Concrete and Reinforced Concrete (Beton und Stahlbeton)

Building related GHG-E	Traffic related GHG-E	Total energy	Land use change	Recycled material	Recyclability	Lifespan
1	A	1	A	1	1	1

The recent RVS 10.02.12 published in 2023 defines contract award criteria for public works contracts (Tab. 4). In best bidder procedures, the contracting authorities have the option of specifying additional quality criteria to evaluate different bids in addition to the price during the tendering process. This recent RVS already provides the option of taking climate-friendly criteria into account. So far, however, only the criteria of recyclability are considered when awarding contracts in accordance with the RVS. A higher minimum weighting of climate-relevant indicators compared to other quality indicators would give the climate impact a greater influence when awarding construction projects.

Tab. 4. Climate criteria evaluated for RVS 10.02.12 Contract Award Criteria for Public Works (Zuschlagskriterien für Bauaufträge im Verkehrswegebau)

Building related GHG-E	Traffic related GHG-E	Total energy	Land use change	Recycled material	Recyclability	Lifespan
3	A	1	1	3	1	1

The Austrian motorway operator Asfinag already applied this RVS in some recent procurements and some pilot projects are under way.

4. CONCLUSIONS

In future infrastructure planning, a life cycle assessment (LCA) including GHG emissions will be increasingly used, applying LCA methods for different anticipated mobility scenarios. So far, LCA is applied to construction products, construction elements and individual structures. LCA should also be applied for full infrastructure projects, which also includes traffic-related GHG emission. The guidelines RVS and RVE will be prepared to include climate relevant criteria in the future for transportation projects of different size.

Starting a new guideline, the FSV requires a statement of the objectives, needs and audience of the guidelines (motive report). This statement contains now questions on the eight climate relevant criteria according to Fig. 2.

When implementing climate-relevant criteria in future RVS/RVE, their quantitative assessment is required. For the quantitative determination of GHG-E (CO_2eq/GWP), the methodology LCA according to EN ISO 14040 and 14044:20212, the ecological sustainability assessment of engineering structures according to ÖNORM EN 15643:2021 4 as well as EN 15978:2012 and EN 17472:2020:03 (2020) and the preparation of environmental product declarations for construction products according to ÖNORM EN 15804:2022 3 can be used. A method to quantify other criteria, such as land use, should be developed in a cross-sectional group of the FSV in the future.

A reduction in GHG-E through a revision of the RVS can be achieved at three different levels of new road infrastructure:

1. At the strategic level of transport planning, GHG-E should be determined by a mandatory quantitative study showing CO_2eq per infrastructure scenario as the sum of traffic-related (CO_2eq × transport performance) and construction-related GHG-E (i.e. CO_2eq/over a defined observation period). Decisions on new road and rail infrastructure should consider total CO_2eq as one indicator besides safety and efficiency.
2. At the level of tendering, awarding and building new roads, a quantitative LCA of construction-related GHG-E should be mandatory. The indirect climate relevant indicators of Fig. 2 should be considered if appropriate.
3. At the level of construction products, construction elements and construction methods, it is recommended that the calculation of GHG-E is done in detail. The embodied emissions must be declared applying appropriate environmental product declarations (EPD´s). The definition of suitable EPD´s will be a continuous effort and must be mentioned in future guidelines.

5. REFERENCES

EN 15643 (2021), “Sustainability of construction works – Framework for assessment of buildings and civil engineering works”.

EN 15804 (2020), “Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products”.

EN 17472 (2022), “Sustainability of construction works. Sustainability assessment of civil engineering works. Calculation methods”.

Fellendorf, M., Heck, D., Juhart, J. and Steininger, K. (2023), “Klimacheck RVS/RVE – Überprüfung bestehender RVS/RVE auf Klimaberträglichkeit und Festlegung der Vorgangsweise für die Neuerstellung von RVS/RVE”, Studie im Auftrag der FSV, Graz.

ISO 14040 (2006), “Environmental management – Life cycle assessment – Principles and framework”.

ISO 14064 (2018), “Greenhouse gases - Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals”.

ISO 14067 (2018), “Greenhouse gases – Carbon footprint of products – Requirements and guidelines for quantification”.

THE EVOLUTION OF THE RAILWAY SYSTEM OF THE EUROPEAN UNION FROM A REGULATORY PERSPECTIVE

Josef Doppelbauer
European Union Agency for Railways (ERA)
120 rue Marc Lefrancq, FR-59307 Valenciennes

SUMMARY

Transport is fundamental for social and economic development, but, on the other hand, the transport sector contributes 25% of Greenhouse Gas emissions in the European Union, and, unlike other sectors, transport emissions have not decreased in the last 20 years. Rail as a guided transport system with low friction has excellent environmentally friendly properties. In order to reach the decarbonisation objectives for transport, volumes need to shift more and more to sustainable modes, especially to rail. In addition to the outstanding environmental characteristics of rail – one passenger kilometre by train consumes only about one tenth of the energy as compared to a private car – safety (rail is the safest mode of transport) and convenience also speak for the train. Challenges for rail arise in terms of price and quality – delays and train cancellations cloud the positive balance. Our vision for the European railway system is to no longer have any technical or operational boundaries, thereby providing freedom of movement, and standardisation in order to achieve economies of scale. Coordinated evolution towards the Single European Railway Area (SERA) needs a proper regulatory basis, which is provided by the regulation on the Trans-European Network (TEN-T) and by the Technical Specifications for interoperability, in particular for Control, Command and Signalling (CCS). Managing the rail capacity across the network is another important subject that needs to be addressed by European regulation as well.

1. INTRODUCTION

As the European railway system is a complicated system with competing national and contractual interests, with complicated procedures and complicated liability rules, development of both passenger rail and rail freight in the EU have not met political objectives. A modal shift to rail has been an EU policy target since quite some time – however, in reality, over the past years the modal share of rail has been stable if not slightly declining. As the carbon crisis connected to climate change is imminent, the timing of measures is important – the earlier the effect, the better it will be for the environment. The rail modal share across borders is still significantly lower than the domestic one. The fragmentation of the railway system, both from an operational and from a governance perspective, creates dependencies, diffusion of accountability and systemic risks such as the difficulty in coordinating big investments.

In addition, the last few years have been marked by crises – first the COVID pandemic, then the energy crisis triggered by the Russian aggression in the Ukraine. These crises have not left the European transport sector unscathed, both mobility patterns and supply chains have been impacted. The recent revival of passenger and freight transport can therefore be considered as a success. Secondly, the renewed interest in night trains can also be mentioned, and, from the point of view of the European Union Railway Agency, the convincing establishment of the European rail vehicle authorisation process since 2019. With now more than 80,000 vehicles authorised so far, the Agency covers most of these procedures in the European Union, swiftly and in a transparent process, thereby encouraging and facilitating harmonisation for cross-border operation.

The difficulties affecting cross-border rail (this is where there would be the most significant growth potential for rail) by adding cost and delays have serious consequences, as rail freight is in heavy competition with road transport, while passenger rail competes with both road and with short distance flights.

The Agency continues to work towards the reduction of technical and operations barriers within the rail market through, among others, on the amendment of TSIs to be aligned with the technical innovations, the harmonisation of national rules among the Member States, and supporting the deployment of ERTMS as System Authority. The Agency will also continue to foster developments in the field of digitalization, such as Linked data, databases and registers optimisation as well as developments under the TAP TSI. The digitalisation of the transport sector will offer better accessibility for customers, and the integration of the different transport modes into a multimodal transport system will expand the offer, while optimizing environmental sustainability.

2. RAIL AND THE ENVIRONMENT

In our transport system, rail is the mass transport mode with the lowest greenhouse gas emissions and the lowest external costs, the highest degree of energy independence (especially if the electricity comes from the EU's renewable sources), the highest efficiency in land-take and the most durable assets. These factors give rail several green competitive advantages over other modes of transport and the potential to become the backbone of a green multimodal transport system.

Even if rail is more environmentally friendly than the other modes of transport, the railway sector still has an impact on the environment; railway noise is the most important effect, with 22 million Europeans exposed. Rail transport also emits greenhouse gases and other pollutants but to a negligible level compared with other modes of transport, producing only 0.4 % of the greenhouse gas emissions in the transport sector. Finally, land is used to build infrastructures, with long-term effects on nature conservation and biodiversity.

Despite being the most sustainable mode of transport, railways have been unable to increase their modal share in the transport mix in the past decade. Rail is the most sustainable, affordable and effective transport mode to meet the goal of decarbonisation. However, trains need to run alongside and in cooperation with other modes of transport to carry goods and people in the most effective way. Such a multimodal approach requires the seamless integration of the transport modes, facilitated by digital technologies.

3. TRANS-EUROPEAN NETWORK FOR TRANSPORT (TEN-T)

The EU's trans-European transport network policy, the TEN-T policy, is key for transport planning and operation. Developing a coherent, efficient, multimodal, and high-quality transport infrastructure across the European Union needs appropriate instruments. The revised Regulation on the Trans-European Network for Transport (TEN-T) Guidelines was adopted by the European Parliament in the first half of 2024. This is a fundamental step towards achieving a single European railway area.

The concept of a Trans-European Transport Network (TEN-T) is essential for the coordination of major rail projects, physical and digital, across Europe. The overall development of European rail corridors including cross-border, regional and high-speed infrastructure, will help to shift more passengers and freight to sustainable modes like rail and meet the European Green Deal targets. The new regulation is to be considered as a key action of the European Green Deal and the European Commission Sustainable and Intelligent Mobility Strategy, and aims to:

- Make European transport grow in a more sustainable, environmentally friendly way, reducing greenhouse gas emissions and pollution and improving its efficiency,
- Develop more fluid and efficient transport, eliminating existing bottlenecks and improving interoperability and multimodality,
- Increase the resilience of the TEN-T to climate change and other disruptive situations, and
- To improve the governance of the TEN-T.

In short, the idea is to build an effective and efficient multimodal network in Europe of railroads, roads, inland waterways, short sea shipping routes interconnected with each other and with urban nodes, seaports, inland ports, airports and intermodal terminals. Among the main elements of the provisions are:

- The rail infrastructure must allow for both the core network and the extended core network to allow passenger trains to run at speeds of 160 km/h or higher from 2040 onwards.
- The technical requirements established in the previous Regulation are maintained: the railway network must allow the circulation of trains of 740 m in length and with an axle weight of 22.5 tons and provides for a nominal track gauge for new railway lines of 1,435 mm.
- Railway tracks must be adapted to at least a P400 standard (reference P400 defines the standard according to which the maximum height at which a semi-trailer can be transported on a train is limited to four meters).
- The compulsory deployment of the European Rail Traffic Management System (ERTMS) on the three networks, with clear deadlines, progressively replacing the signalling and safety systems of each country.
- Better and faster connections for passengers and freight with urban areas, ports, airports, and multimodal freight terminals.
- The migration to the European standard nominal track gauge with exemptions.
- Airports with more than 12 million passengers to be connected to the trans-European railway network, including the high-speed railway network where possible;
- Operational parameters are introduced in infrastructure management. For example, the average waiting time for a train at the border should not exceed 15 minutes and 90% of international trains should arrive at their destination with a delay of less than 30 minutes.
- The number and handling capacity of the intermodal terminals must be adapted to the expected growth in traffic flows, as well as to allow the circulation of 740 m long trains on the network.

The trans-European transport network must also improve transport connections with the EU's neighbouring countries. In this respect the European Transport Corridors (ETCs) integrate Ukraine and Moldova and the six Western Balkan partners into the new regulation. In particular, four transport corridors go into Ukraine (North Sea – Baltic, Rhine – Danube, Mediterranean and Baltic Sea – Black Sea – Aegean Sea), while the Western Balkans – Eastern Mediterranean corridor goes into the Balkans. The new TEN-T maps will significantly contribute to improving connectivity between Ukraine and Moldova with the European Union.

3.1. Gradual development

For each type of infrastructure (rail, road, maritime, airports, inland waterways, intermodal terminals and urban nodes), the regulation defines the infrastructure components. That is, the elements included in the infrastructure, the requirements that these components must meet for both the overall network and the core network, and the additional priorities for their development.

The Regulation proposes a gradual development of the TEN-T in three stages: a core network to be implemented by 2030; an extended core network to be completed by 2040; and a comprehensive network to be completed by 2050. In fact, the core network and the extended core network consist of parts of the trans-European transport network that must be developed as a matter of priority in order to achieve the objectives set.

The revised TEN-T Guidelines introduce ambitious requirements and challenging provisions that should come hand-in-hand with equally ambitious financing and funding mechanisms. Massive investments are needed to complete the TEN-T network: €500 billion is needed by 2030 for the core network and €1,500 billion is needed by 2050 for the comprehensive network.

3.2. Military mobility

In response to Russia's aggression against Ukraine, the Commission has reinforced its support for dual-use transport infrastructures for military mobility. The EU Action Plan on Military Mobility 2.0 reflects the work developed in this regard.

To harmonize the rules for the trans-European transport network and the EU military transport network, in late 2023 the Council adopted revised military requirements, the scope of which covers logistics hubs, fuel supply chain infrastructure, lessons learned from the Russia-Ukraine war and military criteria for the evaluation of proposals for dual-use infrastructure projects.

4. ERTMS

The idea behind the European Rail Traffic Management System (ERTMS) is European integration in the area of train protection and signalling, thereby achieving technical compatibility, and a way into the future that is based on cooperation.

The deployment of ERTMS (consisting of ETCS and the radio system GSM-R) is crucial for the modernisation of Europe's railway infrastructure and is being meticulously coordinated at both national and European levels. The revised TEN-T regulation has established specific milestones to guide the comprehensive deployment of ERTMS across Europe. By 2030, the goal is to complete the TEN-T core network according to existing TEN-T standards, which include the electrification of the entire rail network and the capability to operate 740-meter trains. This initial phase focuses on upgrading infrastructure to meet these standards, ensuring a solid foundation for further enhancements.

By 2040, the ERTMS deployment on the extended core network is expected to be completed, adhering to new standards such as a minimum line speed of 160 km/h for passenger rail. This milestone also emphasizes green transport initiatives and enhanced digitalisation, aiming to deploy ERTMS on the entire TEN-T network while phasing out national systems. The addition of the 2040 milestone is a strategic move to accelerate the network's completion, aligning with the EU's climate ambitions for 2050.

The final milestone, set for 2050, targets the completion of the entire Trans-European Transport Network, encompassing all sections within the comprehensive network. This long-term goal envisions a fully integrated, efficient, and interoperable rail system across Europe, with ERTMS as its backbone.

4.1. Progress and Challenges across Member States

Significant progress has been made in several Member States regarding ERTMS deployment, although the pace and approach vary widely. Luxembourg stands out as a frontrunner, having completed ERTMS deployment across its entire network. Belgium has also made notable strides, equipping over 60% of its network and targeting full deployment by the end of 2025. Italy is leveraging financing from the EU Recovery and Resilience Fund to advance its ERTMS deployment, demonstrating a robust commitment to modernizing its rail infrastructure.

In contrast, larger transit countries such as France and Germany face more complex challenges. However, Germany's flagship projects, such as the Stuttgart-Ulm corridor, provide optimism for meeting the TEN-T network's milestones despite current budget constraints. The varied progress highlights different motivations and obstacles across Member States. For instance, Denmark's ERTMS rollout is driven by the obsolescence of its current system, while Belgium focuses on enhancing safety. Italy, on the other hand, prioritizes increased capacity and digitalization.

The deployment process is not without hurdles. Financial constraints and a shortage of skilled labour pose significant challenges. Additionally, upgrading standard infrastructure like interlockings requires considerable time and financial resources. Compatibility testing for new systems further complicates the deployment, often causing delays. Despite these challenges, the revised TEN-T regulation and the establishment of the "ERTMS Forum" have improved coordination at the EU level. This forum integrates national implementation plans into a cohesive European master plan, providing a realistic and transparent approach to ERTMS deployment.

4.2. The 2023 Revision of the TSI CCS

ETCS has reached a level of maturity where its specifications are well-established and stable. The Technical Specifications for Interoperability for Control, Command and Signalling (CCS TSI) underwent a significant overhaul in 2023, incorporating new functionalities and preparing for future technological integrations. The 2023 revision of the CCS TSI introduced several critical updates, including functionalities for Automatic Train Operation (ATO) and preparations for the Future Railway Mobile Communication System (FRMCS). These updates are designed to enhance the system's capabilities and ensure its readiness for future technological advancements. Importantly, all errors identified in the 2016 version have been corrected, providing a robust and reliable foundation for ERTMS.

ERA continues to play a pivotal role as ERTMS System Authority in maintaining and updating the ETCS specifications. Currently, ERA is addressing minor issues in the 2023 version of the CCS TSI and preparing for the next major review scheduled for 2027. The stability of the specifications over recent years has ensured backward compatibility, facilitating seamless integration of new functionalities into the existing system.

4.3. Outlook for ERTMS

One of the most significant upcoming advancements for ETCS is the integration of the Future Railway Mobile Communication System (FRMCS). Essentially triggered by the obsolescence of GSM-R. FRMCS represents the next generation of mobile communication for railways (corresponding to 5G). ERA is currently reviewing the second batch of FRMCS specifications, which will form the basis for extensive testing in 2025-2026. The results of these tests will feed into the 2027 TSI revision, paving the way for the market readiness of the FRMCS radio component.

Another exciting prospect for ETCS is the introduction of higher Grades of Automation (GoA), specifically GoA 3 and 4. These levels of automation will enable fully automated train operations, significantly improving operational efficiency and safety. The integration of ATO functionalities into ETCS is a critical step towards realising this vision, providing the technical foundation for advanced automation.

ATO GoA 3 involves unattended train operations, where trains operate autonomously but with on-board attendants available to handle emergencies. GoA 4 represents fully autonomous train operations, with no on-board staff required. The transition to these higher levels of automation will require significant technological advancements and rigorous testing, but the potential benefits in terms of efficiency, capacity, and safety are substantial.

The potential integration of satellite technology into train communication systems is another promising development for ETCS. Satellite-based communication can significantly reduce the costs associated with trackside equipment, which currently represents a substantial portion of the infrastructure investment for train control systems. By leveraging satellite technology, rail operators can achieve more reliable and cost-effective communication solutions, enhancing the overall efficiency and resilience of the railway network.

Satellite technology can also improve coverage in remote and challenging terrains, where traditional communication infrastructure may be difficult or expensive to deploy. This capability is particularly relevant for expanding rail services to underserved areas, contributing to a more inclusive and comprehensive transportation network.

Looking ahead, the future of ETCS is characterized by a blend of stability and innovation. The system's maturity and well-established specifications provide a solid foundation for ongoing enhancements, while new technologies such as ATO and satellite communication promise to expand its capabilities. The coordinated efforts at the EU level, guided by the revised TEN-T regulation and the ERTMS Forum, ensure a transparent and realistic approach to ERTMS deployment and evolution.

5. RAIL CAPACITY MANAGEMENT

The railway network needs not only to be built, technically fitted, and maintained according to the appropriate parameters – it also needs to be properly managed, in order to deliver the required performance. Infrastructure Managers must manage the network to make the best possible use it, satisfying to the extent possible all railway undertakings' requests, while finding time for maintenance and development work on the infrastructure. Infrastructure capacity and traffic management involves exchanges with the railway undertakings and ultimately results in a timetable of rail services. In order to be efficient, in particular for long distance freight, rail capacity and traffic management must operate across borders – it cannot be that, for example, for rail freight across three countries, the first country would offer two freight train paths per hour, the second country two, and the third only one In the context of the Greening Freight package, the European Commission in July 2023 has published a proposal for a Railway Infrastructure Capacity Regulation. The proposal is intended to optimise railway capacity, improve cross-border coordination, increase punctuality and reliability, and ultimately attract more freight to rail. This proposal has in turn been amended by the European Parliament, and finally been discussed in the Council of the European Union.

In June 2024, the Council adopted a General Approach on the Commission proposal. The Council partially reverts the Commission intentions, in a move towards making European rules proposed by the Commission unbinding and open to national derogations. This will lead to a situation where rail freight continues to operate on various national patchworks. It will mean continued fragmentation and sub-optimal exploitation of the available European railway infrastructure capacity and, crucially, an inadequate support to European supply chains. In the coming months, the final text of the Capacity Management Regulation will be negotiated between the European Institutions.

6. CONCLUSIONS

Rail is by far the most energy-efficient mode of transport, and very safe. However, the modal share of rail in the European Union is low – a modal shift to rail needs targeted investment in a coherent, integrated European network. The 2024 revision of the TEN-T Regulation provides the legal basis for the evolution of the network. In summary, the objective is Europeanization – from a patchwork of national systems to a European network – this will require standardization and interoperability, in particular for the Control, Command and Signalling system. ERA as System Authority for ERTMS and as Authorising Entity will continue to support the transformation to the Single European Railway Area, supporting also the multimodal integration along the transport chain, and digitalisation towards an intelligent railway network. The fundamental objective remains to achieve a sustainable, efficient, and interoperable rail network across Europe by 2050, with its performance managed by an efficient cross-border capacity management framework.

7. REFERENCES

Joint Communication of the European Parliament and the Council (10.11.2022), "Action plan on military mobility 2.0".

Commission Implementing Regulation (EU) 2023/1695 of 10 August 2023 on the technical specification for interoperability relating to the control-command and signalling subsystems of the rail system in the European Union and repealing Regulation (EU) 2016/919.

European Union Agency for Railways (June 2024), "Rail Environmental Report".

Green Deal: Greening freight for more economic gain with less environmental impact (July 2023).

Regulation (EU) 2024/1679 of the European Parliament and of the Council of 13 June 2024 on Union guidelines for the development of the trans-European transport network, amending Regulations (EU) 2021/1153 and (EU) No 913/2010 and repealing Regulation (EU) No 1315/2013.

European Commission (9.12.2020), "Sustainable and Smart Mobility Strategy – putting European transport on track for the future".

MINIMISING THE ENVIRONMENTAL IMPACT OF THE USE OF GRITTING AGENTS IN WINTER ROAD MAINTENANCE (RVS 12.04.15) REPORT ON THE STATUS OF THE REVISION

Dr. Peter Nutz
City of Vienna, Municipal Department 48
peter.nutz@wien.gv.at

SUMMARY

This paper details the need for updating the regulations regarding the use of gritting agents for winter road maintenance. It highlights the requirements for road safety and the environmental impacts of such agents. Four main groups are involved: road users, society, the environment, and road authorities. Each has different, often conflicting, objectives that need to be balanced. Reduction of gritting material is key for the environment. The document emphasizes balancing safety, environmental protection, and cost-effectiveness in winter road maintenance. It calls for updated practices and regulations to minimize environmental impacts while ensuring road safety.

1. NEED FOR UPDATING

The requirements for road safety in winter road conditions necessitate the use of grit or de-icing agents in winter road maintenance. Their material requirements are regulated in RVS 12.04.16 Gritting agents, which has been revised as a result of the further development of pre-wetted salt or brine spreading.

The revision of RVS 12.04.16 (gritting agents) means that RVS 12.04.15 (environmental impact of gritting agents) and the associated working paper no. 11 must also be updated and merged into the new RVS 12.04.15.

2. PARTICIPANTS OF WINTER SERVICE

There are at least four groups of stakeholders whose objectives are sometimes diametrically opposed. However, with the exception of road user the optimisation of winter road maintenance can only be done by the road operator. The road operator can only optimise winter road maintenance at the interface between the demands on themselves, the users, the environment and society. A further complication is the very tight budget, which must be utilised in the best way possible in order to meet all of these requirements. Fig. 1 shows the four groups and their narrow interfaces.

First and foremost, road users want to get to their destination safely and quickly. Ideally, the road should therefore always be dry and undamaged. A snow-covered road can only be driven on safely at an appropriate (reduced) speed. This results in an undesirable loss of time, which causes many road users to complain to the road operators. Furthermore, a high level of driving comfort, which is partly lost due to the higher demands on driving skills.

For economic reasons, society as a whole attaches great importance to a safe transport system. Accidents, traffic jams and similar traffic obstructions have a negative impact on the overall system and should be minimised as far as possible through appropriate measures and legislation. In addition, a balance between the individual groups is important to society, as any injustices can lead to resentment.

Above all, the environment is interested in minimising, or preferably eliminating, the impact of winter road maintenance. From this point of view, the best winter service is the one that is not carried out at all. Neither plants and animals nor habitats should be damaged. In addition to the direct effects of gritting materials, noise, pollutant emissions, etc. must also be taken into account.

It is now up to the road operator to resolve these target conflicts and carry out the winter service operationally. If winter road maintenance is done properly, the operator also expects legal certainty with regard to claims for damages following accidents caused by excessive speed on winter road surfaces, for example. However, the funds should be used economically; the road operator is not compensated for any economic damage prevented. In the case of a traffic-based toll, however, lower traffic volumes due to weather conditions result in direct financial losses, which are to be avoided by the winter road maintenance service.

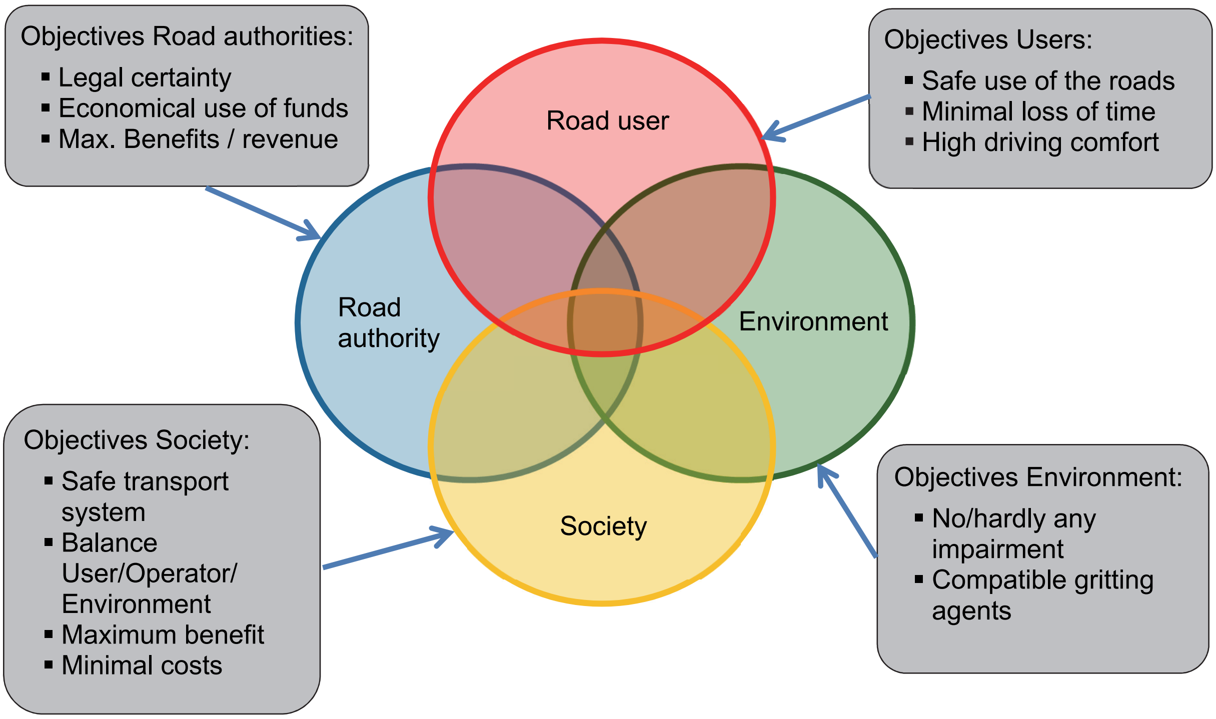


Fig. 1. Participants of winter road maintenance

3. TYPES OF GRITTING OR DE-ICING MATERIAL

3.1. Abrasives

In contrast to de-icing agents, abrasives work on a mechanical level and therefore immediately after application and regardless of the temperature. The mode of action is to provide the tyre with additional rock tips, which can be used to transfer horizontal forces. On the side of the carriageway, individual grains of grit jam in ice or snow and transfer the corresponding horizontal forces. The advantage of grit spreading lies in its immediate effectiveness after spreading and the increase in grip even on already packed snow surfaces, as the grit is pressed into the snow or ice when vehicles drive over the snow surface. De-icing agents on the other hand, need a certain amount of time (5 min to 60 min) to develop their full effect in the loose snow, but immediately begin to have a thawing effect. However, if the snow cover is thicker than the grit diameter, the grit has hardly any effect.

Due to the relatively rapid displacement of the grit from the rolling lane, de-icing grit is primarily suitable for low-traffic municipal roads. In addition, grit can also be used on roads where salting is prohibited, although the disadvantages mentioned must be accepted. In urban areas, grit can also be used for the maintenance of pavements.

3.2. De-icers

De-icers covers all gritting materials that use a chemical process to lower the freezing point of water aggregates below the road surface temperature and thus prevent slippery roads. In general, these are salts, applied to the road surface forming a solution with rain, snow, frost or dew. The aim of salt spreading is to prevent the formation of ice by lowering the freezing point of the solution or brine below that of the road surface temperature.

The de-icing agents used in winter road maintenance lower the freezing point further and further as the concentration increases until the so-called eutectic point is reached. This point refers to the concentration with the associated freezing point from which further increases in concentration do not lead to a further reduction in freezing point. The amount of snow or ice that a de-icing agent de-icing agent can be converted into liquid is therefore limited and strongly dependent on the ambient temperature.

De-icing agents are the means of choice on motorways, motorways, national roads and in larger cities in Europe. Due to the rapid development of pre-wetted salt technology and the associated low salt consumption, there is a general trend towards de-icing agents.

While many chemicals are able to work as de-icers in the laboratory for winter service sodium chloride is the main de-icer. It is effective, save to use, cheap and compared to many others better to the environment.

4. APPLICATION METHODS

The simplest, but also the most inefficient way to spread grit is by hand, which is practically only used by individuals to spread smaller areas like driveways or pavements. For use in winter road maintenance, mechanical spreading using a spreading disc has become established, which ensures that the spreading material is spread evenly. The spreading material is conveyed from the hopper into a downpipe via augers or belts and falls onto the rotating spreading disc and is thrown onto the road surface. While the spreading disc on older or simpler devices is fixed and runs at a rigidly coupled speed, the inclination of the spreader and the speed are controlled electronically on modern spreaders. This allows the driver to set spreading widths and quantities, which can be kept largely constant at different travelling speeds. New developments in winter service tend to apply liquid de-icing agents. Spreading dishes can be used after adaption. Also spraying bars with fine nozzles are in use.

4.1. Dry salt spreading

With dry salt spreading, as with grit spreading, only the dry, free-flowing spreading material (in this case salt) is spread via the spreading disc. This original method of spreading salt is now only common in smaller municipalities due to the high losses caused by drifting during spreading. The spreaders in these municipalities are often still designed for gritting and can therefore be used for dry salt spreading without any effort. The use of pre-wetted salt spreading is also not practical for small devices due to the restrictions imposed by the payload.

4.2. Pre-wetted salt spreading

The high losses caused by salt drifting directly during dry salt spreading were reduced by the introduction of pre-wetted salt spreading from the 1970s onwards. With pre-wetted salt spreading, dry, free-flowing salt is mixed with a salt solution on the spreading disc of the spreading vehicle and spread together. This enables better spreading and a more even spreading pattern with lower initial losses. The moisture in the brine causes the individual grains of salt to stick together and form larger clumps, which are less likely to be blown away by the wind and also adhere better to the road surface than dry grains of salt. In practice, this means that more salt is available for thawing snow or ice compared to dry salt spreading or that the same thawing effectiveness is achieved with lower salt consumption.

The salt solution used to moisten the dry salt usually has a concentration of between 18% and 23%. Sodium chloride, calcium chloride or magnesium chloride can be used to produce the solution. The salt solution is carried in a tank attached to the spreader, usually in a salt concentration of around 20%, originally to minimise the risk of freezing at very low temperatures. The salt solution is either supplied as a ready-mix in tankers or large canisters or produced at the bases themselves.

The brine and dry salt are only combined on the spreading disc immediately before spreading in order to avoid the formation of lumps in the device, which are difficult to remove. Depending on the manufacturer, this takes place either in the downpipe or directly at the spreading disc. The reason for this is the difficult storage of moist salt, which does not remain free-flowing and can therefore no longer be spread. The spreading disc must be visually checked for damage or salt residue before each spreading run in order to ensure a uniform spreading pattern. The longitudinal and lateral distribution on the carriageway is subsequently carried out by the traffic.

The mixing ratio between salt solution and dry salt is possible from 0% salt solution (dry spreading) to 100% salt solution (pure brine spreading), whereby a mixing ratio of 70% dry salt and 30% salt solution (FS 30) has proven itself in practice. Scientific studies, for example by (Badelt, 2007), also point to the good ratio between the amount of salt applied and low scattering losses in FS.

Studies from the 2013/2014 season in Lower Austria (Neuhold and Steininger, 2014) show that very good results can also be achieved with a degree of moistening of 50% to 70%, provided that the spreaders have been correctly calibrated. In these studies, the amount of residual salt was analysed at different degrees of moistening and the effect was evaluated by the drivers.

4.3. Brine spreading

Despite a significant reduction in initial losses due to the change from dry salt spreading to wet salt spreading, these are still very high at up to 60%. The obvious solution of further increasing the proportion of liquid in pre-wetted salt spreading is limited due to the unfavourable application of liquid via the spreading disc. Since around 2008 the use of brine sprayers, which spread brine via nozzles, has been under increasing consideration in Germany. The salt container on the vehicle is replaced by a large tank and the spreading disc by nozzles or spray bars. Due to the direct spraying of the brine onto the road surface, discharge losses can be kept to a minimum.

The biggest disadvantage of brine spreading in practice to date has been the low quantity of de-icing substance for the same load weight. On the one hand, this leads to small quantities of de-icing salt being applied for the same range or a shorter range when applying the same quantity of de-icing substance.

4.4. Spreading losses and further discharge by traffic

After the high initial losses immediately during and after the spreading process, a slower decrease of the salt takes place with asymptotic progression in the case of dry or wet roads. In this case, the salt is mainly transported from the rolling lanes to the edges of the road, as can also be seen with grit spreading. This type of salt loss is largely independent of time and is best related to the number of vehicles that have travelled since the road was treated. Fig. 2 shows three areas that mark typical zones for residual salt loss.

Blue: This area represents the very heavy losses shortly after spreading. The initial losses are included. In general, it can be seen that the residual salt content on the road very quickly drops below 10 g/m², especially with high spreading rates. High spreading rates should therefore generally be scrutinised.

Green: The majority of the measured values are in the green range, which represents the traffic losses. Salt also remains in the depressions of the road surface texture.

Red: In the red area, it is noticeable that despite a general decrease in the amount of residual salt, only a few measurements provide results below 2 g/m². This happens if there is so much water on the road the salt runs of with it. On dry or moist roads small amounts of salt remain on the road even after prolonged traffic influx. This can be particularly important in icy conditions.

Differences in the decrease in residual salt can be seen very clearly in one key parameter. As NaCl is a stable compound under atmospheric conditions, the quantity can only be reduced by mechanical displacement or dissolution in (precipitation) water.

Heavy losses without residual salt only occurred in the measurements carried out on wet road surfaces. When the road surface was dry or wet, a certain amount of the applied salt of approx. 0.5 g/m² to 3 /m² always remained on the road surface. In dry weather, a small amount of residual salt remains in the texture of the road surface for a longer period of time, which is available as a de-icing agent to form a separating layer when it rains. Only through precipitation the salt is completely removed from the road surface.

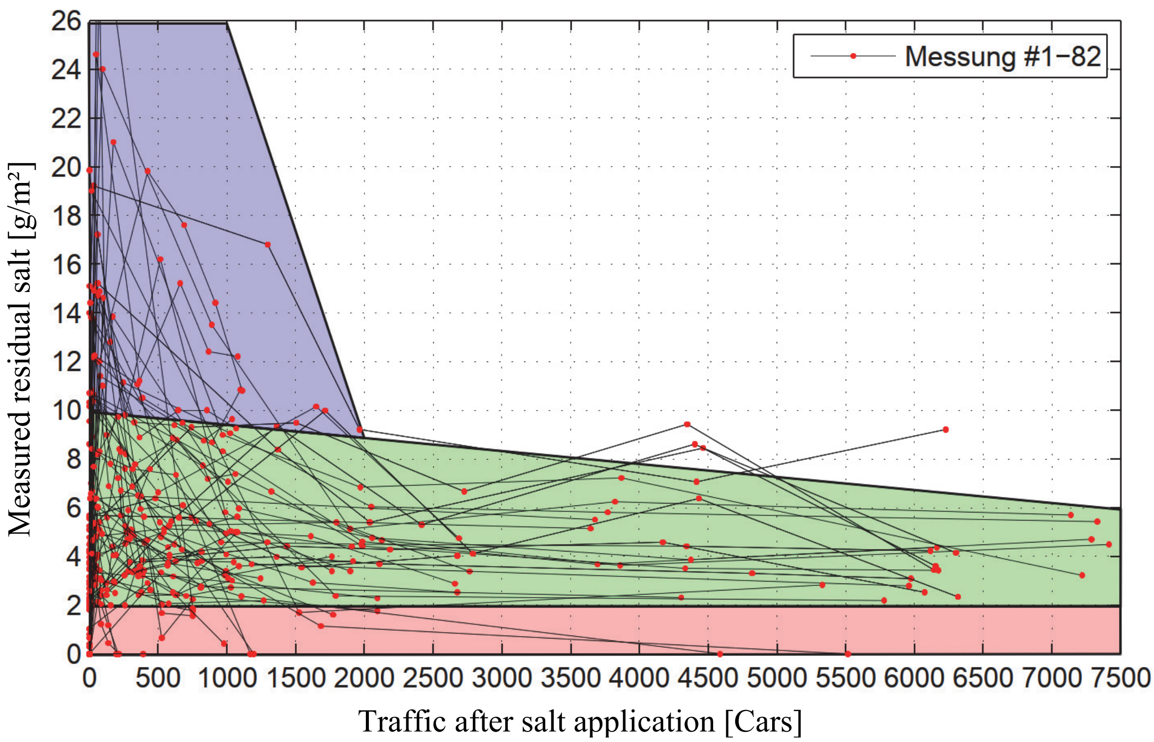


Fig. 2. Salt losses after treatment

With a deeper road surface texture and dry weather conditions, a small amount of residual salt can therefore still be expected on the road surface after one to two days. To summarise, the measurements show the lowest decreases in the amount of residual salt on a damp road surface (adhesive effect), the highest decreases on a wet road surface (splashing and washing off) and medium decreases on a dry road surface (swirling effect).

Further significant correlations could not be clearly recognised based on the available measurements.

5. ALTERNATIVES TO SODIUM CHLORIDE

Local authorities are constantly testing possible alternatives for sensitive areas. This is often encouraged by manufacturers of de-icing substances. They bring substances that are by-products or waste products from industry and have a de-icing effect onto the market as targeted alternatives to sodium chloride. It is also common for mixtures to be offered, whereby in most cases the de-icing substance is calcium chloride. In most cases, however, this is only recognisable after more detailed research, if at all. The exact composition of these de-icing agents is often not disclosed by the manufacturers.

A survey of the members of the winter road maintenance working group of the World Road Association PIARC shows a similar picture. Although alternative de-icing agents are occasionally used around the world, this is always as a test or in a very limited area. Sodium chloride is also the agent of choice worldwide for icy and snowy roads.

6. ENVIRONMENTAL IMPACT

6.1. Air quality

The use of grit in winter service creates dust, primarily due to the following causes:

- Dust as a result of friction between the individual grains when grit is prepared, manipulated and spread using spreaders.
- As soon as grit is mechanically stressed on the road by vehicle tyres, the material is additionally refined, which leads to further dust formation.
- Added to this – albeit to a lesser extent – is the increased abrasion of the road surface caused by grit and also the increased tyre abrasion.

The resistance of a rock to refinement and therefore also to the formation of fine dust depends on a number of parameters. For example, the mineral composition and microstructure properties of one and the same type of rock can have different effects on the strength and thus the formation of fine dust that occurs during mechanical stress.

In addition to this, when using deadening gritting agents, after around 400 vehicle passages, the grit is practically transported from the wheel tracks to the edge of the road and to the centre. This is one of the reasons why the use of grit is not recommended at higher traffic volumes - taking into account the condition of the road surface and the drainage of the road.

When using pre-wetted salt, dust is bound to the road surface and carried away with the melting water. As a result, the fine dust pollution is significantly lower than when using grit.

De-icing grit should only be applied in the form of pre-wetted salt or brine. As a result, the development of dust through preparation and manipulation as well as the spreading of the gritting material is completely eliminated.

After a road surface sprinkled with pre-wetted salt has dried, salt dust can be whirled up on the road surface, especially at low temperatures and low humidity, depending on the amount of residual salt.

One of the main effects of pre-wetted salt and pure brine spreading is that the fine dust particles caused by exhaust fumes, abrasion from tyres, brake and clutch linings, road abrasion, domestic, commercial and industrial fumes and deposits caused by wind erosion are carried away with the melt water via the drainage systems.

Dust generation can vary greatly when sweeping traffic areas. According to the state of the art, sweeping operations must always be carried out as "wet sweeping", as an uncontrollable amount of dust is released when "dry sweeping" is carried out. The most effective way to minimise the development of dust when cleaning roads is by washing. This must also be taken into account when maintaining secondary surfaces, pavements or footpaths and cycle paths. The sweepings must be recycled or disposed of in accordance with RVS 12.01.11 "Economical handling of road maintenance materials".

6.2. Soil

Soils around roads are among those locations that are most strongly influenced by thawing or gritting agents. Immediately next to the road, these are usually artificially compacted fill soils. The function of these soils as a habitat for organisms and as a root zone is additionally impaired by dryness and high soil temperatures, especially during the vegetation period. Overall, soils along roads are characterised by a high and small-scale variability of soil characteristics such as pore volume, grain size and density, which must be taken into account when assessing environmental influences.

Due to the lower anion absorption capacity of the soil, the chloride carried in by precipitation water is quickly transferred to deeper soil layers. Sodium, on the other hand, has a higher tendency to accumulate in soils. The leaching of de-icing salts into deeper soil layers is accompanied by increasing siltation and compaction. This makes it more difficult for plants to absorb water in the root zone, which in turn causes drought stress and leads to their death.

6.3. Vegetation

Plants can absorb salts in different ways:

- Uptake via the leaf surface (see leaf fertilisation),
- Uptake of soil water via roots.

Salt exposure can have the following direct effects on plants:

- Contact damage (e.g. corrosive effect through application to the leaf surface),
- Osmotic damage,
- Drought damage due to dead root tissue,
- Accumulation in the organism (necrosis when the species-specific damage thresholds are exceeded, leaf loss),
- Nutrient imbalances (e.g. disturbance of the potassium balance leads to problems with nitrogen uptake).

Contact damage generally only occurs within a few metres of the roadside. The much greater damaging effect of salts is caused to plants via the water absorbed by their roots.

The uptake of chloride via soil water is highly dependent on the local conditions. Relevant inputs of chloride can occur in the area of concentrated discharges or seepage. Unfavourable site conditions can lead to threshold values being exceeded. The absorbed chloride dose depends on the chloride concentration in the soil water and, above all, on the residence time of saline water in the root zone.

As it is primarily the soil moisture and not the groundwater that is relevant for vegetation, drinking water-related guideline values cannot necessarily be used as assessment values for the protection of plants. There is therefore no generally applicable limit value for chloride levels in groundwater that are tolerable in terms of vegetation protection. The actual influence of chloride on vegetation depends on the respective plant species (chloride tolerance), their site conditions and the distance from the ground.

According to the BMVIT guideline "Infiltration of chloride-contaminated water" (BMVIT, 2019), the chloride tolerance of crops must be taken into account when determining a guideline value for the permissible influence of chloride on industrial water extraction. Accordingly, compliance with an indicator value of 200 mg/l chloride is sufficient for the protection of less salt-sensitive agricultural crops. In the case of salt-sensitive special crops such as viticulture and fruit growing, damage to crops can occur at unfavourable locations at a chloride concentration of less than 100 mg/l, according to this guideline.

According to ÖWAV regulation sheet 407 (ÖWAV, 2016), irrigation water with a chloride content of less than 70 mg/l is suitable for almost all plants. At chloride levels between 70 and 140 mg/l, the water is only suitable for chloride-tolerant plants, but chloride-sensitive plants already show slight to moderate damage.

6.4. Water

In general, all bodies of water, including groundwater, must be kept clean and protected in the public interest so that, among other things, deterioration is avoided and the condition of ecosystems with regard to their water balance is protected and improved. In particular, groundwater and spring water must be kept so pure that it can be used as drinking water.

Surface waters must be kept clean so that surface waters can be used for public and commercial purposes and fish waters can be preserved. From an ecological point of view, the use of alternative de-icing agents such as urea, phosphate compounds, ammonium salts etc. is not an alternative to road salt in terms of water quality. Urea and ammonium salts also contain nitrogen, which pollutes the soil and ground and spring water.

As they are dissolved in the meltwater, de-icing agents can enter a receiving watercourse directly through the road drainage facilities. Chloride in the water can cause stress to algae and higher aquatic plants. This is due to the imbalance between intracellular and extracellular concentrations of inorganic ions (BMLFUW, 2014).

The anthropogenic chloride concentration in surface water is not exclusively due to salt scattering but can also originate from other chloride-containing media (e.g. fertilisers).

Freshwater organisms have developed different ways of adapting to changes in their environment. However, not all species can tolerate high salinity levels. In addition, sudden, massive changes in the environmental concentration are particularly problematic. After analysing field findings and toxicity tests, the four biological quality elements (algae, macrophytes, invertebrates and fish) and amphibians can be ranked according to their sensitivity to chloride as follows:

Algae > Macrophytes > Amphibians > Invertebrates > Fish

Water hardness has a significant influence on chloride toxicity. Due to the buffering effect of lime, higher chloride concentrations are tolerated. The influence of water temperature is less clear. The toxicity of chloride tends to increase with water temperature for most species.

In order to assess the effects of chloride on surface water accordingly, the following regulations should be consulted:

- Quality Objectives Ordinance for Surface Water Ecology:
  A parameter value of 150 mg/l chloride – regardless of the bioregion and the basic saprobic status – is specified for compliance with the very good and good ecological status of a body of water.
- Wastewater Emission Ordinance:
  The permissible concentration when discharging into a receiving water body is to be determined in each case depending on the characteristics and properties of the water body with regard to toxicity for algae, daphnia and fish.

The extent of chloride contamination in groundwater depends primarily on the nature of the surface layers, the distance from the surface, the respective aquifer and the direction of groundwater flow. As an inorganic substance, chloride is not subject to degradation. The anthropogenic chloride concentration in groundwater is not exclusively due to salt dispersion, but also to other chloride-containing media (e.g. fertilisers). Depending on the geological conditions, geogenic chloride contamination of groundwater can occur.

Water contaminated with chloride due to thawing fertilisers penetrates the groundwater through seepage and has a negative effect on taste, for example. Chloride in water also increases the corrosion of metal pipes and concrete.

In order to assess the effects of chloride in groundwater, the following regulations should be consulted:

- Drinking Water Ordinance “Trinkwasserverordnung” (TWVO, 2001):
  The indicator value for chloride in drinking water, above which the causes or any necessary measures must be analysed, is 200 mg/l. Care must be taken to ensure that the water does not have a corrosive effect.
- Quality Target Ordinance QZV Chemistry Groundwater (QZVO, 2010):
  The threshold value for chloride in groundwater, which must not be exceeded for reasons of health and environmental protection, is 180 mg/l.

7. PRINCIPLES

Minimising the environmental impact of gritting agents is essentially based on

- Choice of gritting agent used,
- Application method used,
- Planning and implementation of winter road maintenance.

As an alternative to grit and road salt, other blunting and thawing gritting agents are also available. Some of these can be used selectively or regionally. However, their large-scale use is limited. Their environmental impact must also be assessed individually and separately.

Due to aspects of availability, cost-effectiveness and the unclear long-term effects of large-scale use, there are currently no alternatives to the use of sodium chloride and grit.

8. RECOMMENDATIONS

The ecological and economic aim of winter road maintenance is to use as little gritting material as possible!

Only as much grit as absolutely necessary? This requires a number of basic principles!

- Awareness of the problem, training and expertise for all employees involved in winter road maintenance.
- Careful planning and management of operations requires experience and quality in management.

- Suitable equipment for the sites and emergency vehicles (IT, storage capacity, brine mixing systems, gritting equipment)!

Other recommendations include the following:

- As much snow as possible must be removed from the road by applying gritting material or road salt.
- The natural load of the source rock of the grit must be low due to its mineral or pollutant content.
- Recommended as a blunting gritting agent: Basalt or basalt-comparable hard rock and dolomite recommended. The use of slag, ash, quartz chippings, quartz sand and recycled concrete chippings is not permitted.
- The use of pre-wetted salt is always preferable to the use of dry salt.
- Preventive pre-wetted salt spreading with 5-10 g/m².
- Mixtures of blunting and thawing grit only in special cases.
- Application reports on quantities used.
- Transport routes for gritting materials must be kept as short as possible.
- No dry sweeping!
- Winter service vehicles that comply with the current emission limits (low-emission vehicles are to be favoured).
- When awarding contracts for winter services, the emission class of the winter service vehicles used must be taken into account.
- If possible, do not discharge snow directly into bodies of water.
- If the regular, punctual introduction of large quantities of clearing snow into a watercourse proves to be absolutely necessary, the actual condition of the watercourse must first be assessed and the expected effects on the ecology, morphology and hydrology of the watercourse must be analysed.

9. CONCLUSIONS

The large-scale use of alternatives to sodium chloride and grit is currently limited due to availability, cost effectiveness and unclear long-term effects.

There are no generally environmentally friendly alternatives to sodium chloride and grit. Each alternative must be assessed individually and separately.

Several recommendations are given in the Document from the awareness, training and expertise for all staff involved in winter maintenance to careful planning and management of operations requires experience and quality management and appropriate equipment for sites and emergency vehicles is necessary.

During operational winter service the use of wet salt is preferable to dry salt spreading use of brine is even better. Preventive spreading of moist salt at 5-10 g/m².

These recommendations are aimed at minimising the use of gritting material in winter road maintenance and reducing its environmental impact

10. REFERENCES

Badelt, H. (2007), “Optimierung der Anfeuchtung von Tausalzen”, Verkehrstechnik V 156, Bundesanstalt für Straßenwesen, Bergisch Gladbach.

Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft (2014), “Chlorid Auswirkungen auf die aquatische Flora und Fauna mit besonderer Berücksichtigung der vier biologischen Qualitätselemente gemäß EU-WRRL”, Wien.

Bundesministerium für Verkehr, Innovation und Technologie (2019), “Leitfaden Versickerung Chloridbelasteter Strassenwässer”, Wien.
Neuhold, J. and Steininger, M. (2014), “Erfahrungen zur Solestreuung in NÖ – Streubild-analysen und Restsalzmessungen”, FSV Schriftenreihe, no. 14, pp. 19–25.
ÖWAV-Regelblatt 407 (2003), “Empfehlungen für die Bewässerung”, Überarbeitete Neuauflage des ÖWAV-Arbeitsbehelfs Nr. 11.
Qualitätszielverordnung Chemie Grundwasser – QZV Chemie GW; BGBl. II Nr. 98/2010
Verordnung des Bundesministers für soziale Sicherheit und Generationen über die Qualität von Wasser für den menschlichen Gebrauch (Trinkwasserverordnung – TWV); BGBl. II Nr. 304/2001

ROAD MAINTENANCE IN THE 21th CENTURY

Domonkos Koch
MKIF Zrt.
2040 Budaörs, Akron u. 2.

SUMMARY

In its 1987 report, the United Nations first defined the concept of sustainable development. Since then, it has become evident that the transition to sustainability will not only involve challenges but also require sacrifices. The sector of road maintenance must enhance its resilience to challenges emerging from climate change. To find the best responses to these challenges road maintenance companies, such as MKIF Zrt., first of all have to transform the prevailing cultural values of their own. New way of thinking arises in incorporating of new materials and structures, renovation strategies, management of recovered materials, ecological impact of roads and safety concerns. With the technological advancement it becomes possible to build and maintain more durable roads, to approach to circular economy, to work and travel more safe and to reduce the environmental impact of roads.

1. BACKGROUND

In the „Burndtland-report" the United Nations defines the concept of sustainable development as „*meeting the needs of the present without compromising the ability of future generations to meet their own needs*" (World Commission of Environment and Development, 1987). At least in the late 90s it become clear that this goal cannot be achieved. The human consumption exceeds the limitations of sustainability (Wackernagel, 2002). The only remaining questions are how smooth will be the transition to a sustainable future, what challenges do we face and what sacrifices must be done during this period. As the cultural values are changing with the acceptance of the inevitable end of growth the goal of the global sustainability has to be transformed to the goal of local resilience. (Meadows, Randers, Meadows, 2022).

MKIF Zrt. is one of the biggest road maintenance company in Hungary with more than 1200 employees operating a 1242 km long motorway network which makes it one of the largest concession companies in Europe. The strategic objective of MKIF is to ensure the safe operation and development of a road network that promotes economic development and social mobility in Hungary. To achieve this goal MKIF has to enhance its resilience in the natural, social and economic environment.

2. CHALLENGES IN ROAD MAINTENANCE

Road maintenance is much more about operating and maintain the existing road network rather than building new ones, but the specific tasks of MKIF require a complex approach for both maintenance and network expansion works. All of the listed challenges are connected and have impact on each other and one must know that other authors may suggest other groups or would identify more challenges.

2.1. Natural challenges

2.1.1. Climate change

Climate change is a common topic nowadays. It means that the known patterns of climate are changing. From the view of road maintenance temperature and precipitation patterns are the most important. Global data are gathered since more than a century. The trends in Hungary are parallel with the global ones:

- annual average temperature is increasing (Fig. 1),
- number of days of heat (T > 25 °C) is increasing (Fig. 2),
- number of days of frost (T < 0 °C) is decreasing (Fig. 3).

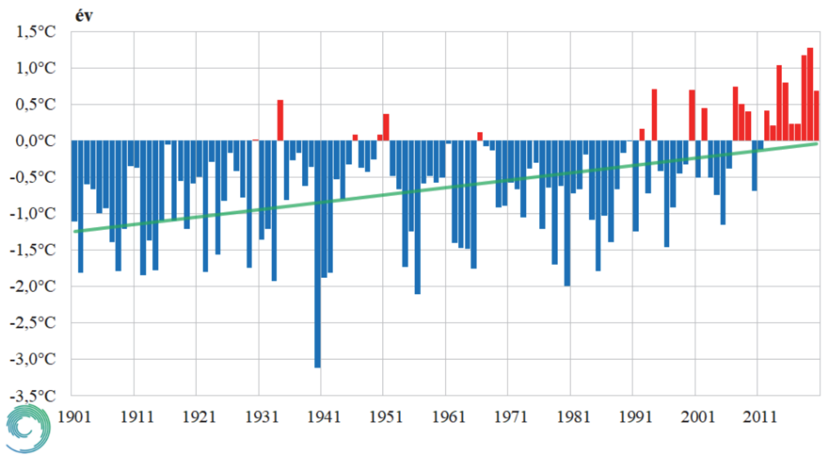


Fig. 1. Annual average temperature changes between 1901–2020. (www.met.hu)

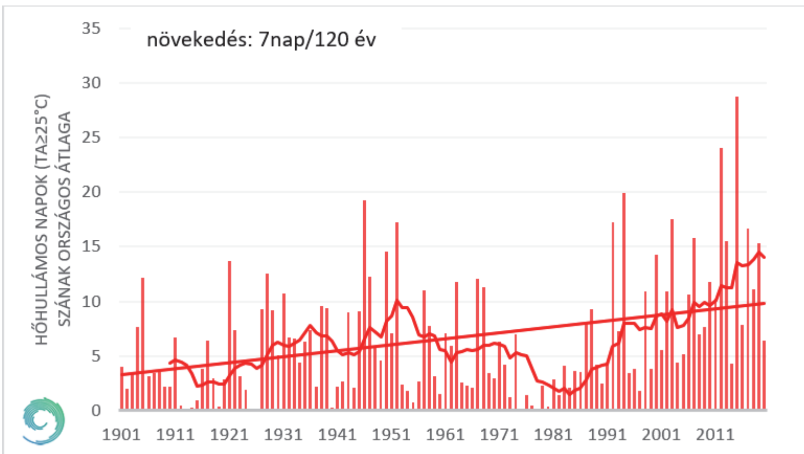


Fig. 2. Number of days of heat between 1901–2020 (www.met.hu)

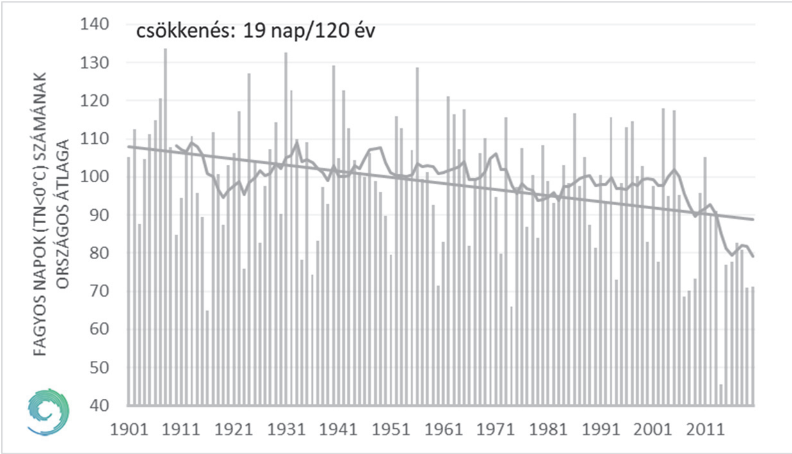


Fig. 3. Number of day of frost between 1901–2020 (www.met.hu)

The increasing temperature raises problems for the pavements. The higher the temperature the lower the stiffness, the deterioration of the pavement is accelerated. Rut depth will increase faster than before but also pavement lifetime is reducing since the strains are larger due lower stiffness. This phenomenon may indicate more renovation work leading more emission, congestion and accidents.

The decreasing number of frosty days does not mean winter maintenance duty will disappear in time, only that the existing infrastructure (salt storage halls, equipment etc.) are oversized but it means also that there is a safety reserve.

The precipitation patterns are also changing:

- annual average precipitation total is constant (Fig. 4),
- number of rainy days is decreasing (Fig. 5),
- number of days with heavy rain (R > 20 mm) is increasing (Fig. 6).

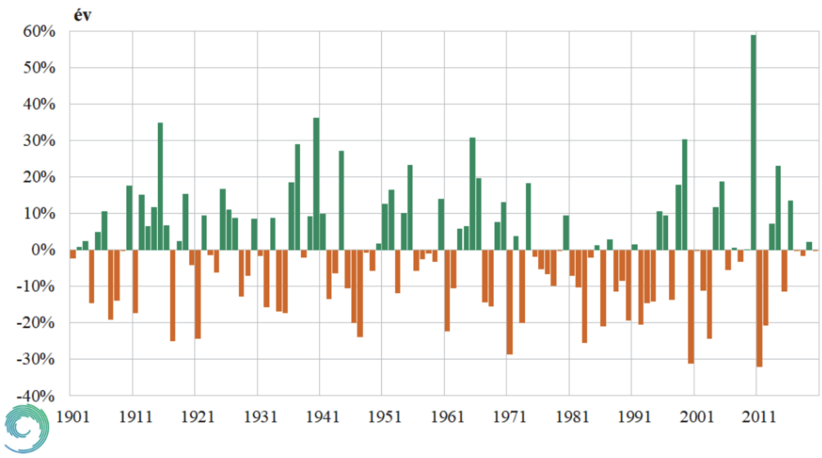


Fig. 4. Annual average precipitation total (www.met.hu)

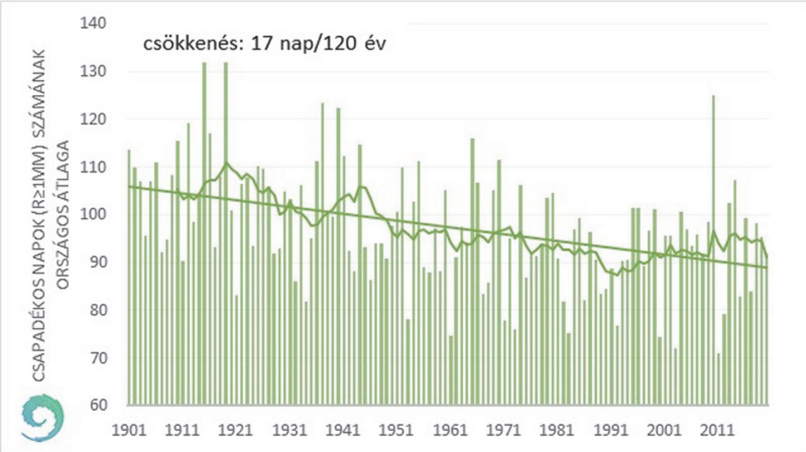


Fig. 5. Number of rainy days (R > 1 mm) (www.met.hu)

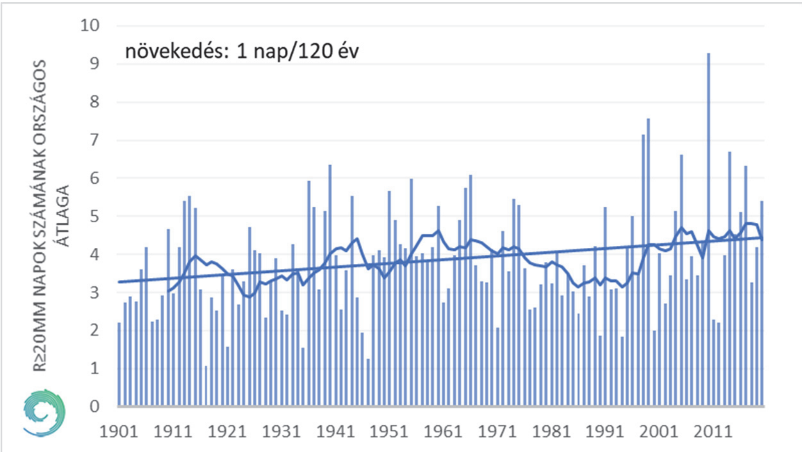


Fig. 6. Number of days with heavy rain (R > 20 mm) (www.met.hu)

The non-changing amount of precipitation is positive, but the distribution is worrying. The decreasing number of rainy days means the same amount falls down on fewer occasion, meaning the intensity of the rain will grow. The intense rain threatens the stability of slopes. In very heavy rain the cross-slope gradient of the pavement is not large enough for the water to run off, meaning water films can develop which is extra danger to drivers. The cross section of the drainage channels may not be large enough to drain the water away. Flash floods may occur while the higher water level can increase the moisture in embankment which causes bearing capacity problems. The fluctuating distribution of precipitation also leads to challenges in vegetation maintenance.

2.1.2. Depleting resources

Natural resources are finite amounts. In road infrastructure stone, bitumen and embankment materials are the most essential. The spatial distribution of stone and gravel mines is uneven in Hungary, while in recent years the whole road infrastructure segment faced struggles with bitumen (oil) and steel supply. During renovation a lot of demolished material is generated. On one hand a road maintenance company struggles to supply the need of new materials, on the other hand as a responsible asset manager needs to account for demolished materials.

2.1.3. Decline of biodiversity

Beside climate change decline of biodiversity is also a common topic when talking about sustainability. At first look it can be surprising that this phenomenon has an impact on road maintenance. Although the endangerment of large-bodied animals e.g. tigers or pandas receives greater attention, the extinction of plants is the main concern for road operators. In 1998 34 thousand species out of 270 thousand was in danger. (Holden, 1998). The appearance of invasive species is a threat not only for agriculture but also for roads. The maintenance of vegetation becomes more difficult, fast growing invasive species in the central separation lane or on the slopes require more intervention from the operators causing increasing costs and safety concerns. Winter maintenance is hardened with increasing number of locations with high danger of snow drifting because of deforestation, while when it is combined with the depressed ground-water level dust drifting can be a decisive factor during normal maintenance.

2.2. Social challenges

2.2.1. Safety first

Despite the fact that statistics of traffic accidents improves (Eurostat, 2022), for road operators, road workers and road users safety become more and more important. Traffic is growing, the traffic speed is increasing and the change of our natural environment also increase safety concerns. Every minute an operator spends on road during work is a danger for every parties. A road user ignores 9 traffic signs before a temporary traffic diversion when it causes accident. (Benedek, 2024). The goal of road operators is to reduce the working time on the road and reduce the number, length and duration of traffic diversions.

2.2.2. Needs of 21th century

The expectation of road users are changed. With the increasing driving experiences the need for reducing travel time is stronger than ever while the distance range of one tank makes possible to reduce the number of stops. If a driver stops, it wants to handle everything: refuel, use of toilet, eat and drink, relax etc. A road operator should serve all the requirements in one place. The drivers are more self-conscious, they want to decide the route depending on the latest traffic news. On the other hand, operators want to collect more and more data from traffic, and both parties need the information in real time.

2.3. Economic challenges

2.3.1. Funding new projects

Road maintenance can be affective only if financing is constant, predictable and sufficient. But in the specific place of MKIF, funding new projects has also new challenges that have never been faced before. Lenders finance projects only if they comply with the objectives of Green Deal of European Union. With the so-called ESG Act entering into force on 1 January 2024, the voluntary corporate sustainability reporting and supply chain due diligence indicating the corporate commitment to sustainability will become mandatory in several steps and will gradually – in the timeframe set by the Act – be extended to large enterprises and all other large, small and medium-sized companies of public interest in Hungary. The sustainability report must include data and information related to sustainability issues concerning the contractor's activities, including the connections of the contractor's business model and strategy to sustainability issues, climate objectives, the tasks and responsibilities related to sustainability matters, sustainability risks, opportunities and adverse impacts, as well as the tools aimed at managing these aspects and their effectiveness.

3. ANSWERS

A road operator must follow the latest innovations to find the best answers to the challenges listed above. The task of operator is to intervene in the road's service in the right time and right way to expand the service life.

3.1. Technical solutions for changing climate

3.1.1. Sustainable roads

For the increasing temperature the adequate solution is to build high temperature-resistant pavements rather than implement more renovations. Binders with higher penetration and higher softening point such as Pmb 45/80-80 can produce the best performances at high temperatures, but the inbuilt performance measurements are still in progress. (Sronka, 2024). Other promising binder type is rubber bitumen which can perform at least similar to polymer bitumens (Gáspár, Tóth, Primusz, Almássy, Hunyadi, Szentpéteri, 2019) (Almássy, Geiger, 2020). To achieve the longer service life, new concepts of pavement structure design are spreading. Positive results of trial section of Perpetual Pavements on M85 (Koch, 2021) and M6 (Sronka, 2024) lead the stakeholders to design the pavement of the biggest upcoming motorway development (M1 lane expansion) as a perpetual pavement with a service life of 30 years.

In the history of engineering there was concept "water is the enemy of an engineer". Therefore the goal of design was to drain the water as fast and as far as possible from the road. Because of safety reasons the water must run off from the pavement. We can prevent the slope erosion with dense and strong vegetation which require water to grow. This leads the road operators to water retention rather than drainage. The strong vegetation not only on slopes but in the environment of roads slows down the water run off which is the only sustainable way prevent flashfloods.

3.1.2. Circular economy

The road operator has to manage all the demolished materials which can be plenty if renovation works are implemented. In the past waste-management approach was prevailing but the reclaimed materials management approach can lead to circular economy. The concept is easy, the further life of reclaimed material can be one of the following:

- if road operator can reuse it, than reuse it,
- if road operator cannot reuse, but somebody else can, sell it,
- if nobody can reuse it, it is waste.

The best example is the reclaimed asphalt. Hungary is lagging behind on this area (EAPA, 2021), using only 3% of RA in all asphalt production, but will catch up to Europe in the next years.

A road operator has to analyze the usage of RA. There is no doubt that asphalts with RA content can perform the initial performance requirements but there is no evidence found yet to prove they will still performing the same after 15-20 years. Other environmental concern with RA is the higher energy consumption when production, but the overall carbon footprint can be reduced up to 50% during lifetime with optimizing the material transports and renovation works (Buttita, Giancontieri, parry, Lo Presti, 2023). But make no mistake the most environmental-friendly renovation is what doesn't need to be carried out.

Every demolished material must be accounted as reusable, selling or waste material, road operators must account also for traffic signs, embankment materials, drainage elements, fences etc.

While carrying out M1 lane expansion works MKIF show as an example of circular economy. Circular economy plan was carried out before with 98% of reuse rate of reusable materials (mostly humus, pavement materials and traffic signs).

3.1.3. Ecological solutions for roads

MKIF commissioned a study on the vegetation in central separation lane. The study claims that the vegetation in central separation lane has a very low ecological value due to two things. It cannot be function as a habitat for animals because it is too narrow for bigger ones, while the insects are often blow away by traffic wind. The other reason is the plant diversity is very low and often invasive species are planted. Analyzing the costs of separation lane vegetation the study states that cost of planting and maintaining it for 1 year is equal to plant forest on 110 ha.

Forests beside roads have a lot of advantages:

- They serve as protection against snow and dust drifting.
- They break the visual monotony of roads.
- They reduce the impact of air movements on the plant culture.
- They reduce the evaporation processes in the soils, thus protecting the soil from drying out. Moreover, they help to balance the soil's moisture content.
- They protect the top layer of soil, rich in humus, from water erosion caused by sudden downpours of rain.
- They provide habitats for living, feeding, hiding, moving, and breeding for wildlife, thereby maintaining and increasing biological diversity at the local level. Therefore, it is beneficial if these plant strips are continuous or connect at multiple points.
- They are advantageous compared to monocultures, representing aesthetic value in the landscape due to their diversity and year-round presence.
- They can also increase the usability value of resting places.

With the approval of the Grantor MKIF is ready to relocate and expand the green lane from the center to the sides of the road.

3.2. Answers to social challenges

3.2.1. Safety

Despite the improving statistics, achieving the Vision Zero is still far away. The geometry of road and the traffic signs must be clear to the drivers to select the proper speed and avoid accidents. But if an accident does occur, the road and the equipment must be forgiving. Truck Mounted Attenuators (TMA) are placed often on MKIF network before the workplace. This equipment absorbs the energy of the collision protecting the driver and the road workers in the same time. It is also a good example of circular economy because it is almost 100% reusable after crash.

The best way to avoid accidents is when they are prevented. Prevention can be achieved with reducing the time road operators spending on site. MKIF started pilot project aiming to replace the daily road inspection duty with drones. The road inspector has only drive on site only if a task emerges. After the first trial in 2023 the biggest challenge of this technology was the range (Szigeti, 2023), but a second generation drone-base station system it is expected to be solved.

3.2.2. New answers for 21th century

Real time communication that is beneficial for both road operators and road users can be carried out with variable message signs and camera system. During M1 and M7 expansion works MKIF will implement one VMS portal in every 500 m, probably cameras need to be install in every kilometer.

Service level of rest areas must be improved also. Even in simple rest areas, the opportunity of buying snacks, drinks and coffee should be available even with only an automat and even if the current Technical Specification states the opposite. Toilets for families can be carried out, what a dad with daughter or a mom with son can use comfortably. Fenced dog park would be also warmly welcomed. MKIF is carrying out a homogenous outlook plan for rest areas, where some of the ideas above have been taken into consideration.

3.3. Financing

ESG certification must be aimed for both road operator companies and projects. The ESG certification process is underway for MKIF as a company, and the M1 lane expansion project is certificated, which can be a following example for all road operators in Hungary.

4. CONCLUSIONS

The road is a built environment in the nature they exist together. Synergies can be reached if we look at our existing environment as a partner and the limitations are taken into consideration. MKIF is pointing a way for every member of road infrastructure. It looks after the most effective technologies to operate its network the most sufficient way but as the identified challenges have various affects, all of them needs to be treated as a complex problem and require complex solutions. It was shown in this paper that these new challenges can be answered with open mind, rethinking of prevailing principles and technological innovation

5. REFERENCES

World Commission of Environment and Development (1987), “Our Common Future”, Oxford University Press, Oxford, 41 p.

Mathis Wackernagel (2002), “Tracking the ecological overshoot of the human economy”, Proceedings of the Academy of Science, 99, no. 14: 9266-9271, Washington D.C.

Donella Meadows, Jorgen Randers, Dennis Meadows (2022), “A növekedés határai”, Kossuth Kiadó, Budapest.

Felhasznált adatok és módszerek – Hőmérséklet- és csapadéktrendek – met.hu

Constance Holden (1998), “Red Alert for Plants”, Science 280.

Eurostat (2022), “Key figures on European transport”, European Union, 40 p.

Fruzsina Benedek (2024), “Egy összehangolt mátrix szerint bonyolítják le hazánk legnagyobb útfelújítási programját”, Magyar Építők, Budapest.

2023. évi CVIII. törvény A fenntartható finanszírozás és az egységes vállalati felelősségvállalás ösztönzését szolgáló környezettudatos, társadalmi és szociális szempontokat is figyelembe

vevő, vállalati társadalmi felelősségvállalás szabályairól és azzal összefüggő egyéb törvények módosításáról.
A fenntartható befektetések előmozdítását célzó keret létrehozásáról, valamint az (EU) 2019/2088 rendelet módosításáról szóló 2020/852/EU rendelet.
Gábor Sronka (2024), "Különböző kötőanyagokkal készített, fáradásnak ellenálló aszfalt alapréteg viselkedése reológiai és aszfaltmechanikai szempontból", Az Aszfalt, XXXI, 2024/1, pp. 6-14.
László Gáspár, Csaba Tóth, Péter Primusz, Kornél Almássy, Dóra Hunyadi, Ibolya Szentpéteri (2019), "A hazai GmB kötőanyagú útpályaszerkezeti rétegek komplex viselkedési értékelése", KTI Közlekedéstudományi Intézet és BME Út és Vasútépítési Tanszék Vizsgálati Jelentés.
Kornél Almássy, András Geiger (2020), "Gumibitumen alkalmazások a nagyvilágban", Az Aszfalt, XXVII, 2020/2, pp. 33-38.
Domonkos Koch (2021), "Első hazai örökaszfalt próbaszakasz rétegeinek összehasonlítása a hagyományos pályaszerkezeti rétegekkel", Az Aszfalt, XXVIII, 2021/2, pp. 12-22.
EAPA (2021), Asphalt in Figures 2020.
Gabriella Buttitta, Gaspare Giancontieri, Tony Parry, Davide Lo Presti (2023), "Modelling the Environmental and Economic Life Cycle Performance of Maximizing Asphalt Recycling on Road Pavement Surfaces in Europ". Sustainability 2023, 15, 14546.
Diána Szigeti (2023), "Drónok használata az útüzemeltetésben", Az Aszfalt, XXX. 2023/2, pp. 16-20.

REMUNERATIVE INNOVATIONS ON THE FIELD OF STRUCTURAL ENGINEERING

György L. Balázs, Marwah M. Thajeel, Wisam K. Tuama, Sándor Sólyom
Budapest University of Technology and Economics
H-1111 Budapest, Műegyetem 3.

SUMMARY

The performance of infrastructure including roads, bridges and railways mainly depend on the selected materials, the way of application of those materials, the structural form that was selected and the maintenance strategy for use.

Development of new materials and technologies contribute considerably to the success of applications.

The intention was herein to summarize the most recent developments that can be used for bridges like 3D concrete printing, non-metallic reinforcement – FRP as well as fibres embedded into cement matrix – and a new type of reinforcing element. The paper also provides test results and discussions given in these areas.

1. INTRODUCTION

Present paper intends to review major developments concerning concrete bridges. These include development of:

- 3D Concrete Printing (Section 2),
- non-metallic reinforcements for internal reinforcement or external reinforcement for strengthening (Section 3),
- CFCM – as a new non-metallic reinforcement that is cement based including fibres (Section 4),
- PERFYCON – is a new material including three dimensional steel fibres (Section 5).

2. 3D CONCRETE PRINTING

3D Concrete Printing is an additive technology that indicated a lot of results also in the field of bridges.

Based on the support by the Hungarian Research Grant VKE 2018-1-3-1_0003 "Development of advanced concrete elements". The Laboratory of Construction Materials and Technologies at the Budapest University of Technology have the chance to make research with this technology since 2022.

2.1. Our experience

Fig. 1 indicates our robot and concrete mixer which are part of our 3D concrete printing system. Fig. 2 indicates first bridge in Hungary produced in 3D concrete printing. This has been the possibility for us to learn the main characteristics of the 3D printing technology. Fig. 3 indicates an example of a concept that has been developed in our laboratory. The idea is to provide segments of a bridge girder that can be reinforced and completed a later phase when requested.

a) Robotic arm b) The mixer and extruder

Fig. 1. 3D concrete printer system (Budapest University of Technology and Economics, Laboratory of Department of Construction Materials and Technologies (Thajeel, Balázs, 2024)

Fig. 2. First bridge in Hungary produced by 3D concrete printer (Budapest University of Technology and Economics, Laboratory of Department of Construction Materials and Technologies)

Fig. 3. Concept of printed segments of a bridge in 3D concrete printing that are joined by reinforcement and infill concrete (Budapest University of Technology and Economics, Laboratory of Department of Construction Materials and Technologies)

2.2. 3D-Printed Concrete Bridge in Alcobendas (Madrid, Spain)

Year Completed:	2016
Type:	Pedestrian bridge
Material:	Reinforced concrete

This 3D-printed bridge, developed by the Institute of Advanced Architecture of Catalonia (IAAC), spans 12 meters and features a parametric design optimized for material efficiency. It was the world's first 3D-printed concrete pedestrian bridge, showcasing how 3D printing can produce aesthetically appealing and structurally sound infrastructure with minimal waste (Fig. 4).

Fig. 4. 3D concrete printed pedestrian bridge in Alcobendas (Madrid, Spain) completed in 2016 (De la Fuente, Blanco, Galeote, Cavalaro, 2022)

2.3. Striatus 3D-Printed Concrete Bridge (Venice Biennale, Italy)

Year Completed:	2021
Type:	Pedestrian bridge (temporary installation)
Material:	3D-printed concrete blocks (without reinforcement)

Designed by Zaha Hadid Architects and ETH Zurich, the Striatus bridge is an unreinforced, 3D-printed concrete bridge that was exhibited at the Venice Biennale. The bridge was printed using concrete in a way that optimized compression forces, allowing the structure to stand without reinforcement. This project demonstrated how 3D printing could challenge traditional design and construction methods by leveraging advanced engineering and computational techniques (Fig. 5).

Fig. 5. 3D concrete printed pedestrian bridge (Venice Biennale, Italy) concrete blocks without reinforcement completed in 2021 (ETH Zurich, BRG, Architects, Z.H., CODE, Incremental3d, HOLCIM, 2022)

2.4. OptiBridge - Ghent University, Belgium

Year Completed:	2022
Type:	Pedestrian bridge
Material:	3D-printed concrete

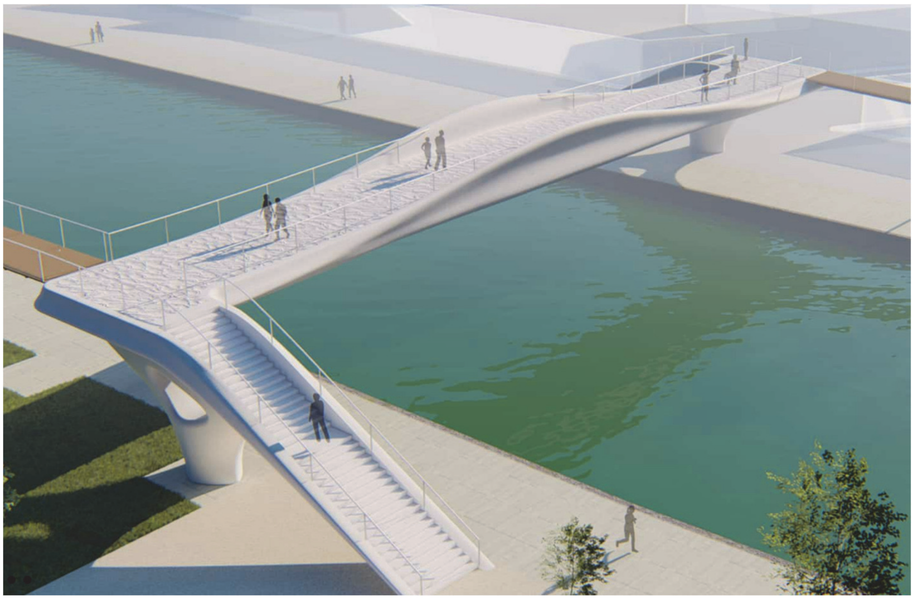
OptiBridge is the second 3D-printed concrete footbridge designed and constructed by Ghent University. It was developed using advanced topology optimization, which involves using computational algorithms to determine the most efficient material distribution, minimizing material use while maintaining structural integrity. The topology optimization process ensured that the design removed unnecessary material from areas that experience lower stress, resulting in a lightweight yet strong structure. This method mimics organic structures like bones or tree branches, which have evolved to use material efficiently. The bridge was printed using 3D concrete printing technology, showcasing how this innovative process can produce optimized, structurally efficient designs that are difficult or impossible to achieve using traditional construction methods (Fig. 6).

Fig. 6. OptiBridge – Ghent University, Belgium (2022) (Ooms, Vantyghem, Tao, Bekaert, De Schutter, Van Tittelboom, De Corte., 2022)

2.5. XtreeE 3D-Printed Bridge (France)

Year Completed: In progress
Type: Pedestrian bridge
Material: 3D-printed concrete

XtreeE, a French 3D printing firm, is collaborating with various partners to develop a series of 3D-printed concrete bridges across France. These projects focus on optimizing material usage and achieving intricate design geometries that are difficult to create with traditional construction methods. The company is using large-scale 3D printers to produce the components for these bridges (Fig. 7).



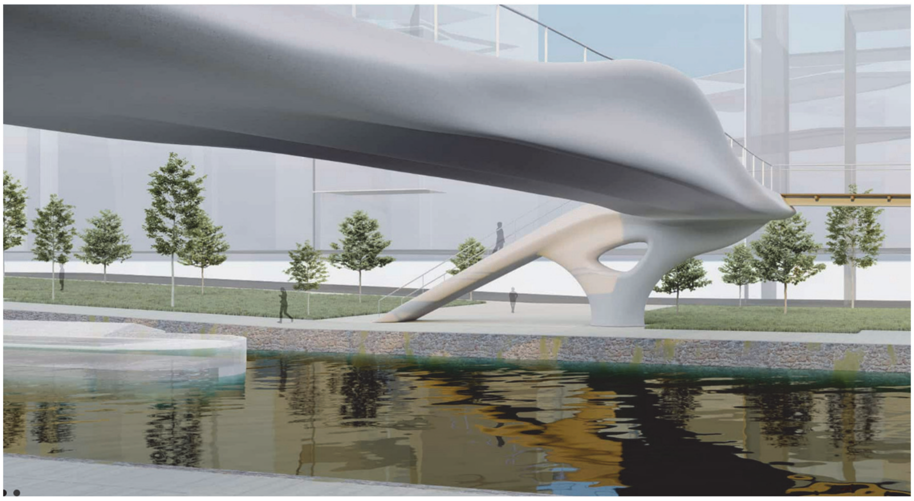


Fig. 7. Xtree 3D concrete printed pedestrian bridge (France - progress) (XtreeE, An innovation partnership for the design-build of a 3D-printed concrete footbridge. Accessed 29 September 2020)

2.6. 3D concrete printing for bridge construction - main benefits

Using 3D printing for bridge construction offers several key benefits (Hwang, Khoshnevis, 2004):

1. Speed of Construction
Rapid Fabrication: 3D printing can significantly reduce the time needed to design and construct bridges, allowing for quicker project completion.

2. Material Efficiency
Reduced Waste: The additive manufacturing process uses only the necessary amount of material, leading to less waste compared to traditional construction methods.

3. Design Flexibility
Complex Geometries: 3D printing enables the creation of intricate and customized designs that would be difficult to achieve with conventional techniques.

4. Cost-Effectiveness
Lower Labour Costs: The automation of the printing process can reduce labour requirements, potentially lowering overall project costs.

5. Sustainability
Use of Recycled Materials: Many 3D printing projects incorporate recycled materials into concrete mixes, enhancing environmental sustainability.

6. Reduced Need for Formwork
Simplified Construction Process: Traditional concrete construction often requires extensive formwork, which can be costly and time-consuming. 3D printing eliminates much of this need.

7. Customization
Tailored Solutions: Bridges can be designed to meet specific site conditions and aesthetic requirements, allowing for more personalized infrastructure solutions.

8. Enhanced Structural Performance
Optimized Designs: Advanced software can optimize bridge designs for strength and durability, potentially leading to better performance over time.

9. Labour Shortage Mitigation
Reduced Workforce Dependence: By automating parts of the construction process, 3D printing can help address labour shortages in the construction industry.

10. Innovative Testing and Prototyping
Rapid Prototyping: New designs can be tested and iterated quickly, facilitating innovation in bridge engineering.

3. NON-METALLIC REINFORCEMENTS FOR BRIDGES

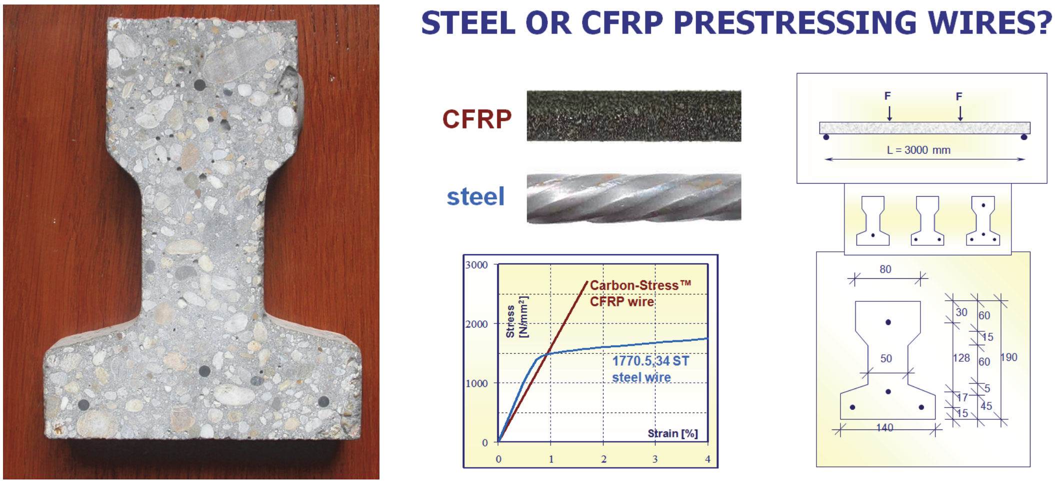
There is an intention to apply high strength, non-metallic reinforcements that are non-susceptible for electrolytic corrosion as internal embedded reinforcement or externally bonded reinforcement.

First Hungarian application of non-metallic reinforcement in tunnelling was carried out “soft eye application” during the construction of M4 underground line by the Gellért station below 60 m level (Fig 8).

Fig. 8. Soft eye application during the construction of M4 underground line by the Gellért station (Photo: courtesy of Lajos Bán)

3.1. Non-metallic reinforcements for bridges as internal reinforcements

Within the Project supported by the Hungarian Ministry of Innovation *2018-1.3.1-VKE* including high strength, non-corrosive fibre reinforced polymer reinforcement in bridges, we would like to present here our preliminary results on application of FRP reinforcement as internally prestressed with CFRP (Carbon Fibre Reinforced Polymer) wires (Fig. 9).



Cross-section *Material and experimental properties*

Fig. 9. Comparative study on concrete beams prestressed either with steel or with CFRP wires (Borosnyói, Balázs, 2007)

3.2. Non-metallic reinforcements for strengthening of bridges

Retrofitting of concrete structures by using externally bonded reinforcements has been published in *fib* Bulletins № 14 and 35. By using FRPs for strengthening, two techniques are distinguished: application of external bonded reinforcement (EBR) (Hollaway, Leeming, 1999; Balázs, Almakt, 2000) or near surface mounted (NSM) reinforcement (Blaschko, 2001; Szabó, Balázs, 2008). Both techniques, especially EBR, gained a wide range of applications in the last two decades.

Fig. 10 presents example for careful preparation of strengthening with CFRP materials.

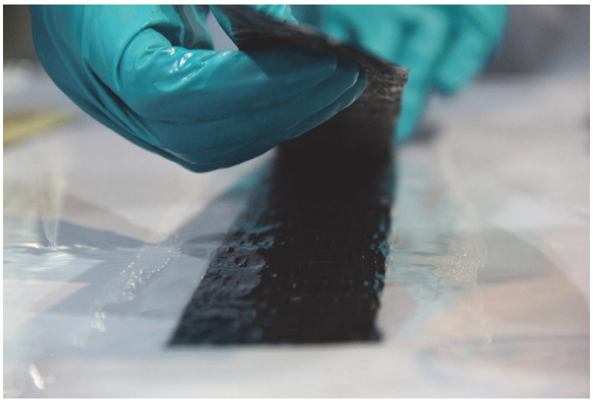
 

Fig. 10. Application of FRP in form of strip (left) and wrap (right)

An interesting example for bridge strengthening with CFRP EBR in Budapest is presented herein (Balázs, Almakt, 2000). The approach span of Petőfi bridge in Budapest was constructed of precast prestressed pre-tensioned concrete bridge girders with an additional cast in situ reinforced concrete deck. The first girder suffered seriously from corrosion, i.e. five prestressing strands from twenty–nine were completely corroded in the girder situated under the tram line. Several ways for strengthening were analysed and finally the decision was taken to bond 5 pieces of 28 m long Sika CarboDur® strips of medium modulus of elasticity. This operation was performed during night after the tram traffic had stopped. The whole bottom flange of the girder was finally covered by a protecting layer against further ingress of de-icing salts into the concrete. Unfortunately, the chloride content of concrete before strengthening was already relatively high and therefore further failure of the prestressing tendons is not excluded. Regular deflection and strain measurements are carried out for control.

4. CFCM – AS A NEW NON-METALLIC REINFORCEMENT THAT IS CEMENT BASED INCLUDING FIBRES

The new reinforcement is called *Carbon Fibre Reinforcement in Cementitious Matrix* and abbreviated as *CFCM reinforcement.* The reinforcement consists of longitudinal fibres embedded into cement matrix with a special process. The process is based on a new patent by Ferenc Csurgai (PCT/HU2017/050010 int., 11 April 2016, final patent: P1700140, dated 7 April 2017). Since matrix of the CFCM reinforcement is cement based and has contact to the concrete, this composite system provides contact of cement based materials and not contact to cement base to polymer based as by FRP.

4.1. Basic properties

Any cross-sections and any special forms can be created of the CFCM reinforcement as long as it is not hardened. This includes the possibility to produce reinforcement either like conventional bars or strips or layers. The fresh CFCM reinforcement can be incorporated in the cross-section anywhere even without concrete cover because the electrolytic corrosion is excluded of CFCM reinforcement.

Fig. 11 indicates the fresh reinforcement after the production process. This is a soft and formable product as long as the cement hydration is delayed.

Fig. 11. Photo of formable reinforcement just after production (Balázs, Sólyom, 2023)

The CFCM formable reinforcement is a special form of reinforcement with the possibility to give its shape (1, 2 or 3 dimensional) just before or during the casting process of the concrete element, unlike steel reinforcement where the product has its well determined solid form, or any precured Fibre Reinforced Polymer (FRP) reinforcement where branch of fibres are embedded in resin matrix which already hardened during production.

The favourable situation with formable reinforcements:

- compared to steel reinforcements, there is no need for production of iron, then steel,
- compared to FRP reinforcements, there is no need for pultrusion.

Using formable reinforcements, the compatibility of reinforced concrete as system will improve considerably since both concrete as well as the reinforcement are cement based. Consequently, the interaction of reinforcement and concrete have special characteristics (Balázs, Csurgai, Sólyom, 2022). The compatibility defined by the same binder may provide improved bond and improved durability involving sustainability and also improved fire resistance compared to the steel reinforced or FRP reinforced concrete systems (Fig.12). These advantages may be support by the *wet to wet technology* whenever the fresh CFCM reinforcement is applied into the fresh concrete during casting (Balázs, Csurgai, Sólyom, 2022).

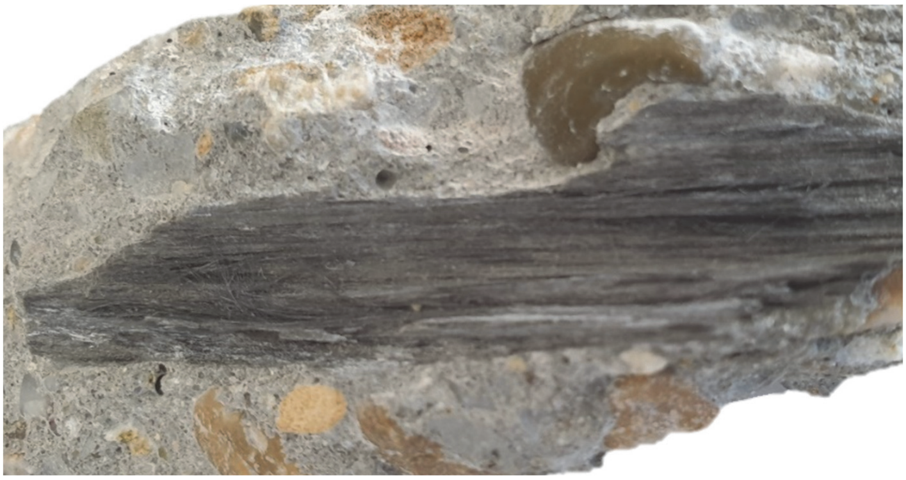


Fig. 12. The bond of formable reinforcement in direct contact to concrete creates an excessive bond (Balázs, Csurgai, Sólyom, 2022)

4.2. CFCM – Tests as reinforcement for bridges

Preliminary tests have been carried out to possible application of CFCM reinforcement for a bridge girder (Fig. 13).

In this case all of the tensile reinforcement was provided by CFCM reinforcing bars and the shear reinforcement by steel stirrups. In a later experiment we changed even the shear reinforcement by CFCM stirrups.

The load–deflection curve of the CFCM reinforced girders were bilinear, indicating considerable deformation capacity until failure.

Fig. 13. Bridge girder with CFCM reinforcement (Balázs, Sólyom, 2021)

5. PERFYCON – IS A NEW MATERIAL INCLUDING THREE DIMENSIONAL STEEL FIBRES

Intentions are often directed to high performance materials in order to meet on durability as well sustainability.

A *new reinforcing element has been developed* and has a 3 dimensional form. It is produced from a single wire in successive steps of bending and creating finally four closed loops that are connected in the same centre. Fibre name is: Starex; and the name of the concrete which includes Starex in an appropriate composition of concrete is called as: Perfycon (patent Perfycomp Co., P1600552).

The fibre can have different diameters and different lengths of loops depending on the type of application, i.e. depending on the sizes of the element and type of execution (placing, pumping, shotcreting, self-compacting, etc.). The fibre material is steel.

Herein we can report only about an extraordinary characteristic of the influence of this fibre in concrete. The concrete cube prepared in SIFCON form and loaded in compression did not fail completely but kept a considerable part of the load even after 50% strain. The reason was the internal confinement provided by the three dimensional fibres.

Fig. 14. Extraordinary strain of SIFCON including three dimensional fibres (PERFYCON) in compression

6. CONCLUSIONS

Presented study indicated innovations:

- 3D Concrete Printing for bridges;
- non-metallic reinforcements for internal reinforcement or external reinforcement for strengthening;
- CFCM – as a new non-metallic reinforcement that is cement based including fibres;
- PERFYCON – is a new material including three dimensional steel fibres.

All these contribute to the performance and characteristics of concrete structures, especially of bridges.

7. ACKNOWLEDGMENTS

Authors acknowledge the support by the Hungarian Research Grant VKE 2018-1-3-1_0003 "Development of advanced concrete elements".

The *Stipendium Hungaricum Scholarship* Program is highly acknowledged for supporting the PhD studies and research work.

8. REFERENCES

Balázs, G. L., Sólyom, S. (2023), "Formable reinforcement", *Proceedings* of Conceptual Design 2023 Oslo.

Balázs, G. L., Csurgai, F. Sólyom, S. (2022), "Bond of CFCM", Proceedings (Eds. Hoffmann, J, and Plizzari, G.), "Bond Anchorage Detailing", 5th In Conf. Bond in Concrete 2022, Stuttgart, 25-27 July 2022, IWB Stuttgart University, pp. 945-954.

Balázs, G. L., Sólyom, S. (2022), "CFCM cementkötésű szénszál armatúrákkal készített FPT 45–8,80 hídgerendák hajlítóvizsgálatának eredményei", Project Report 2019-1.1.1-PIACI-

KFI-2019-00142 Tartósabb, könnyebben beépíthető és megnövelt teherbírású előregyártott betonelemek és hatékony gyártási technológia fejlesztése, BME Budapest 09.11.2021.
De la Fuente, A., Blanco, A., Galeote, E., Cavalaro, S. (2022), "Structural fibre-reinforced cement-based composite designed for particle bed 3D printing systems", Case study Parque de Castilla Footbridge in Madrid. Cem. Concr. Res. 157, 106801 https://doi.org/10.1016/j.cemconres.2022.106801.
ETH Zurich, BRG, Architects, Z.H., CODE, Incremental3d, HOLCIM (2022), "Striatus 3D Concrete Printed masonry", URL https://www.striatusbridge.com/ (Accessed 29 September 2020).
Hwang, D, Khoshnevis, B. (2004), "Concrete wall fabrication by contour crafting", Proceedings of the 21st International Symposium on Automation and Robotics in Construction, https://doi.org/10.22260/isarc2004/0057.
Ooms, T., Vantyghem, G., Tao, Y., Bekaert, M., De Schutter, G., Van Tittelboom, K., De Corte, W. (2022), In: Buswell, R., Blanco, A., Cavalaro, S., Kinnell, P. (Eds.), "The Production of a Topology-Optimized 3D-Printed Concrete Bridge BT" – Third RILEM International Conference on Concrete and Digital Fabrication. Springer International Publishing, Cham, pp. 37–42.
Thajeel, M. M., Balázs, G. L. (2024), "3D concrete printing with robot – resulted properties", Online Journal of Robotics & Automation Technology, March 2024, http://dx.doi.org/10.33552/OJRAT.2024.02.000540
XtreeE, An innovation partnership for the design-build of a 3D-printed concrete footbridge. URL XtreeE | The large-scale 3d (Accessed 29 September 2020).

SOME QUESTIONS ABOUT THE FUTURE OF STRUCTURAL CONCRETE AND OF ENGINEERS AND DESIGNERS

Michel Virlogeux, Honorary President FIP and fib
Professor at the Ecole Nationale des Ponts et Chaussées
Bonnelles, France

SUMMARY

The climatic change, due to large carbon emissions, is a major threat for our civilisation, calling for dramatic changes in our economy, especially for transport and construction. Fabrication of cement and concrete takes a significant part in carbon emissions, which will certainly increase in the near future due to the necessary needs in developing countries. How could engineers reduce this impact, and continue using an essential material for the good of society. But what is today the influence of engineers in our society?

1. INTRODUCTION

I have been invited to give a keynote lecture at the MAÚT30 International Scientific Symposium, the proposed theme being recent constructions in France. As there have not been so many interesting structures erected in France these last years, I could have extended this theme, an occasion to present some recent projects in which I had been involved.

But, due to my past responsibilities in fib, and to more than 50 years of bridge design, I consider that I must concentrate this lecture on the major problems of our profession:

- the future of concrete, which is today considered as producing too much carbon emissions, and is supposed to be replaced by other materials;
- and the evolution of our profession which is less and less creative. The nature of structural codes, the way numerical means are used, and the development of artificial intelligence tend to transform engineers into simple technicians.

We must – our profession, our associations, starting with *fib* – react against this situation and promote engineering and creativity in our domains.

2. THE FUTURE OF CONCRETE

2.1. Carbon emissions and natural resources

Concrete constructions are accused in some media, and by some politicians, to be one of the major producers of carbon emissions, and to exhaust natural resources, sand and gravel mainly.

It is also accused, together with construction of roads, of being a major cause of soil artificialization. A part of the public opposes now to the construction of motorways, forgetting that in the early seventies 16,000 persons per year were killed in France in road accidents. It is only about 3,000 these last years, due to the progress in the car industry which drastically increased driving safety, to the repressive system, but above everything by the construction of a large and safe motorway network, carefully maintained.

As usual, the advantages are taken as a due, and the drawbacks only are considered.

2.2. Which material to replace concrete?

It is true that the fabrication of cement produces large carbon emissions and that fabrication of concrete needs much sand and gravel. But no other material can totally replace concrete.

Fabrication of steel – another material essential in our civilisation – also produces large carbon emissions, and exhausts natural resources.

Replacing concrete with wood to erect houses or buildings would rapidly exhaust existing forests, which are not in very good condition in my country due to the climatic emission. And we can often see what the effect of strong hurricanes on houses made of wood in the United States is. We cannot go back to stones and wood.

Nobody dares to say what the effective cause of these massive carbon emissions is: this is the unlimited growth of human population. When I was young, in 1950, there were 2.6 billion inhabitants on earth, of which a very large majority lived in very frugal conditions; on November 2022, the population reached 8.0 billion; not all of them lived according to the American way of life, but in many countries the individual consumption increased, with a growing number of cars and other energy-consuming equipment.

We can anticipate that construction will be increased in the future in developing countries which have not yet an adapted equipment level of roads, railways, hospitals, habitation buildings, schools, universities.

The equation clearly has no solution.

2.3. Steel and concrete

Steel and concrete will remain the main construction materials for building houses, bridges, factories. They will not disappear, and we shall have to find ways to reduce, as much as we can, the level of carbon emissions and the exhaust of natural materials; limiting – directly or indirectly – the production of concrete.

I am not qualified to say how the carbon emission could be reduced in the production of cement, but we all know that the cement industry develops new processes to produce low carbon cement.

We also know that researchers develop analyses to re-use demolition products, in order to replace, partly or totally, natural sand and gravels, to reduce the consumption of natural materials. It may lead to reduce the concrete characteristics, strength for example, or durability, meaning that these new concretes must find adapted applications.

I had also heard that the production of high-performance concrete produces more carbon emissions than classical concrete. The example I had seen was not fully convincing, since it compared a classical concrete, 40 to 50 MPa, to a high-performance concrete of more than 100 MPa.

I shall come back to this point since the durability of the structures to build must be considered in the selection of materials.

2.4. Thermic isolation of buildings

A major goal for our industry is to reduce the quantity of energy necessary to use our constructions. One of the major questions is the thermic isolation of habitations. We usually think of heating in cold times, but with the climatic evolution we shall also have to consider hot periods.

This problem is extremely critical in France, where this question has not been considered for many years. The result is that a very large part of habitations are cold in winter, hot in summer, and require much energy in the cold seasons.

The evaluation of thermal insulation in France is very technocratic, extremely approximate, and the laws are so complicated that it is difficult to update many of existing constructions.

This is a very major problem to solve in many countries, with important possible savings in energy and in carbon emissions.

2.5. The designer's duty

As already stated, I am not qualified in these domains, but I can react as a designer.

As designers, using cement and steel, using natural resources as sand and gravel, we have a high responsibility in the situation created by the climatic crisis, and must do our best to reduce the societal and environmental cost of our constructions.

We must go back to the three rules laid down by Vitruvius Pollio, at least the first two of them.

Utilitas. As we must reduce the resources used for construction, we must limit constructions to those which are effectively useful to the society. We must stop erecting non-useful, and extravagant structures. This is not so easy, since the tendency has been, these last years, to design for show, for originality. It is no more acceptable to waste materials and resources just for a designer's reputation or a politician's pride.

Firmitas. Of course, structures must resist to applied forces. But I add to the notion of strength the notion of durability.

The erected structures must be useful (*utilitas*) during a very long time to justify the consumption of the used resources, and to reach this goal they must be durable. The materials and resources used for construction must not be spoiled for a short life time. This is not so easy in the modern world, when the target is usually an immediate, short-term benefit.

Long-term durability has a cost; high performance concrete is more durable due to a high compactness; prestressing tendons can be designed to have a high corrosion protection; equipment – drainage, waterproofing – can significantly improve the durability of the structure.

I have seen many mediatic decisions supposedly "ecological" that do not add anything to the structure. The most efficient way to produce sustainability consists in producing structures which can last a long time. Saving some carbon emissions is a mistake if the result is a much shorter service life.

We must consider durability and maintenance much more than we did 30 or 40 years ago. Structures must be designed to be easily inspected and maintained.

Venustas. Of course, I am personally concerned by the architectural quality of constructions, proportions, balance, elegance, and by their adaptation to their site. But we are not at the heart of the climatic crisis question here.

Adaptability. Considering the rapid evolution of the modern world, we must add a fourth rule to the three aims of designers by Vitruvius: adaptability.

It is frequently referred to the life cycle of structures, to consider all the life steps, from erection to demolition. But this concept must not be misunderstood. It is not until demolition has been considered and assessed, with the possible re-use of some materials, that the right objective has been achieved.

I recently listened to a presentation given by Joost Walraven, one of our first presidents. He told us that, in the fifties and sixties, when many people moved from the countryside to cities, habitation buildings were extensively built with apartments for families of four to five persons, parents and children. These buildings are no more adapted to the situation today, with young couples, with separated families, students. The old buildings, no more adapted to the demand, have been demolished to be replaced for a better adaptation to a new demand, resulting in a waste of the materials used when they were erected.

Joost then showed that we must change our construction philosophy, and think of adaptable structures. Meaning buildings with long spans, such that the internal organisation of apartments can be modified if needed, by just replacing the internal substructures, passing from large to small ones, or the other way round, without modifying the main structure.

2.6. Conclusion

The climatic crisis must modify our vision of construction. We must become more responsible of the use of energy, materials and natural resources.

But this good direction is not in agreement with short term interests: no private investor will put more money to long-term durability; nor to erect adaptable structures as those suggested by Joost. They will privilege short-term rentability. Only the public authorities can put the pressure in the good direction.

Engineers and their associations must develop ideas and convince media and politicians of the still major interest of the classical construction materials, concrete and steel, and of the necessary orientations to erect more efficient constructions.

3. *fib*'S DUTY

In my opinion, it is the duty of the *fib* to produce documents in the defence of concrete and concrete structures, not at the attention of its members or of engineers, but of the public and the media; and also to take part in public emissions, radio and television, to explain the developments made to reduce carbon emissions and the use of natural resources; and the advantages of concrete and steel to erect constructions for the good of humanity.

I do not speak of Technical Bulletins (which could be useful as preparatory documents), but of books or presentations made by qualified, well-known professors or engineers, adapted to a large public, able to demonstrate the need of concrete and steel in our civilisation.

It is important to oppose to low quality constructions, as many poorly designed habitation buildings and bridges and as many constructions of a low durability touched by concrete degradation, corrosion and cracks, which have given to concrete a poor reputation.

The *fib* must promote constructions demonstrating that concrete can be a material of excellence, based on a unanimous selection on the basis of an assessment. Some examples are given in Figures 1-9.

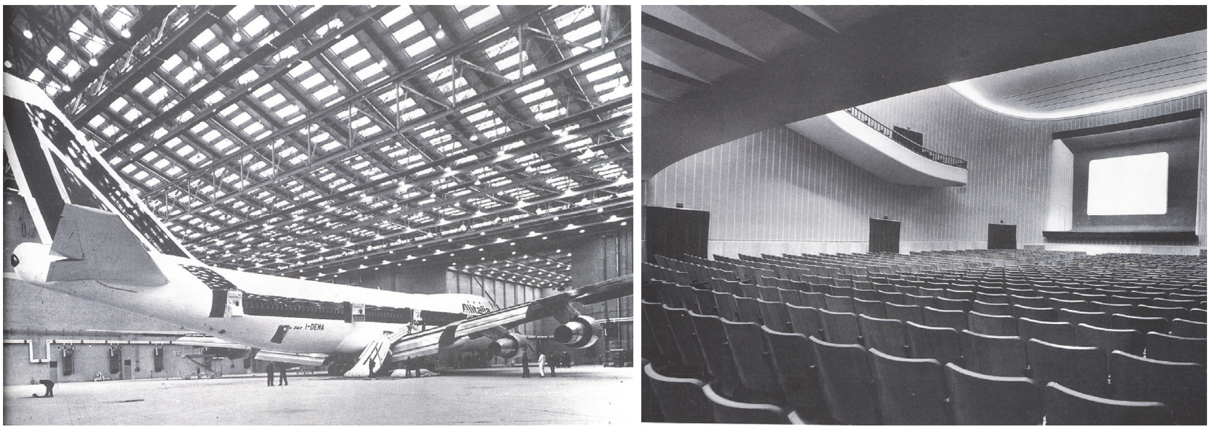


Fig. 1. Aircraft hangar at Fiumicino airport (left) and a cinema in Rome (right) by Ricardo Morandi

Fig. 2. An elegant parking (Ricardo Morandi)

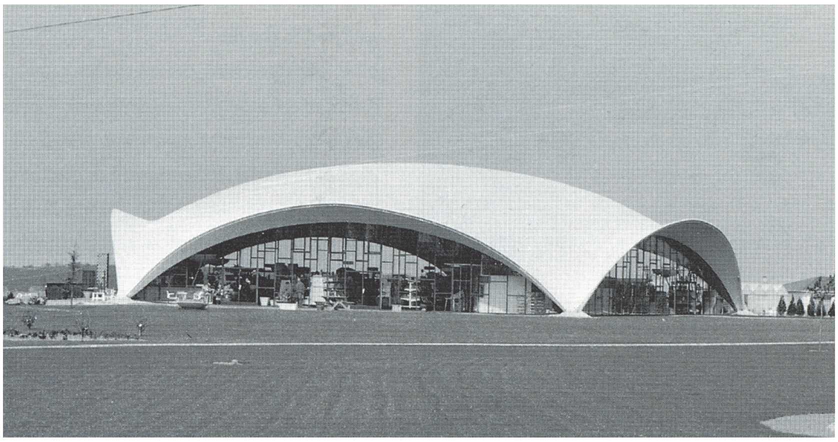


Fig. 3. A garden centre (Heinz Issler)

Fig. 4. A bridge on the River Rhein (Christian Menn)

Fig. 5. The Kehleim Bridge (left) and the Max Eyth See Bridge (right) by Jörg Schlaich

Fig. 6. The Altiani Bridge on the Tavignano

Fig. 7. The Swiss Lake Bridge Czech Republic (Jiri Strasky)

Fig. 8. The Antrenas Bridge (left) and the Truc de la Fare Bridge (right)

Fig. 9. The Bridge on the river Vienne

4. THE FUTURE OF ENGINEERS AND DESIGNERS

4.1. Engineers' influence in society

The tasks described above will not be so easy, since engineers have practically lost any influence in the society and are not able to be listened to by the media and politicians.

Perhaps I am wrong, but I do not see qualified and credible engineers interviewed in the public media to explain how concrete is essential in our civilisation and how the industry works to reduce carbon emissions and the consumption of natural resources. We only hear negative opinions from ecologists or others who cannot propose credible alternatives to erect safe and durable buildings, dams and bridges.

Engineers discuss these questions among themselves, without any impact on society, without any impact on the media. Twenty, thirty years ago, a few journalists came to our conferences. Now, when the situation is critical, I see none.

Our associations must become pro-active, making contacts with the media and political organisations – such as the European Commission – to defend their position.

4.2. Engineers lost a large part of their influence on construction

Engineers lost their influence over large contracting companies due to the development of concessions and design and build competitions. Designers and design offices, even the largest ones, have not the capacity to compete with large contracting companies which can impose their strategy and their financial goals.

Engineers have also lost their influence against architects who are close to media and politicians. Even to erect complex structures, like bridges or large buildings, architects tend to take the lead, not for the best for bridges, and engineers are rarely credited for their creations.

Personally, I think that designing elegant bridges is a part of architecture, one of the six arts ordered by Hegel from the most constrained by material to the purest: Architecture – Sculpture – Painting – Dance – Music and Poetry.

The art of engineers, in designing their structures, is to organise the materials and to master the flow of forces from the loads – including self-weight – to the supports and foundations.

If engineers claim that design is an art and have the ambition of being “artists”, they must be consistent and adopt a more appropriate attitude and language. They must take interest in arts more generally. Each time I visited Jorg Schaich in Stuttgart, he drove me to visit the painting museum; to visit his bridges in the area; to pass in a street in which series of houses have been erected by the masters of the Bauhaus movement.

Each time I was invited by Mineo Morimoto to give lectures in Japan, he drove me in several Japanese places, to visit castles and temples; I even took inspiration from the Kintai Bridge, visited with him during the spring cherry blossom season, to install a pedestrian walkway on an arch bridge in French Brittany.

Above all, we must be able to understand the site and the landscape, to design a bridge or a structure adapted to the site, or a building that fits the urban environment.

4.3. A disastrous evolution

I am very sorry to say that this is not what I usually see.

Often, engineers jump to their computer, build a structural model, and produce a series of numerical results corresponding to factored load combinations. In many cases, they do not even know what the distribution of forces and stresses under permanent loads is, which are in fact governing the life of the structure. Of course, I must recognize that it is necessary to check that the design fulfils the code requirements, but this is not the way to develop a good design.

To be very clear, I do not like our structural codes which are not helping to a good understanding of the structural behaviour.

I had once a heated discussion with a French engineer who had an important position in the preparation of the Eurocodes. He told me that the European governments will have less and less money to spend on construction, due to the increase in social spending and on this point he was right. But from that point, he considered that, to reduce the cost of design, engineers had to be replaced by simple technicians.

Of course, it made me furious, and I then said that I did not appreciate the Eurocodes, which mainly gives application rules, in the American way, without a clear physical meaning. He answered that engineers are so stupid that they must apply codes without understanding them. Many engineers are reduced to simple technicians.

The development of BIM (with some great advantages to avoid construction errors) and artificial intelligence will not help stopping this dramatic evolution.

4.4. Lessons from our predecessors

We must learn from our predecessors, engineers who built fantastic structures in steel or concrete, who were much more than just engineers because of their influence on society: Thomas Telford, Kingdom Isambard Brunel, Gustave Eiffel, John Roebling, Robert Maillart, Othmar Ammann, Eugène Freyssinet, Riccardo Morandi, Nicolas Esquillan, Fritz Leonhardt, René Greisch, Jacques Mathivat, Jörg Schlaich, Jean-François Klein and many others (see Figures 10-16).


Fig. 10. Thomas Telford (left) and Kingdom Isambard Brunel (right)


Fig. 11. Gustave Eiffel (left) and John Roebling (right)


Fig. 12. Robert Maillart (left) and Othmar Ammann (right)

Fig. 13. Eugène Freyssinet (left, in hat) and Riccardo Morandi (right)

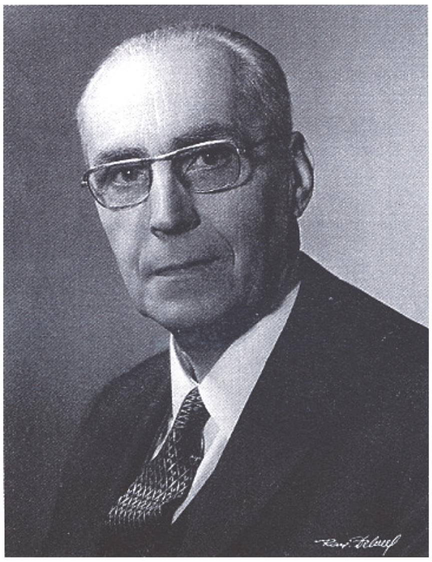
 

Fig. 14. Nicolas Esquillan (left) and Fritz Leonhardt (right)

Fig. 15. René Greisch (left) and Jacques Mathivat (right)

Fig. 16. Jörg Schlaich (left, in tie) and Jean-François Klein (right)

They had a personal approach of design and construction. They based their design on physical bases, on their knowledge of the behaviour of materials, with a clear understanding of the flow of forces, and on a clear sense of architecture and elegance. Many engineers, today, just apply codes, and act as simple technicians.

It is in my opinion in the duties of our associations, *fib* and IABSE at least, to maintain the memory of these great designers, to underline what they gave to the society, and make their best to encourage the apparition of successors, and the design of great structures (Figures 17-23).

Fig. 17. The Rion-Antirion Bridge

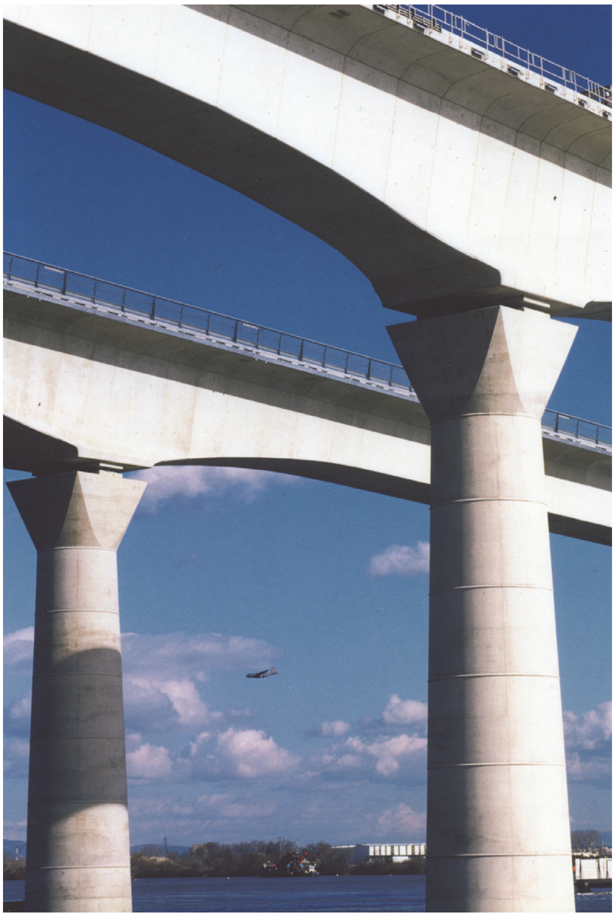


Fig. 18. The Avignon viaducts for the High Speed Train

Fig. 19. The Normandie Bridge

Fig. 20. The Jacques Chaban-Delmas Bridge (left) and the Gignac Bridge (right)

Fig. 21. The Térénez Bridge

Fig. 22. The Millau Viaduct

Fig. 23. The Third Bosporus Bridge (Jean-François Klein and Michel Virlogeux)

5. CONCLUSION

As a conclusion, we need that our associations, and more especially *fib*, promote the role of engineers, and put into light the major evolutions and problems of our industry, and the best built structures.

As it is today, our Journal, Structural Concrete International, with thousands of pages every year devoted to research, and mainly to summaries of doctoral theses, cannot reach this goal. It cannot attract the best papers, which are either not written or will be published elsewhere.

fib is efficiently attracting the academic world, but is losing designers and the profession.

In the critical period produced by the climatic crisis, we must absolutely get out of the comfortable "between us" life and turn to action in the society.

RESEARCH ON BRIDGES AT THE BUDAPEST UNIVERSITY OF TECHNOLOGY AND ECONOMICS

László Dunai
Professor, Member of the MTA, Department of Structural Engineering, BME
3-9. Műegyetem rkp., Kmf. 85, Budapest, H-1111, Hungary

ABSTRACT

Bridge construction is closely related to the development of transport infrastructure and is in its "golden age" when road/railway construction is gaining momentum in a country. In Hungary, three such eras are referred to as the "golden age of bridge construction". The first is the period of the Millennium, when most of the historical Danube bridges were built, in addition to the large number of bridges of the rapidly developing road and railway network. The sad history of the second period the devastation of World War II, when most of the country's bridges were destroyed, their reconstruction was realized in a short time, with enormous work.

The third era of intensive bridge construction began in the early 2000s and continues today. The high-volume bridge construction activity was/is still supported today by research and development scientific and industrial projects. The areas of tasks with scientific demands cover several fields: solid mechanics (structural modelling and analysis, design theory), material science (new building materials, corrosion), fluid mechanics (wind dynamics), IT (BIM, digitalization, measurement technology), as well as issues of sustainability and production/construction technology. Based on the research results and application experience, the international and domestic regulations for bridges have been also renewed in recent years.

The presentation provide an overview of research activities of the Budapest University of Technology and Economics (BME) related to bridges carried out in the last decade and a half. The selected examples illustrate how the theoretical and experimental research supported the rehabilitation and construction of different types of existing – historical – and new bridges, with special structural behaviour and design aspects.

FÖLDMŰVEK TEHERBÍRÁSÁNAK ÉS TERHELÉS OKOZTA ALAKVÁLTOZÁSOK VIZSGÁLATÁNAK HAZAI EREDMÉNYEI

DOMESTIC RESULTS OF INVESTIGATIONS INTO THE LOAD BEARING CAPACITY AND LOAD-INDUCED DEFORMATION OF EARTHWORKS

Szendefy János
Budapesti Műszaki és Gazdaságtudományi Egyetem
1111 Budapest, Műegyetem rkp. 1-3.

ÖSSZEFOGLALÓ

A pályaszerkezet tervezési gyakorlatban jelenleg nem veszik számításba a ciklikus terhelés okozta maradó alakváltozásokat, a pályaszerkezet alatti anyagokat és a hidraulikus kötőanyag nélküli szemcsés alaprétegeket rugalmas anyagként alkalmazzák. Ennek a gyakorlatnak vélhetően az az oka, hogy nem volt olyan talajmodell, aminek segítségével a nagy ciklus szám alatt bekövetkező maradó alakváltozásokat meg lehetett volna határozni. A Whictmann által fejlesztett HCA-modell lehetőséget ad erre, azonban a bemenő paraméterek meghatározás érdekében a pályaszerkezet alatti altalajban működő feszültségviszonyok részletes elemzése szükséges. A cikk azon kutatási eredmények egyes részeit mutatja be, aminek segítségével a feszültségviszonyok és a halmozódó alakváltozások meghatározásra kerültek.

SUMMARY

In current track structure design practice, residual deformation due to cyclic loading is not taken into account, and subgrade materials and granular base layers without hydraulic binders are used as flexible materials. The reason for this practice is believed to be that there was no soil model available to determine the residual deformation over a large number of cycles. The HCA model developed by Whictmann provides a means to do this, but a detailed analysis of the stress relationships in the subsoil beneath the track structure is required to determine the input parameters. This paper presents parts of the research results that have been used to determine the stress-strain relations and the cumulative deformation.

1. BEVEZETŐ

A földművek szerepe, hogy biztosítsák az utak magassági és helyszínrajzi nyomvonalvezetését. A földművek főbb elemei közé soroljuk a bevágások során kialakuló föld vagy szikla rézsűket, a töltések építésekor készülő töltéstestet és a pályaszerkezetet közvetlen alátámasztó földmű felsőrészt.

A bevágási rézsűk tervezésekor a legfőbb szempont az állékonysággal szembeni biztonság biztosítása, annak érdekében, hogy a tervezett utat megvédjük az esetlegesen ráomló talajtól vagy sziklától. Az állékonyság biztosítása mellett természetesen fontos szempont a fenntartható üzemeltetéshez szükséges geometriai kialakítás, ami tartalmazza a hajlások, osztópadkák és a növényzet megtervezését. Az állékonyság alapvetően a kialakított geometriától, a talajrétegződéstől függ, összetett rétegződés esetén nehezen felállítható geotechnikai modell van, ami jelentős kockázatot jelenthet. Azokon a helyeken, ahol a tervezett út a jelenlegi terepnél magasabbra adódik, töltéssel lehet a magasságkülönbséget áthidalni. A töltések tervezése során az elsődleges cél szintén az állékonyság biztosítása, ami részben a töltés alatti altalaj teherbírásától, esetleges más altalaji anomáliától, részben pedig a töltésrézsű állékonyságától függ. Mivel a töltés anyagát tervezetten választjuk és az építés során is lehetőségünk van annak folyamatos felügyeletére, így a bevágási rézsűkkel szemben az ebből fakadó kockázatok csökkenthetőek, jobban kezelhetőek. A töltések alatti altalajtörések is általános esetben kevésebb kockázatot rejtenek, mint a bevágási rézsűk.

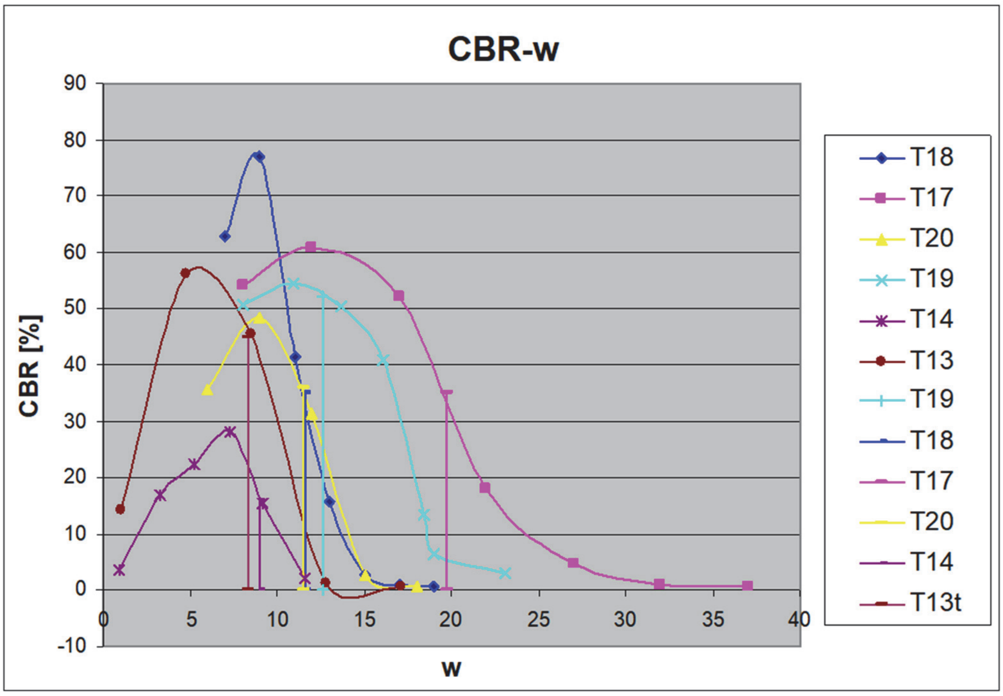
A töltések megfelelő anyagból és tömörségben való elkészülése, valamint az altalajban lejátszódó süllyedések kezelése azért is kiemelten fontos, hogy a pályaszerkezet a töltés alakváltozása miatt ne szenvedjen káros deformációt. Amennyiben ezek biztosítottak, úgy a pályaszerkezet alapozásának megtervezése során már csak a földmű felső rész tulajdonságai lesznek a mérvadóak, így annak részletes tervezésével, elemzésével kell foglalkozni. Alapkövetelményként állíthatjuk azt fel, hogy a földmű felsőrésznek kellően teherbírónak kell ahhoz lennie, hogy a pályaszerkezet alatt talajtörés, jelentős oldalkitérés és ilyen módon nagy alakváltozás, deformáció ne következhessen be. Ez a kritérium a modern útépítésben már rutin feladatnak számít, így ilyen jellegű, védő rétegben bekövetkező talajtörés jellegű problémával ma már egyre kevesebbszer lehet találkozni.

Az emberiség fejlődésével, a globalizáció megjelenése okozta robbanás-szerűen megnövekedett forgalmi terheléssel, új kihívásoknak kell a pályaszerkezet tervezőknek és építőknek megfelelniük. Az utakon közlekedő nagyszámú gépjármű forgalom nagyszámú ciklikus terhelést ad a pályaszerkezetnek és azon keresztül a földmű felső részének. A talajban lévő feszültség terjedés és az ennek köszönhető feszültség leépülés miatt a forgalmi terhelés okozta többlet feszültségek csak egy korlátozott mélységig jutnak le, így elegendő csak azt a földmű részt az ilyen típusú terhelésnek ellenállóvá tenni, ami ezzel érintett. Ebből adódóan a földmű felső részében ezen funkció betöltése miatt speciális, nagy terhelésű anyagok kerülnek felhasználásra. A továbbiakban ezen felső rész teherbírása és a ciklikus terhelés okozta maradó alakváltozások mértékének meghatározása kerül tárgyalásra.

2. A TALAJOK TEHERBÍRÁSÁNAK ÉS A TERHELÉS OKOZTA ALAKVÁLTOZÁSOKNAK A MEGHATÁROZÁSI MÓDJAI

2.1. Statikus terheléssel mért teherbírás

A talajok teherbírásának vízre való érzékenysége jól ismert dolog a szakirodalomban. Különösen érzékenyek a víztartalom változásra a hazánkban felszín közelében gyakran előforduló átmeneti talajok (pl.: lösz, homokos iszap folyóüledékek) és a kötött talajok. Ezen talajok vízérzékenysége olyan nagymértékű, hogy sokszor már a tömörítéshez szükséges optimális víztartalom mellett is jelentős teherbírás csökkenéssel kell számolni, ami néhány % víztartalom növekedés hatására gyakorlatilag nullára redukálódik. Az 1. ábra iszap és agyag talajok CBR teherbírását mutatja be a víztartalom függvényében, ahol a függőleges vonalak az adott talajok optimális víztartalom értékét mutatják. Ennek a vízérzékenységnek az eredménye, hogy ezek a típusú talajok a pályaszerkezethez közel már nem használhatóak, nem építhetőek be.



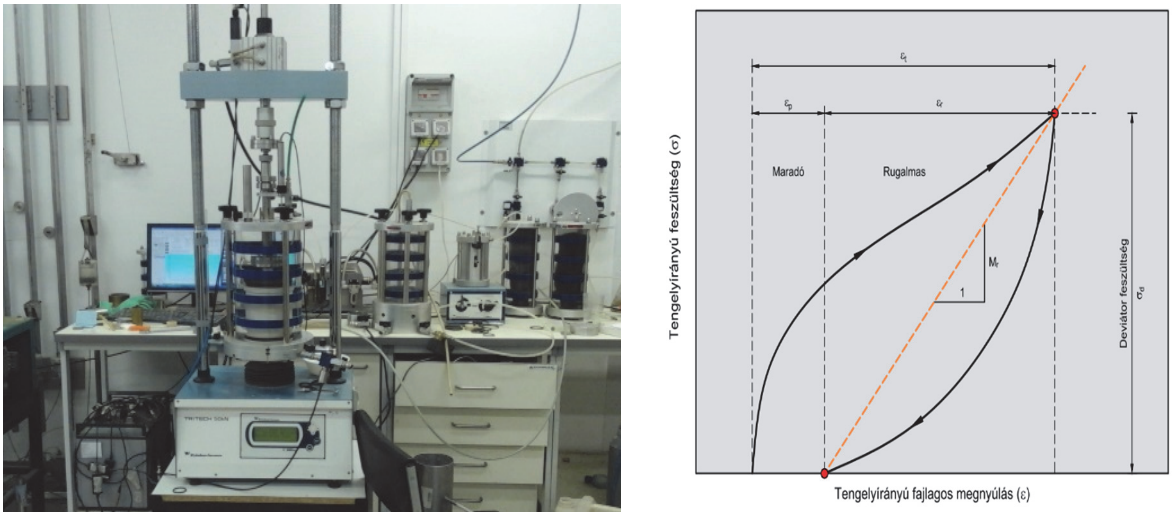
1. ábra: Átmeneti és kötött talajok teherbírása a víztartalom függvényében (függőleges vonalak a w_{opt} jelölik) (Szendefy, 2009)

Az 1. ábrán látható vizsgálatok még a talajok statikus talajparamétereinek a mérésére készültek. A laboratóriumban mérhető CBR teherbírásból jól számítható a jelenlegi úttervezésben is használt E_2 teherbírási modulus, amivel az adott talaj merevsége jellemezhető. A hazai és a nemzetközi pályaszerkezet méretezés döntő része jelenleg is ezeket a statikus terhelésből számított rugalmassági modulusokat használja a talajok teherbírásának jellemzésére.

2.2. Reziliens modulus

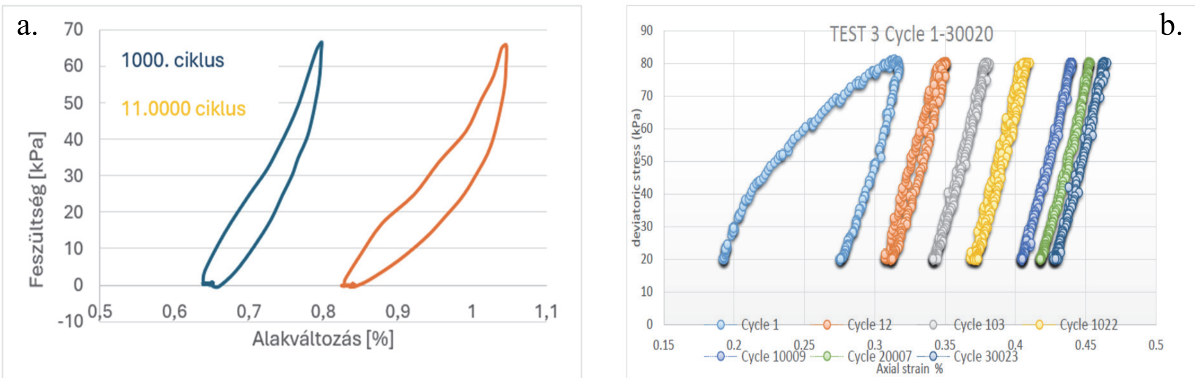
A járműforgalom azonban ciklikus terhelést okoz a pályaszerkezet alatti földműben, ezért a kutatók elkezdték vizsgálnia a talajok ciklikus terheléssel szembeni merevségét. A talajok ciklikus terhelés alatti alakváltozásának meghatározása nagy kihívást jelentett a szakmánknak. Ezt a kihívást részben a vizsgálóberendezések korlátai okozták, részben pedig a földmű felsőrészben uralkodó feszültségviszonyok ismeretének hiánya. Ciklikus terhelés mérésére alkalmas triaxiális mérőberendezések hazánkban a 2010-es években jelentek meg, aminek hatására több fiatal kutató (Back, 2017, Bán, 2023, Szilvágyi, 2018, Vámos, 2014) is ezen berendezésekkel végzett vizsgálatok különböző talajtulajdonságok meghatározása céljából.

A ciklikus terhelés alatti alakváltozásokból számolható a Reziliens modulus (M_r), amely ilyen módon már az egyes tengelyáthaladások során elszenvedett rugalmas alakváltozást adja meg. A reziliens modulust a terhelési ciklus végén mért alakváltozás és a terhelés csúcsértékénél mért alakváltozás hányadosából számíthatjuk. A vizsgálatok szerint azonban a ciklikus terheléshez tartozó hiszterézis hurok a tehermentesítés során nem a 0 alakváltozáshoz, hanem egy kismértékű maradó alakváltozáshoz tér vissza (2. ábra). Ezt a maradó alakváltozást a pályaszerkezetek méretezésénél nem veszik figyelembe, a számításoknál használt talaj merevséget az M_r-rel jellemzik. Az egyes ciklusok után maradó alakváltozás valóban elhanyagolhatóan kicsi a rugalmas alakváltozáshoz képest, azonban a nagyszámú terhelési ciklusok során kialakuló maradó alakváltozások halmozódása miatt már számottevő alakváltozás mérhető ki (3. ábra).



2. ábra: Triaxiális berendezés a BME Geotechnikai Laboratóriumában és a Reziliens modulus elvi ábrája

Erre a maradó alakváltozásra figyeltünk fel a laboratóriumi vizsgálataink során és kezdtünk el velük részletesebben foglalkozni. A laboratóriumunkban nagyszámú M_r vizsgálat készült Back Márta és Vámos Máté kutatásai keretén belül. Míg Back alapvetően a hazánkban gyakran előforduló lösz talajok tulajdonságait és azok stabilizálása során tapasztaltak mérésével foglalkozott, addig Vámos inkább a homokok vizsgálata felé fordult egy még fejlettebb anyagmodell részletes vizsgálata érdekében.

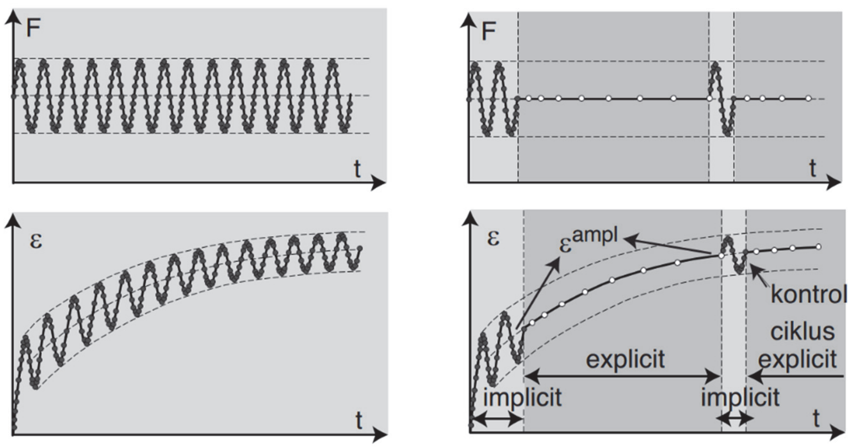


3. ábra: Hiszterézis hurok eltolódás halmozódó maradó alakváltozás miatt (a., lösz talaj Szendefy, 2017, b., homok talaj, Anas 2018)

2.3. HCA-talajmodell

A laboratóriumi vizsgálatok során felismertük és megbizonyosodtunk róla, hogy vannak maradó alakváltozások, azok numerikus modellezése során mégis korlátokba ütköztünk. A számítások megfontolása során arra jutottunk, hogy a maradó alakváltozások pályaszerkezetre gyakorolt hatásának vizsgálatára két út vázolható. Az egyik ezek közül, ha a maradó alakváltozások értéke, mint egy statikusan elérhető alakváltozás kerül figyelembevételre, tehát az M_r értékének számítása során a rugalmas alakváltozáshoz hozzáadásra kerül a maradó alakváltozás is, ezzel csökkentve az M_r értékét. Ez sajnos nem tudja azt modellezni, hogy ez a leromlás csak időben alakul ki, így a talaj teherbírásának alul becslését szolgálná. A másik irány lehet a végeselemes programokban használt speciális anyagmodellek alkalmazása. A 2000-es évektől nagyon jelentős tapasztalatra tett szert a hazai kutatói és tervezői gárda a numerikus analízisekben, a 2010-es évektől ráadásul megjelennek a 3D modellezés lehetőségei is, ezért adta magát, hogy ebbe az irányban legyenek próbálkozások. Több évi kutatómunka és külföldi szakmai konzultációk után sem akadt olyan talajmodell, amivel megfelelően modellezhető lett volna a ciklikus alakváltozások során létrejövő maradó alakváltozás a végeselemes szoftverekkel. Talán legközelebb a hipoplasztikus modellek álltak, de ezek hosszadalmas kalibrálása sem vezetett sikerre.

Nem csak ezek a sikertelenségek, hanem más körülmények is azt hozták, hogy a 2010-es években megjelenő Wichtmann által fejlesztett HCA-modell irányába történt elmozdulás. A HCA-modell (High-Cycle Accumulation modell) az egyik legjobban dokumentált, számos laborvizsgálattal igazolt olyan típusú anyagmodell, ami alkalmas az ismétlődő terhelésből származó maradó alakváltozások meghatározására. A HCA-modellt Niemunis et al. (2005) publikálták és Wichtmann doktori disszertációjának (Wichtmann, 2005) számos modellkísérletével verifikálták. A HCA-modellt homok talajok alacsony intenzitású ($\varepsilon^{ampl} < 3 \cdot 10^{-3}$), hosszan tartó terhelésére (akár 2 millió ciklus) fejlesztették ki. Megbízhatóságát több száz ciklikus triaxiális laborvizsgálattal kalibrálták a szerzők, ahol kiemelendő Wichtmann munkássága (Wichtmann, 2005; Wichtmann et al., 2006, 2007, 2010a, 2010b, Wichtmann and Triantafyllidis, 2016).



4. ábra: A tisztán implicit és a HCA-modell vegyes szemléletmódja (Wichtmann, 2016)

A HCA-modell alapgondolata, hogy kombinálja az implicit, növekményen ($\dot{\sigma} - \dot{\varepsilon}$) alapuló fejlett anyagmodelleket és az explicit, ciklusszám – maradó alakváltozás modelljét ($N - \varepsilon^{acc}$). A HCA-modell végeredményeként a halmozódó maradó alakváltozást $\boldsymbol{\varepsilon}^{acc}$ mint vektormenyiséget adja meg N-számú konstans feszültségamplitúdójú ciklikus terhelés hatására. Bemenő paraméterként szükség van a talaj állapotjellemzőire, mint a hézagtényező, az átlagos normálfeszültség, a feszültségállapot és a ciklikus alakváltozási amplitúdó (ε^{ampl}). Ez utóbbi egy hagyományos anyagmodell segítségével számolható ki implicit módon úgy, hogy közben a ciklikus feszültség lépcsőzetesen kerül felvitelre, és az alakváltozási amplitúdó az alakváltozási növekmények összegeként kerül kiszámításra. Ezek után az alakváltozási amplitúdó, mint bemenő adat segítségével kerül meghatározásra az explicit modellel a maradó alakváltozás az *N*-számú konstans feszültségamplitúdójú terhelésre. A modell lehetőséget nyújt arra, hogy az explicit szakaszok megszakításra kerüljenek, és az alakváltozási amplitúdó a megváltozott állapotjellemzőkkel (például merevebb viselkedés a tömörödés következtében) újra kiszámításra kerülhessen (Vámos-Szendefy, 2023b). Az alakváltozások számításakor a rugalmas és a maradó alakváltozások mértéke nagyban függ a feszültségviszonyoktól, azaz milyen a ciklikusan terhelt talaj részecskére ható függőleges deviátorfeszültség és a nyírószilárdság feszültségének aránya, amire döntő hatással van az oldalirányú megtámasztást reprezentáló vízszintes feszültségek nagysága.

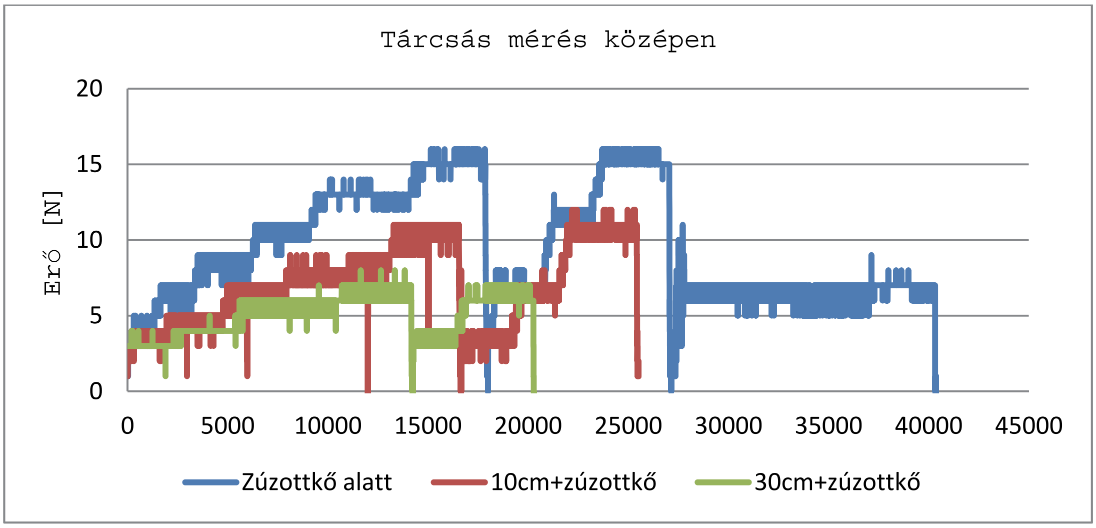
3. CIKLIKUS TERELÉSBŐL ADÓDÓ MARADÓ ALAKVÁLTZÁSOK SZÁMÍTÁSA

Az útpályaszerkezetek alatti maradó alakváltozások várható értékének számítására Vámos a doktori értekezésének kutatásában a fenti modellek analógiáján egy egyszerűsített számítási modellt fejlesztett Excel programban. A program a hajlékony pályaszerkezetek alatti egyes talajrétegekben (zúzottkő alapréteg, javítóréteg, altalaj) határozza meg implicit számítással a rugalmas elven számolt pillanatnyi alakváltozásokat (ε^{ampl}), valamint HCA-modellel, explicit számítással a halmozódó maradó alakváltozásokat (ε^{acc}) a ciklikusan fellépő forgalmi terhelésből. A következőkben a számításokhoz szükséges feszültségviszonyok meghatározásához vezető kutatások és a számítások néhány eredménye kerül bemutatásra.

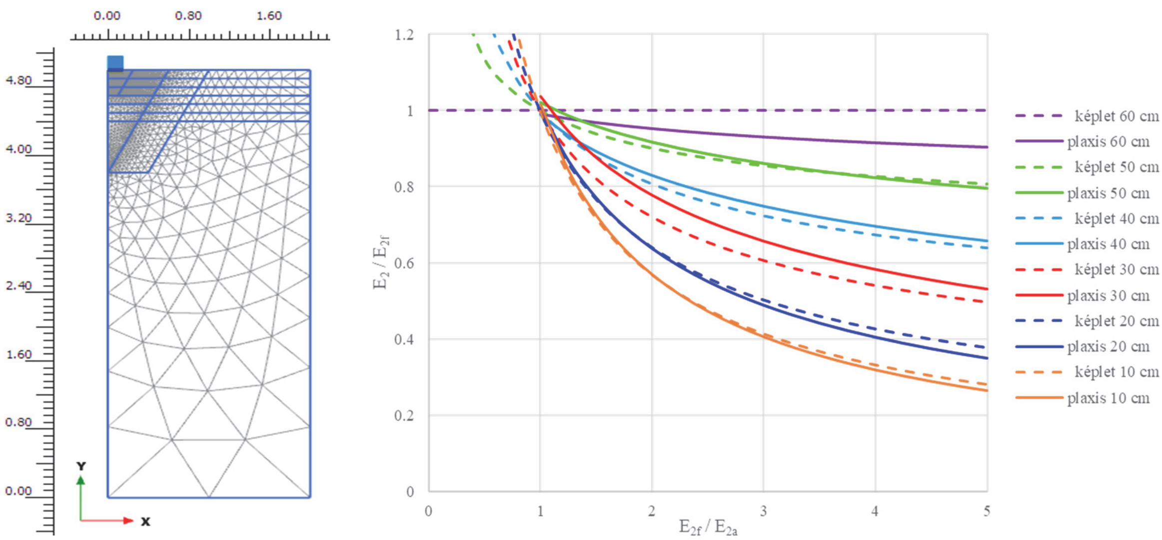
3.1. Földmű felsőrészben működő feszültségviszonyok végeselemes modellezése

A számítások során előállításra kerülő rugalmas (ε^{ampl}) és maradó alakváltozások (ε^{acc}) meghatározásához meg kell határozni a pályaszerkezet alaprétegében és a földmű felső részében működő függőleges és vízszintes feszültségeket. Az említett zónában lévő feszültségállapot meghatározása összetett folyamat, mivel a feszültségállapot időben változó; a kezdeti önsúly feszültségek mellett hatással vannak a feszültségtörténetre az építés közbeni folyamatok, így például a tömörítőgép okozta előterheltség, majd a forgalom okozta terhelés. Az összetett folyamatok miatt analitikus módszerekkel már kevéssé számolhatóak ezek a feszültségviszonyok, ezért végeselemes modellezés került alkalmazásra.

Az útépítéshez kapcsolódó feszültségviszonyok mérésével már korábban készültek kutatások az M_r mérések feszültségbeállításai céljából. Ennek keretén belül helyszíni mérések készültek földnyomásmérő cellákkal statikus és könnyűejtősúlyos teherbírásmérések során a mérőtárcsa alatt különböző mélységekben (Szendefy, 2017). A mért eredmények (5. ábra) jól illeszkedtek a mérések határmélység elméletével kapcsolatos korábbi hazai kutatásokhoz (Tompai, 2008), illetve az egyszerűsített feszültségeloszlás elméletekkel végzett számítási eredményekhez. A feszültségviszonyok numerikus analízésének egyik első lépéseként paraméter analízis készült statikus tárcsás teherbírásmérésekhez, aminek segítségével kalibrálásra kerültek a Plaxis geotechnikai végeselemes program HSS talajmodelljének paraméterei (Káli, 2020). Tulajdonképpen ezen elemzések (6. ábra) eredményeit használta fel a VEK-BME Végeselemes pályaszerkezet tervező program kutatása is, ami a korábban említett halmozódó alakváltozások végeselemes számítása miatt a talaj paramétereket csak rugalmas tartományban tudja továbbra is kezelni.

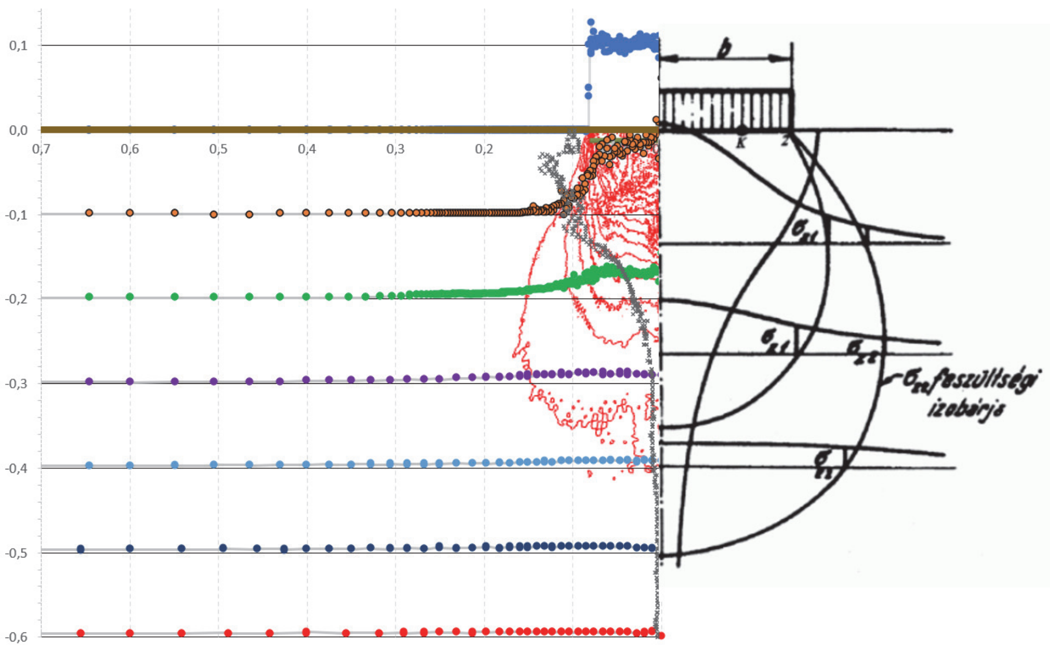


5. ábra: Statikus tárcsás teherbírásmérés terhelési lépcsői során mért erők a tárcsa alatti különböző mélységekben (Szendefy, 2017)

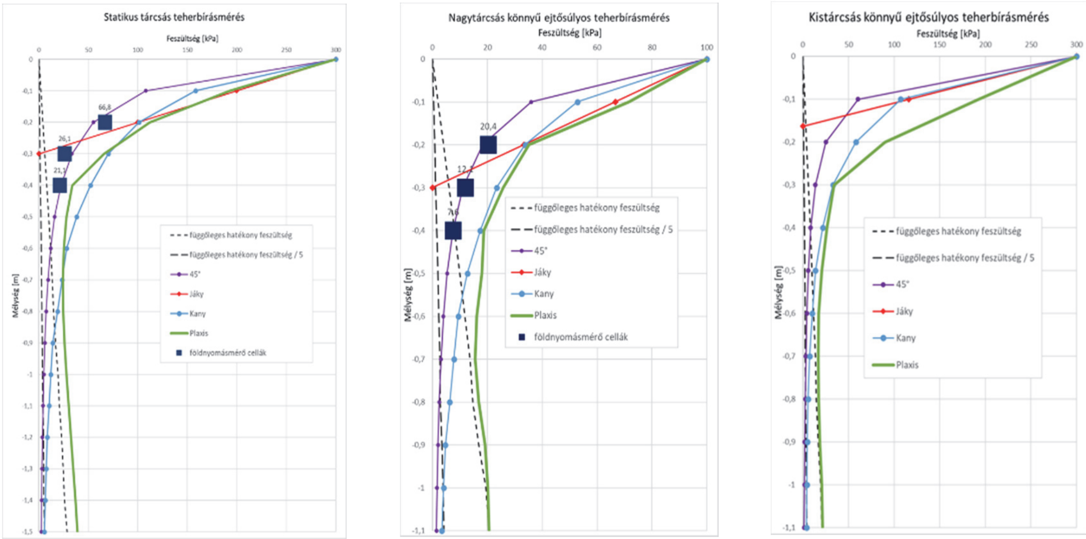


6. ábra: Statikus tárcsás teherbírásmérés numerikus modellje és a kétrétegű teherbírás tervező grafikon numerikus modellel való számítása (Káli, 2020)

Ezen vizsgáltok továbblépéseként numerikus vizsgálatok készültek a teherbírásmérő eszközök alatti feszültségek vizsgálata céljából. A helyszínen mért tárcsa alatti feszültség és annak mélységgel való leépülése került megvizsgálásra. Bár helyszíni feszültségmérés csak statikus és nagy tárcsás könnyűejtősúlyos berendezések alatt történt, a helyszíni mérések során készültek kis tárcsás könnyűejtősúlyos mérések is (Káli, 2022). A numerikus vizsgálatok így mindhárom hazánkban alkalmazott minősítési eszközre elkészítésre kerültek (8. ábra). A 7. ábra jobb oldala a szakirodalomban megtalálható elméleti feszültségterjedést mutatja be, míg az ábra bal oldala a Plaxis végeselemes program számításaiból kinyert, különböző mélységben működő feszültségeket mutatja.



7. ábra: Végeselemes modellezés és elméleti feszültségterjedés ábrázolása (Káli, 2022)

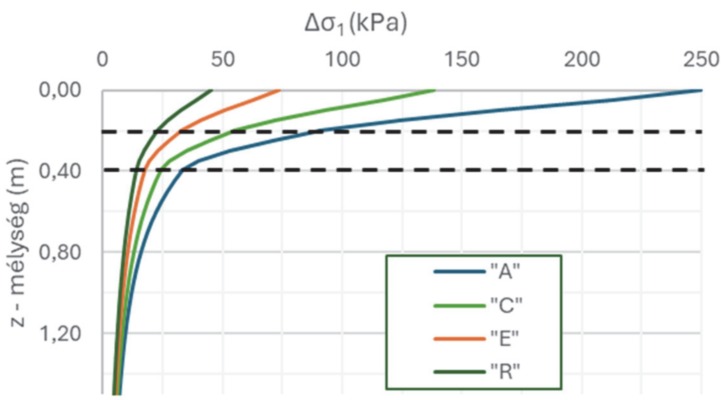


8. ábra: Statikus tárcsás, nagy tárcsás és kis tárcsás könnyűejtősúlyos teherbírásmérés tárcsája alatti feszültségek mélységben való lefutásának mért és számított értékei (Káli, 2022)

A modellezés során számított eredmények és tapasztalatok alkalmazásával került megalkotásra a HCA-modell vizsgálathoz szükséges végeselemes számítási modell annak érdekében, hogy annak bemenő paramétereihez megfelelő térbeli feszültségi viszonyok legyenek meghatározhatóak.

3.2. Függőleges és vízszintes földnyomások elemzése

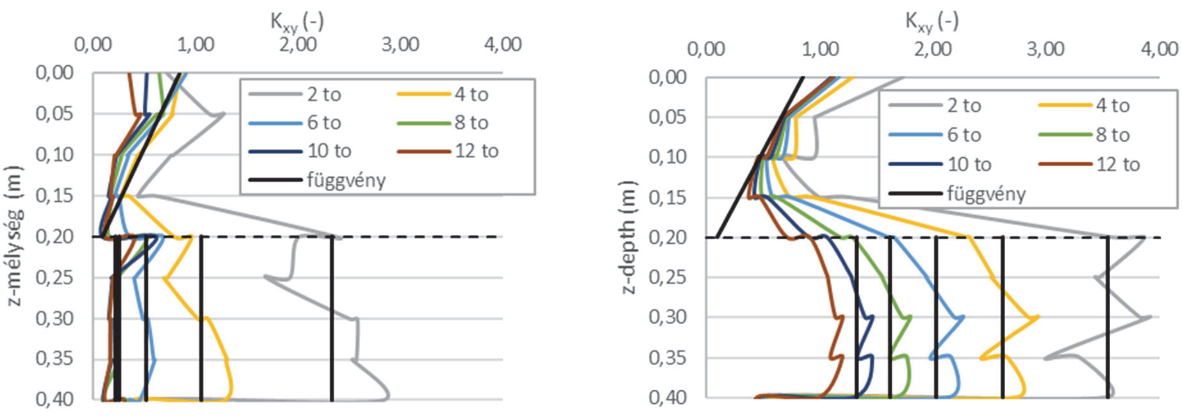
Vámos (2023a., 2023b) kutatása során egy olyan analitikus számolási eljárást fejlesztett ki, ami a végeselemes feszültségviszonyokat felhasználva határozza meg pályaszerkezet alaprétegében, a földmű felsőrészben és az altalajban a függőleges és a vízszintes feszültségviszonyokat a rugalmas és maradó alakváltozások számítására. Ezeket bemenő adatként használva a HCA-modellhez, annak számítása alapján képes a nagy ciklusszámú terhelések esetére a várható maradó alakváltozásokat meghatározni. A hazai laboratóriumi eszközök és alapkutatások hiányában hazai talajra nem sikerült HCA paramétereket előállítani, ezért Wichmann (2007) által publikált szemcsés talajok paramétereit használva végezte el a számításait. A kutatás során végzett nagyon sokrétű és átfogó munkából csak néhány kiragadott eredmény kerül az itteni cikk keretén belül bemutatásra. További részletes kutatási eredmények Vámos doktori disszertációjában, illetve a már publikált folyóirat cikkekben olvashatóak (Vámos-Szendefy, 2023a, 2023b, 2024a, 2024b).



9. ábra: A többlet függőleges feszültségek lefutása az A-C-E-R terhelési osztályok pályaszerkezeteinél jól graduált homok altalaj esetén (Vámos-Szendefy, 2023b)

A pályaszerkezet alatti hidraulikus kötőanyag nélküli zúzottkő alaprétegben, a földmű felsőrészben, valamint az altalaj vagy töltéstest további részében ható, az egységtengely terhelés egyik abroncsa alatti függőleges többletfeszültségből adódó feszültségeloszlást mutatja be a 9. ábra. A különböző feszültségek az eltérő forgalmi terhelésnél használt típuspályaszerkezetek aszaltvastagságának különbségéből adódnak. A legkisebb feszültség értelemszerűen a legvastagabb *R terhelési osztály* (29 cm), míg a legnagyobb feszültség a 10 cm vastag *A terhelési osztály* pályaszerkezet aszfaltvastagságnál adódott. Látható, hogy jelentős, közel ötszörös különbség van a kettő között az alapréteg tetején, de még a védő réteg alatt is 2,5-szeres a függőleges többlet-feszültség különbség. A burkolatról átadódó feszültségek nagyságát az aszfalt vastagság mellett más tényezők is befolyásolják, mint például az aszfalt hőmérséklete. A számítás során referencia hőmérsékletű aszfalttal készült a feszültségek meghatározása, amely számítások jó egyezést mutattak a Colas Út Zrt. próbaszakszán mért aszfalt burkolatú út alá beépített földnyomásmérő cellával mért eredményekkel. Az aszfalt hőmérséklet pályaszerkezet merevségre gyakorolt hatásáról ismert – részletesen foglalkozott vele a szintén BME PhD hallgató Cho (2022) – hogy a merevségváltozás miatt a pályaszerkezet alatti zónákra is jelentősen eltérő feszültségek jutnak, amivel Vámos (2024a) is külön foglalkozott. A feszültség lefutásából az látható, hogy valahol 1,2-1,5m-es mélységig hatolnak le az egységtengely terhelésből adódó függőleges feszültségek. A 9. ábrán a modellben alkalmazott 20 cm vastag zúzottkő alaprétegben, majd az alatta lévő 20 cm vastag homokos kavics védőrétegben, végül pedig az alatta lévő jól graduált homoktalajban ható többlet feszültségek láthatóak.

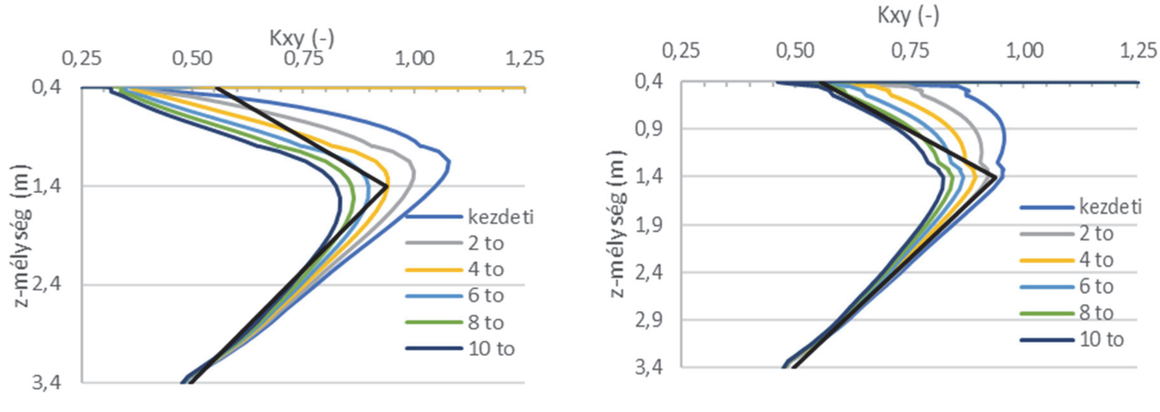
A talajok alakváltozásnak számításához használt modellnél a rugalmas és a maradó alakváltozások aránya a feszültségviszonyoktól függ, így a függőleges feszültségek mellett a vízszintes feszültségek kiszámítása volt elkerülhetetlen. A vízszintes feszültségek alakulása rendkívül összetett, több tényezőtől is függ, mint például a réteg pályaszerkezet burkolat alatti helyzete, a burkolat vastagsága, valamint a többlet függőleges feszültség és a beépítés során alkalmazott tömörítési feszültség hányadosából. A vizsgálatok alapján a zúzottkő alaprétegben egy lemezszerű hatás lesz a mértékadó, aminek hatására a réteg felső öve nyomottá, míg az alsó része húzottá válik. Ebből adódóan a felső részen kompressziós állapot (passzív földnyomás), míg az alsó részen expanziós (aktív földnyomás) állapot fog előállni. A védőrétegben a számítások szerint a tömörítési feszültség és az abroncs teherből adódó többletfeszültség hányadosából adódó túlkonszolidáltság lesz a mértékadó, ezért nagyban függ a teher nagyságától és a burkolat vastagságától. A túlkonszolidáltság szintén kompressziós állapotot, így magasabb földnyomástényezőt, míg a normálisan konszolidált eset az alacsonyabb nyugalmi földnyomástényezőt eredményez (10. ábra)



a., b.,

10. ábra: A vízszintes földnyomás tényezők értéke a zúzottkő alaprétegben és a védőrétegben a tengelyterhelés függvényében (a., A terhelési osztály, b., C terhelési osztály aszfalt burkolat vastagság esetén) (Vámos-Szendefy, 2023a)

Az altalajban a védőréteghez hasonlóan, a felső kb. 1,15 m vastag részen egy túlkonszolidáltságból adódó nyugalminál nagyobb földnyomás tényező, míg lefelé haladva egy nyugalmi földnyomáshoz való visszarendeződés figyelhető meg (11. ábra).

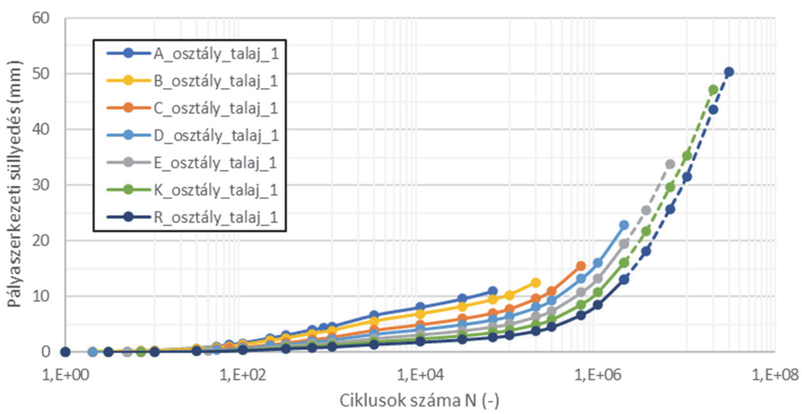


a., b.,

11. ábra: A vízszintes földnyomás tényezők értéke az altalajban a tengelyterhelés függvényében (a., A terhelési osztály, b., C terhelési osztály aszfalt burkolat vastagság esetén) (Vámos-Szendefy, 2023b)

3.2. Halmozódó alakváltozások számítása

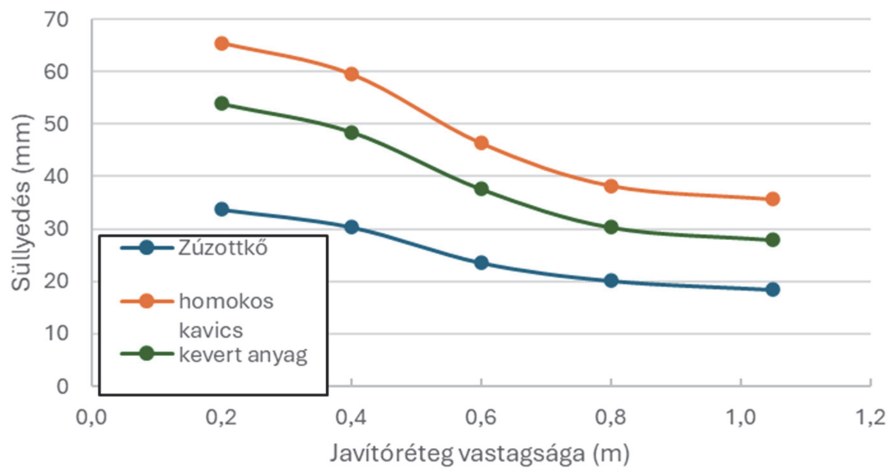
A feszültségviszonyok alapján számított alakváltozások ismeretében a HCA modell segítségével számíthatóvá válnak a ciklusszámok hatására bekövetkező süllyedések. A számítások szerint a süllyedések ~90%-a az altalajban fog kialakulni, míg a fennmaradó 10% többsége a védőrétegben alakul ki és a teljes süllyedés csupán 1-2%-ért felelős a zúzottkő alapréteg. Az altalajra minél nagyobb függőleges devitáor feszültség jut, az természetesen annál nagyobb süllyedést fog eredményezni. Ebből adódóan ha egységtengely terhelésre viszgáljuk a különböző pályaszerkezeteket, akkor azonos ciklusszámhoz a vékonyabb pályaszerkezettel rendelkező *A osztály*nál lesznek a legnagyobbak a süllyedések, míg az *R osztály*ban a legkisebbek. A ciklusszámok növelése természetesen további terhelési egységeket okoznak, amik hatására egyre nagyobb halmozódó alakváltozások fognak kialakulni. Ebből kifolyólag az egyes terhelési osztályokhoz tartozó élettartalom ciklus-szám végére, még a kisebb amplitúdó feszültségek ellenére is a nagy számban halmozódó alakváltzások miatt az *R osztály*ban lesznek a legnagyobbak a süllyedések, míg az *A osztály*ban a legkisebbek. Az élettartalom ciklusszámok alatt bekövetkező várható süllyedéseket mutatja be a 12. ábra.



12. Az egyes terhelési osztályoknál kialakuló, az FZKA felszínén értelmezett pályaszerkezeti süllyedés az egységtengely áthaladási ciklus-számok függvényében a rosszul graduált finomhomok altalaj esetén (Vámos-Szendefy, 2024a)

A fent leírtakból az következtethető ki, hogy a süllyedések csökkentése alapvetően az altalajra jutó feszültségek csökkentésével, vagyis a magasabb merevségű rétegek vastagságának növelésével érhetőek el. A 12. ábra alapján belátható, hogy az aszfalt burkolat vastagságának növelése milyen módon csökkenti a burkolat alatti süllyedéseket, azonban ha a zúzottkő alapréteg vagy a szemcsés anyagú védőréteg vastagsága kerül megnövelésre, úgy az altalajra szintén kisebb feszültségek fognak lejutni. Az alap- vagy védőréteg a süllyedések csak igen kis százalékáért volt felelős, így ezen rétegek vastagításából adódó többlet süllyedések is elenyészőek lesznek ahhoz képest, amit az altalajra jutó feszültségek csökkentésével az altalajban kialakuló süllyedések csökkenésében el lehet érni. Az aszfalt ára nagyságrenddel nagyobb ezen szemcsés rétegek áránál, így gazdasági elemzés alapján a burkolat alatti alap- vagy védőréteg vastagítása adhat műszakilag és gazdaságilag is optimális megoldást.

Az alapréteg vastagsága a típuspályaszerkezet méretezésnél adott, így inkább a földmű felsőrészébe beépített védőréteg hatása került megvizsgálásra. A védőréteg vastagságának növelésével elérhető süllyedés csökkenést a 13. ábra mutatja be, amelyről 80 cm körüli vastagság olvasható le optimális értéknek. Ez jó egyezést mutat a hazai gyakorlatban az elmúlt évtizedekben kialakult és azóta a műszaki előírásokban is alkalmazásra került 100 cm vastag földmű felsőrész vastagságával. A védőréteg vastagságának vizsgálata mellett számítások készültek a védőréteg anyagának hatására vonatkozóan is. A szakirodalomból és a tapasztalatból is ismert, hogy az éles-szemcséjű anyagok teherbírása magasabb a legömbölyített szemcséjű anyagoknál. A vizsgálatok során összehasonlításra került a zúzottkő, a homokos kavics és az ezek keverékéből készülő védőrétegek alkalmazása során várható alakváltozások mértéke. A 13. ábra alapján megállapítható, hogy az éles-szemcséjű anyagok használatával fele akkora süllyedések alakulnának ki, mint az azonos vastagságú legömbölyített szemcséjű anyagokból kialakított védőrétegek esetében, ami részben a réteg nagyobb merevsége miatt, részben pedig az altalajra jutó kisebb feszültségeknek is köszönhető.



13. Az FZKA tetején számított süllyedések a javítóréteg anyagának és vastagságának függvényében (Vámos and Szendefy, 2024b)

4. ÖSSZEFOGLALÁS

Az útpályaszerkezetekre ható forgalmi terhelésből adódó függőleges feszültségek a pályaszerkezet alatti teherbírás javító és fagyvédő rétegekbe, valamint az alatta lévő altalajba is lehatolnak. A lejutó feszültségek mértéke függ a terhelés nagyságától, a pályaszerkezet vastagságától és a pályaszerkezet hőmérsékletétől is. A földmű felső részében és az alatta lévő talajokban ezek a feszültségek extrém esetben talajtörést, megfelelő kialakítás esetén csak kismértékű alakváltozást eredményeznek. A kismértékű alakváltozások egy része rugalmas, így a teher áthaladásakor visszaáll az eredeti vastagság döntő része, azonban egy része maradó alakváltozásként összenyomódást okoz a rétegekben. A forgalmi terhelés okozta nagyszámú ciklikus terhelés hatására bekövetkező maradó alakváltozások halmozódása miatt a pályaszerkezetben deformáció alakul ki, ami a pályaszerkezet életartalmát, a burkolat forgalombiztonságát csökkenti. A pályaszerkezet tervezési gyakorlatban jelenleg nem veszik számításba a maradó alakváltozásokat, a pályaszerkezet alatti anyagokat és a hidraulikus kötőanyag nélküli szemcsés alaprétegeket rugalmas anyagként alkalmazzák.

A talajokban kialakuló maradó alakváltozások halmozódása nehezen számítható, mivel a ciklikus terhelés hatására a talajszerkezetben létrejövő változásokat a számítási modellek nem tudják kezelni. A HCA-modell egy olyan speciális anyagmodell, ami ezen változások számbavételére ad lehetőséget, így a nagy számú ciklikus terhelés alatt bekövetkező maradó alakváltozások nagysága jól számíthatóvá válik.

A számításokhoz szükséges rugalmas és maradó alakváltozások meghatározásához ismerni kell a pályaszerkezet szemcsés alaprétegében és az alatta lévő földmű felsőrészben, valamint az altalajban a terhelés hatására létrejövő feszültségviszonyokat. Ennek összetettsége miatt végeselemes modellezést javasolt végezni, ahol a paraméterbeállítások érdekében valós mérési eredmények alapján történő kalibrálást kell végezni.

Az elmúlt egy évtized során több kutatási munka összehangolásával kutató társaimmal sikerült elvégeznünk azokat a helyszíni méréseket, végeselemes számításokat és anyagmodell vizsgálatokat, amelyek segítségével a pályaszerkezet alatti rétegekben kialakuló ciklikus terhelés okozta halmozódó alakváltozások számíthatóvá váltak.

5. IRODALOMJEGYZÉK

Szilvágyi Zs. (2018), “Dunai homok dinamikus talajparaméterei”, PhD értekezés.

Back M., Szendefy J. (2017), “Reziliens modulus mérése és talajstabilizációknál mért értéke”, Útügyi Lapok 5. évf. 10. szám.

Bán Z. (2020), “Liquefaction susceptibility of poorly graded Danube sands”, PhD értekezés.

Vámos M., Szendefy J. (2014), “Kövér agyagok dinamikus alakváltozási tulajdonságainak meghatározása”, XVIII. Nemzetközi Építéstudományi Konferencia, 2014, pp. 325–328.

Szendefy J. (2017), “Aszfaltburkolatú útpályaszerkezetek méretezésének alternatív módszere című tervezői utasítás geotechnikai paramétereinek pontosítására”, Kutatási jelentés.

Anas A. (2018), “Analysis of the soil deormation characteristics on cyclic loaded sand soils”, MSc Diploma.

Niemunis, A., Wichtmann, T., Triantafyllidis, Th. (2005), “A high-cycle accumulation model for sand”, Comput. Geotech. 32, 245–263. https://doi.org/10.1016/j.compgeo.2005.03.002

Wichtmann, T., Triantafyllidis, T. (2016), “An experimental database for the development, calibration and verification of constitutive models for sand with focus to cyclic loading: part I – tests with monotonic loading and stress cycles”, Acta Geotech. 11, 739–761. https://doi.org/10.1007/s11440-015-0402-z

Wichtmann, T. (2005), “Explicit Accumulation Model for Non-cohesive Soils under Cyclic Loading”, Schriftenreihe des Institutes für Bodenmechanik der Ruhr-□niversität Bochum, Bochum.

Wichtmann, T., Niemunis, A., Triantafyllidis, T. (2010a), “On the determination of a set of material constants for a high-cycle accumulation model for non-cohesive soils” Int. J. Numer. Anal. Methods Geomech. 34, 409–440.

Wichtmann, T., Niemunis, A., Triantafyllidis, T. (2010b), “Simplified calibration procedure for a high-cycle accumulation model based on cyclic triaxial tests on 22 sands” https://doi.org/10.1201/b10132-43

Wichtmann, T., Niemunis, A., Triantafyllidis, Th. (2007), "Strain accumulation in sand due to cyclic loading: Drained cyclic tests with triaxial extension", Soil Dyn. Earthq. Eng. 27, 42–48. https://doi.org/10.1016/j.soildyn.2006.04.001

Vamos, M.J.; Szendefy, J. (2023.a), "Calculation Method for Traffic Load-Induced Permanent Deformation in Soils under Flexible Pavements" Geotechnics 2023, 3, 955–974. https://doi.org/10.3390/geotechnics3030051

Tompai Z. (2008), "Földművek és kötőanyag nélküli alaprétegek teherbírásának és tömörségének ellenőrzése könnyű ejtősúlyos módszerekkel", PhD értekezés.

Káli A (2020), "Ipari padlók ágyazataként és útépítési védőrétegként használt durvaszemcsés talaj sajátmodulusának numerikus modellezése", BSc diploma.

Káli A (2022), "Földművek teherbírását minősítő berendezések határmélységének és az okozott feszültségek vizsgálata analitikus és végeselemes módszerrel", MSc diploma.

Vamos, M.J.; Szendefy, J. (2023.a), "Overconsolidated Stress and Strain Condition of Pavement Layers as a Result of Preloading during Construction", Periodica Polytechnica-Civil Engineering 67:4 pp. 1273-1283., 11 p.

Vamos, M.J.; Szendefy, J. (2023.b), "Calculation Method for Traffic Load-Induced Permanent Deformation in Soils under Flexible Pavements", Geotechnics 2023, 3, 955–974. https://doi.org/10.3390/geotechnics3030051

Vamos, M.J.; Szendefy, J. (2024.a), "On the Influencing Factors of Non-Asphalt Originated Rutting in Flexible Pavements", Transportation Infrasturcture Geotechnlogy https://doi.org/10.1007/s40515-024-00441-3

Vamos, M.J.; Szendefy, J. (2024.b), "Magyar és német típus-pályaszerkezetek várható süllyedéseinek összehasonlítása", Útügyi Lapok.

Cho S. (2022), "Incorporating Climatic Effects in teh Design of Asphalt Pavements", PhD dolgozat.

TECHNOLOGIES FOR CONSTRUTION OF CONCRETE TUNNEL LININGS USED IN CZECHIA

Jan L. Vítek
Metrostav a.s. and Czech Technical University in Prague
Koželužská 2450/4, 180 00 Prague 8, Czechia

SUMMARY

The tunnelling in Czechia developed since the first railway were built. After the period of classical tunnelling methods, the advanced technologies came rather recently. Now a number of tunnels are completed and some experiences were gained. The paper tries to illustrate the application of basic technologies of modern tunnels on examples. The mined tunnels are made usually by NATM (New Austrian Tunnelling Method), using a primary lining made of shotcrete and final lining cast in moulds. There is also experience with TBM which was used for Prague subway or for the longest railway tunnel in the country. Many tunnels on the road and railway network are built as cut and cover tunnels. Finally, a special launched immersed tunnel was built in Prague as a part of the subway line.

1. INTRODUCTION

Tunnel structures have a long history in the territory of actual Czechia. Progressive development of tunnels dates to the first half of the 19^{th} century when the railway network was developed. The first horse railway started to be built in 1832 between České Budějovice and Linz. There was no tunnel on this railway. The first railway tunnel (Tatenický tunnel) was open between Olomouc and Česká Třebová in 1845. The south portal is shown in Fig. 1 and the tunnel was only about 146 m long. The tunnels were built at that time using excavation with wooden temporary scaffolding and then they were equipped with lining made of stone masonry.

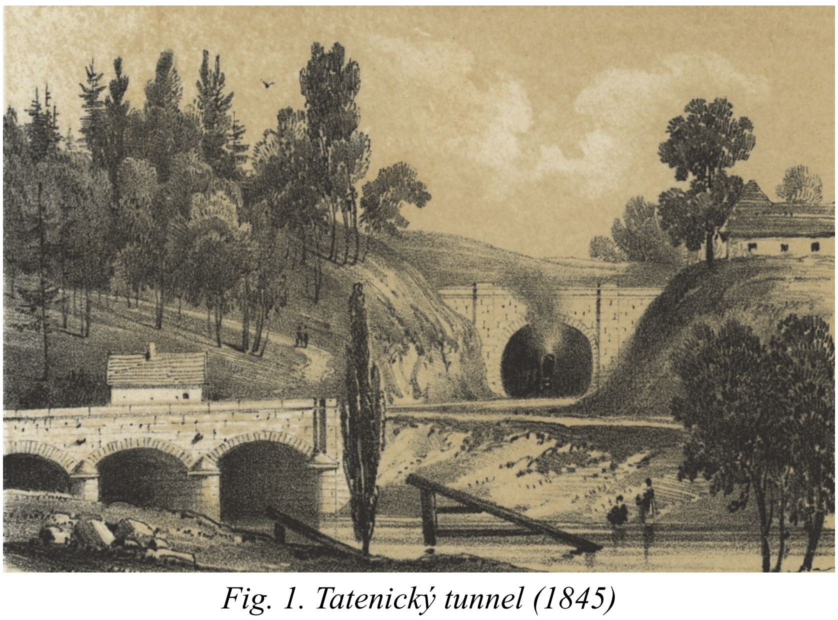


Fig. 1. Tatenický tunnel (1845)

In Prague, three tunnel tubes (Vinohradské tunnels) were built in the city centre just in the neighbourhood of the Main railway station in Prague (Fig. 2). The first tunnel tube about 1,150 m long was built in the period 1869 – 1871. Other tubes were built much later. The sandstone lining of the first tube was replaced by the granite lining in 1945-48.

Fig. 2. Vinohradské tunnels in Prague built subsequently from 1869 to 1989

In 2022, there were 169 tunnels on the railway network in Czechia with the total length of 55.9 km. The Ejpovický tunnel is the longest railway tunnel at the moment, and it was completed in 2018.

The road tunnels started to be built in the beginning of the 20^{th} century. Only few short tunnels were completed before 1990. The main period of construction of tunnels on the road network started after 2000. The longest road tunnel in Czechia at the moment is a part of the city ring road in Prague. With the length of 5,502 m, it is also considered as the longest city road tunnel in Europe. There are 29 tunnels on the road network in operation.

The modern tunnels (built after 1990) involve the mined tunnels and cut and cover tunnels. For the mined tunnels the New Austrian Tunnelling Method (NATM) or the Tunnel Boring Method (TBM) were used. The cut and cover tunnels were built completely or partially in an open construction pit. The paper focuses on construction of concrete tunnel linings.

2. MINED TUNNELS USING NATM

New Austrian Tunnelling Method (NATM) is used very often for shorter tunnels on railways and roads. The excavation process is dependent on geological conditions. The primary lining is made of shotcrete and the secondary lining is usually cast in situ using a movable formwork system. The first road tunnel (Hřebeč) was completed in 1997. Hřebeč tunnel is located on the road 1/35 in west direction of the town Svitavy and it is 354 m long. Many road and railway tunnels were erected using NATM until now.

Usually, the tunnel tubes on motorways are completely independent. The distance between the individual directions of the motorway is increased so that a wide earth pillar between the tunnel tubes was able to carry the load increased load because of excavations of the tunnel tubes (Fig. 3).

Fig. 3. Portal of the Prackovicky tunnel – motorway D8 Prague - Dresden

Tunnel Valík is located on the motorway D5 south of the city of Pilsen (Svoboda, Švarc, 2005). The tunnel tubes are very close each other, and the earth pillar between them was replaced by a narrow concrete pillar. It was a challenging solution because of large load concentration in this pillar. The lengths of the tubes are 380 m and 390 m, respectively. The central pillar was cast in a steel formwork using self-compacting concrete. It became a part of the primary lining of both tunnel tubes (Fig. 4). Finally secondary lining was cast using a traditional movable formwork and the concrete pillar remained between the tunnel tubes. The width of each tunnel tube is 11.5 m which is more than usually, the two traffic lanes and a side lane are of the same width as that outside of the tunnel.

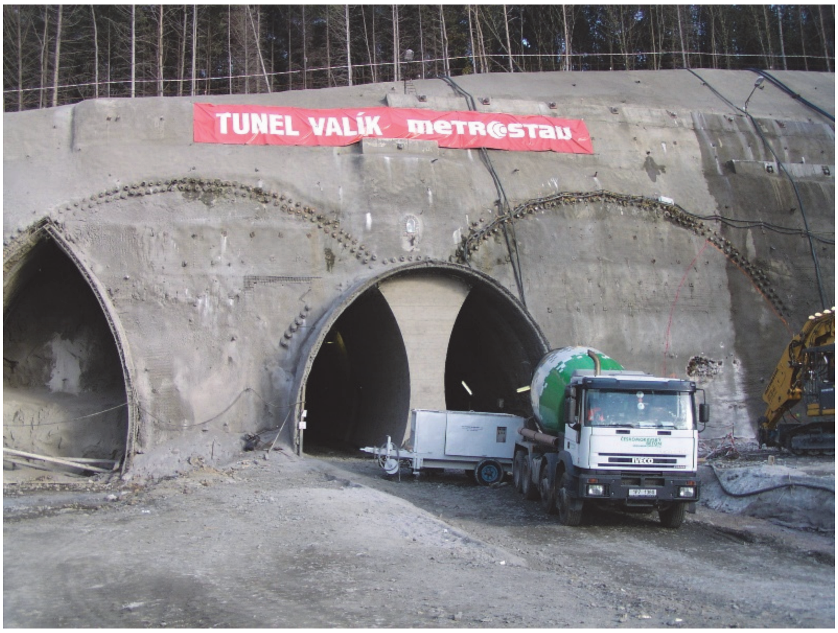


Fig. 4. Central pillar of the Valik tunnel before excavation of main tunnels

The tunnel secondary linings are in most of cases made of reinforced concrete. The railway tunnel in Prague under the hill Vitkov is an example of where the final lining is made of plain concrete.

3. MINED TUNNELS USING TBM

TBM (Tunnel Boring Machines) are used worldwide for longer tunnels. The speed of construction in higher than that of classical excavation methods and the settlements of the terrain above the tunnel are minimized. Simple TBM was used for tunnels of the Prague subway in 70th and 80th of the last century. The last extension of the Prague subway – line A (Cyroň et. al., 2013) was built using a modern EPB machine (Earth Pressure Balanced Machine) produced by the company Herrenknecht. The two machines were used for acceleration of the construction process. The extension of the line A involved construction of 3 mined stations (using NATM) and one station erected in an open pit. The connecting tunnels were built partly NATM (about 750 m) and mainly by TBM. The total length of the subway section was about 6.12 km. The construction works started in 2010, the traffic of the subway was out in operation in 2015.

The outer diameter of the tunnels built by TBM was 6 m. The lining was composed of precast concrete tunnel rings. Each ring had 5 regular segments and 1 smaller conical closing segment. The segments were made of reinforced concrete. The segments are 1.5 m wide and about 3.4 m long. The thickness of the lining is only 250 mm. The segments were made of reinforced concrete of the strength class C50/60. The ring has an outer diameter of 5.8 m. The space between the earth and the lining was grouted. The two machines installed 5,565 rings (= 8,347.5 m). Fig. 5 shows the steel mould for production of segments.

Fig. 5. Mould for production of segments of the Prague subway

The segments must be very precisely produced, the detail of edges in shown in Fig. 6. The sealing of joints was glued to the edge gutter after hardening of concrete.

There is a generally good experience with precast tunnel segments made of fibre reinforced concrete. The geological conditions on the tunnels of the subway generally did not allow for a replacement of the reinforced concrete by the fibre reinforced concrete. But a part of the tunnels had smaller loading. After a detailed experimental verification of the production technology and structural performance under different loading stages in the scale 1:1, it was allowed to assemble a trial section made of fibre reinforced segments.

Fig. 6. Precise shape of the segment with a gutter for glued sealing of joints

There is a generally good experience with precast tunnel segments made of fibre reinforced concrete. The geological conditions on the tunnels of the subway generally did not allow for a replacement of the reinforced concrete by the fibre reinforced concrete. But a part of the tunnels had smaller loading. After a detailed experimental verification of the production technology and structural performance under different loading stages in the scale 1:1, it was allowed to assemble a trial section made of fibre reinforced segments.

The experience from the subway construction was applied in the project of the railway tunnel Ejpovice. The tunnel is located east of the city of Pilsen. The Ejpovice tunnel is at the moment the longest railway tunnel in Czechia (4,150 m). It was completed in 2018. The tunnel has 2 tubes of the diameter of about 10 m. The tubes were built using one TBM machine which was after finishing of the first tube partially dismantled and moved back to the starting position for building of the second tube (Ivor et al., 2017). The precast segments were produced in the precasting plant close to the foundation pit where the excavation works started. From the beginning of the design, the application of fibre reinforced concrete segments was assumed instead of reinforced concrete segments (Vítek and Vítek, 2017). The ring with the outer diameter of 9.5 m was composed of 7 segment of rhomboidal shape and 1 closing segment of the conical shape. One ring was 2 m wide and 400 mm thick. The rhomboidal segments were approximately 3.8 m long. The segments were made of fibre reinforced concrete of the strength class C45/55 with steel fibres 60 mm long with the diameter of 1 mm. The fibre content was 40 kg/m^3. The sealing of joints was not glued after hardening of segments but it was attached to the steel mould and embedded to the segments. Fig. 7 shows a detail of the steel mould with rubber sealing.

The EPB TBM (Earth Pressure Balanced Tunnel Boring Machine) was also produced in the company Herrenknecht in Germany. The machine is shown in Fig. 8. After erection of the tubes the connecting cross-passages were built. The openings have to be made in the precast lining.

The forces carried by the lining in the location of the future opening had to be transferred by the segments in the neighbourhood of the opening. The interaction of segments is necessary, the joints are subjected to bending and shear. The stress concentrations required to use reinforced concrete segments instead of fibre reinforced segments. The joints between the segments were reinforced by connectors which were made of the high strength bars embedded and grouted in the segments. This original technology was patented and it was successfully applied in construction. Before its application, a testing program was organised, which served for verification of the proposed solution. Fig. 9 shows an arrangement of the push out test for specification of the shear capacity of connectors.

Fig. 7. Detail of the steel mould with glued rubber sealing

Fig. 8. TBM used for the construction of the Ejpovice railway tunnel

The connectors are made of the prestressing bar profile 36 mm, which is grouted in the tunnel segments. A number of connectors were applied so that the appropriate forces in the joints could be transferred. Fig. 10 shows the detail of the precast lining with the opening. The grouting pipes of the connectors are visible above the opening. The original solution with connectors is cheap and easy to assemble using the TBM.

During construction of the tunnels some other advanced technologies were tested in connecting cross-passages, e.g. a final lining made of shotcrete, fibre reinforced shotcrete, etc. (Anděl et. al., 2019).

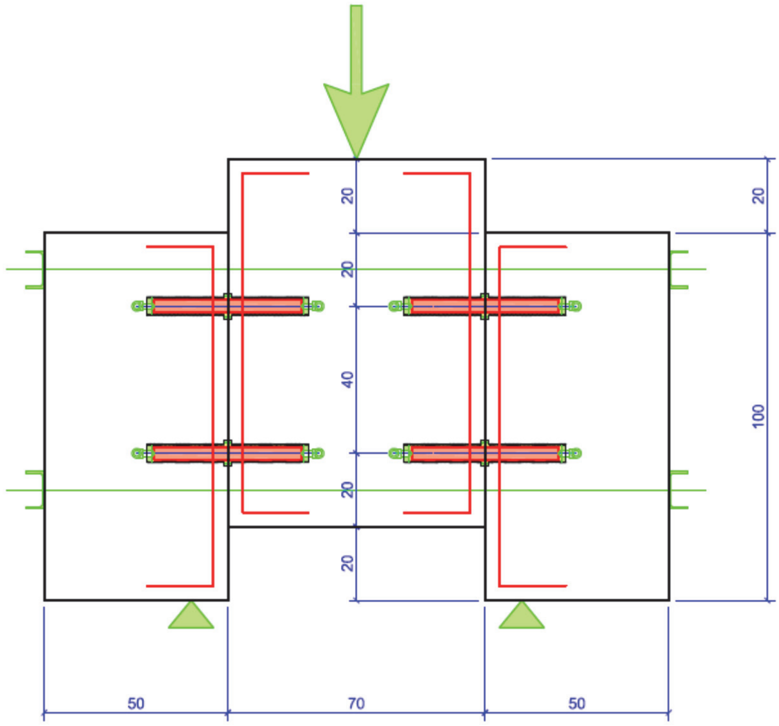


Fig. 9. Scheme of the test of connectors exposed to shear

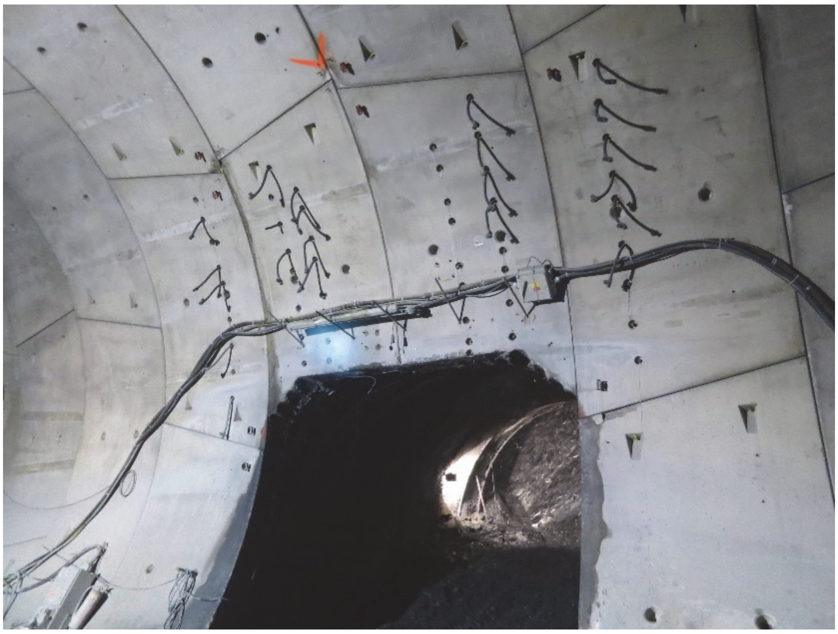


Fig. 10. Opening in the precast lining for the connecting gallery

4. CUT AND COVER TUNNELS

The cut and cover tunnels are suitable for tunnels located close under the terrain. Significant parts of the Prague subway were constructed using this technology. Construction of the city ring road in Prague provided an excellent opportunity also for application of cut and cover tunnels.

City ring road is being built slowly for many years. The last part was open to traffic in 2015. The entire tunnel of the last part was about 6 km long. Different technologies were applied, comprising cut and cover tunnels, cover and cut tunnels (see the next section) and mined tunnels (Valeš et al., 2015). The cut and cover tunnels of two types were built. The tunnels with a classical rectangular cross-section and the tunnel with vaulted cross-section similar to those built by mining technology.

The total length of the classical cut and cover tunnels with rectangular cross-section was about 1.3 km. The tunnels were cast in an open pit. The individual tubes were built for 2 lanes or for 3 lanes, but close to the entrance and exit ramps, the span of the tunnels increased even more (up to about 20 m). The bottom slab was cast first (the thickness of 0.75 to 1 m), the walls followed (the thickness of 0.8 m) and by casting of the top slab the cross-section was closed. The thickness of the top slab was typically 1 m, but if its span increased, the haunches were designed where the thickness at the walls increased up to 1.5 m. The bottom slabs were made of concrete C25/30, the walls and the top slabs were made of concrete C30/37. The barrier waterproofing was made of PVC membrane, in some parts the clay mats were used, and some smaller sections were made of water-resistant concrete without any barrier waterproofing. The fire resistance is also very important. After evaluation of the risk analysis, protection against fire using PE fibres was selected. The fire resistance for the 180 minutes was achieved by addition of 1 to 2 kg PE fibres/m^3 of concrete. The tunnels are designed for the service life of 100 years. Fig. 11 shows a construction of a classical rectangular tunnel for 3 and 2 lanes.

Fig. 11. Classical cut and cover tunnel for 3 and 2 lanes

In the part of the tunnel, where the ramps deviated, the span increased up to about 22 m. It was not convenient to increase the thickness of the top slab, therefore a prestressed slab was used. Fig. 12 illustrates the prestressing tendons in the top slab prior to casting.

The cut and cover tunnels are built quite often, since they provide a reasonable, economical and reliable tunnel solution with a minimum risk of difficulties in terms of leakage or other factors influencing serviceability condition and ultimate load carrying capacity.

Fig. 12. Prestressing tendons assembled in the top slab of the cut and cover tunnel

5. COVER AND CUT TUNNELS

Cover and cut tunnels are used instead of cut and cover tunnels in areas, where the limitation of the traffic above the tunnel should be minimized. The principle of construction assumes, that only a shallow foundation pit is excavated up to bottom surface of the top slab of the tunnel.

From that level the underground walls are built. These walls serve as definitive walls of the future tunnel. They must be built as water resistant walls, there is no further access for installation of any barrier waterproofing. The top slab of the tunnel is cast in the next stage on the top of the underground walls. The top surface of the slab can be protected by a barrier waterproofing. Finally, the construction pit can be filled with the soil and the traffic on the surface can be renewed. The space for the tunnel tubes is excavated under the completed top slab. The excavation works are shown in Fig. 13.

Fig. 13. Excavation works under the protection of the top slab of the tunnel

The bottom slab is cast after the excavation is completed. The detail of connection of underground walls and of the bottom slab is very sensitive to the quality of work, so that the water tightness of the joint was achieved. Similarly, the vertical joints between individual segments of underground walls are not easy to produce. The sealing may deform and then the leakage can appear. On the other hand, this technology allows for the fastest opening the traffic above the tunnel.

The city ring road was in some parts designed under the heavily loaded communications with tram traffic. There was a general interest to minimize the interruption of the traffic. The technology of the cover and cut tunnels was applied in the length of about 1.3 km. Some leakage was observed and it had to be sealed using grouting. Also the surface of underground walls is not very nice, the walls were lined with slabs made of precast fibre reinforced concrete.

6. LAUNCHED IMMERSED TUNNELS

The extension of the subway line C to the north from the Prague city centre required to cross the Vltava River. On the left-hand side of the river, the Holešovice station was already in operation. The line C was planned to cross the river and to continue on the right-hand side of the river to the rather steep hill to the northern territories of Prague. In the time of planning the Holešovice station, it was not decided, if the river crossing would be using a tunnel or using a bridge. Its vertical position was designed allowing for both alternatives. Finally, the city decided that the tunnel was a preferred alternative. Due to the vertical alignment of the route of the line the tunnels were located very close to the river bed, and mining technology was not applicable. Cut and cover tunnels became the only solution. The tender design assumed the construction of the two independent tunnel tubes in three cofferdams, which would be subsequently built in the river. The tunnel tubes would be divided in three parts cast in cofferdams. Such construction was rather slow and expensive. Also, the risk of damage in case of flooding was rather high. The team of the contractor, offered an advanced technology based on combination of launching and floating. After winning a contract the technology was developed in details and the two tubes, each for a single rail were built (Vítek, 2003). The construction of tunnels was completed in 2002, and the first trains used the tunnels in 2004. Now the tunnels are 20 years in operation without any difficulty and without any leakage. Although the tunnels are only about 3–6 m under the river bed, it is said that they are the driest part of the entire subway in Prague.

6.1. Principle of construction

The tunnel tubes are curved in vertical as well as in horizontal direction. Therefore, they are not able to float, they would be unstable in contrary to the immersed tunnels built at the sea crossings. The basic idea was to use the buoyancy for reduction of the weight of the tunnels, and then to launch the tubes from the dry dock built on the right-hand side of the river to the trench excavated in the river bed. In order to keep the tube stable during the launching process, the back side of the tube was supported on the 2 sliding legs and moved along the concrete track. In front side the tunnel tube was suspended on the pontoon. The weight of the tube in dry conditions was 6,700 tons, while when using the buoyancy the weight in the water was reduced to about 70 tons (≈1%) which made it possible to handle with the tube relatively easy.

Fig. 14 shows the dry dock with the completed tunnel tube. The dry dock was a construction pit for the continuing cut and cover tunnels. No special excavations had to be made. At the end of the dry dock there was a small cofferdam which prevents flooding of the dock form the river. A similar small cofferdam was also on the other side of the river. After completion of the tube and its closing on both ends by steel covers, the dry dock was flooded and the cofferdam could be open. The trench in the river bed was excavated and the tube was launched to the trench.

Fig. 14. Aerial view on the dry dock with the tunnel tube prepared for launching

After reaching its final position, the tube was supported on the concrete cross-beam which was cast in the cofferdam on the other side of the river. The tube was in its final position, the cofferdams were closed again, the water from the dry dock was pumped out and the tunnel tube could be opened. The second tube was cast in the dry dock and the operation repeated again.

6.2. Casting and balancing of the tunnel tube

The tunnel tube was made of the water-resistant concrete without any waterproofing. The casting process was developed so that cracking od concrete was minimized. The tube had a square cross-section with outer dimensions 6.5×6.5 m. The thicknesses of the top and bottom slabs were 0.7 m, and the thicknesses of walls were 0.73 m. The cross-section of the tube was cast in one stage in segments of the length of 12 m. In total 14 segments were cast, the total length of the tunnel tube was 168 m. The working joints were only vertical, between the individual segments. A great attention was paid to the reduction of effects of heat of hydration, so that the water tightness of the tube was achieved.

Fig. 15. A partially flooded dry dock with the tunnel tube

The density of concrete as well as the precise dimensions were measured and the weight of the tube was carefully calculated. In order to allow for some scatter of the results, the tube was equipped with tanks filled with water. By adjustment of the water level in tanks, it was possible to find a reasonable weight of the tube suitable for manipulations. Fig. 15 shows a partially flooded dry dock with the completed tunnel tube. The tube at the end of the tunnel provides an access into the tunnel when it was immersed in the water.

6.3. Launching process

The launching process is schematically shown in Fig. 16. The tube moved from the right (the dry dock) to the left. On the rear part of the tunnel tube there is a couple of the sliding shoes, which moved along the launching track. In order to keep the suspension system activated, the braking suspension prestress the entire system. In front, the tube was pulled by two in plan inclined suspensions. These strand units were pulled by hydraulic units located on the left-hand side of the river. Initially the pulling strands were connected to the tunnel tube just in the very front end. When exceeding the half of the launching distance, it was necessary to move the front suspension point from the very front end to the point which is shown in Fig. 16, so that it would be possible to pull the tube to the end when the front end of the tube reached the opening in the sheet piling on the left-hand side of the river. The device called deviator moved the suspension point from the front end the point located at about ¼ of the length of the tube. Vertical forces were carried by the pontoon and by the sliding shoes. 3 supporting points (pontoon and 2 lags in the back) guaranteed a stable position and a clear distribution of load.

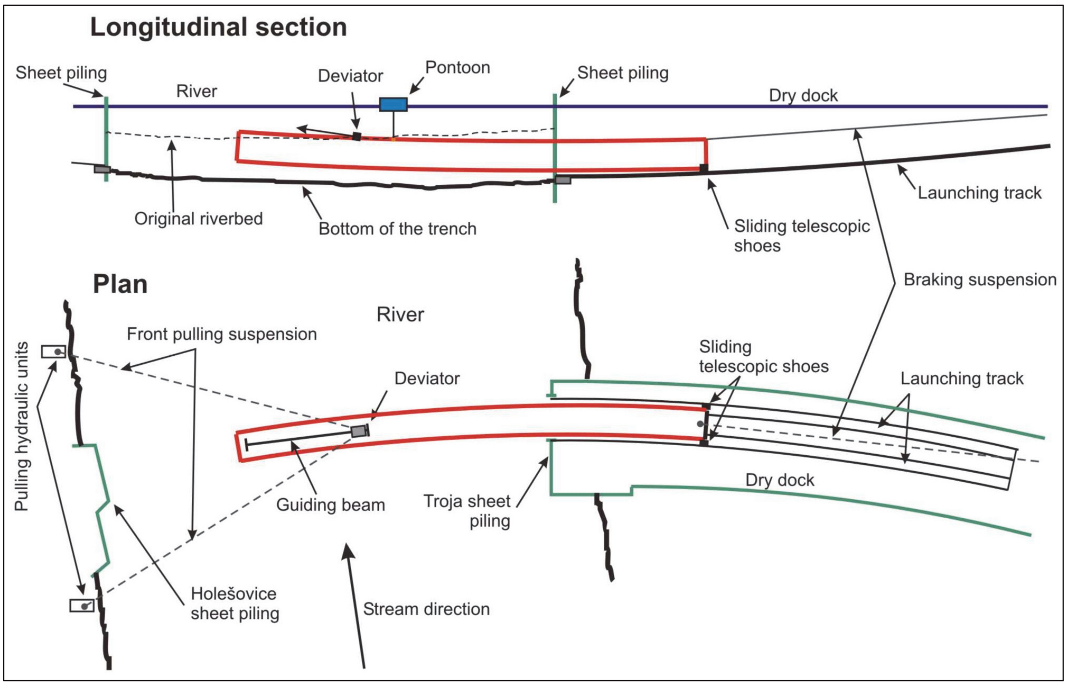


Fig. 16. Scheme of the launching of the tunnel tube

6.4. Final supports of the tunnel

After completion of the launching the tube was supported by textile bags, which were filled with flowable concrete. After hardening the tube was anchored to the river bed using micropiles. This technology was slightly modified at the second tube. Finally, the trench was filled with the sand and gravel, the top slabs of the tubes were in the depth between 3 and 6 m under the river bed.

6.5. Concluding remarks

The launching technology appeared as very successful. The good quality concrete tubes are really watertight, the construction time was short, the tubes were completed including the final supports in about 2 years. Nobody expected that a big flood could threat the construction. The flood came few weeks after launching of the second tube. Fortunately, due to application of this technology, no damages were detected. The technology also significantly reduced the excavations and it was much more friendly to the environment, in comparison with the technology using cofferdams in the river which was used in tender documentation.

7. CONCLUSIONS

The technologies for tunnel construction progressively develop. Czechia is not a country with a high number of tunnels, like the Alpin countries, where the number of tunnels is much higher. On the other hand, Czech tunnel engineers try to use the research results and experience from all over the world and to build tunnels which are on the at least European standard and to contribute by sometimes smaller details to the quality of the completed tunnels. The Czech infrastructure is developing and there is a number of future tunnel projects waiting for construction. The usually rather complex and variable geological conditions which are typical in the Czech conditions require a thorough survey and detailed analysis before the construction can be started.

8. ACKNOWLEDGEMENT

A partial support of the Technological agency of the Czech Republic, project CESTI (No. TE01020168) is gratefully acknowledged.

9. REFERENCES

Anděl, V., Svoboda, P., Hybský, P. and Ivor, Š. (2019), “Ejpovice tunnels-final excavation support of cross passage No. 8 with shotcrete”, Tunel, Vol. 28, No.2, 2019, pp. 4-11.

Cyroň, D., Hybský, P., Rössler, K., Ivor, Š. and Prajer, J. (2013), “Driving single-track tunnels of Prague Metro V.A using earth pressure balance shields”, Tunel, Vol. 22, No. 1, 2013, pp. 4-15.

Ivor, Š., Hybský, P., Sýkora, L. and Anděl, V. (2017), “Ejpovice tunnels. Driving the southern tunnel tube: Shifting and modifying the TBM for driving the northern tunnel tube”, Tunel, Vol. 26, No. 2, 2017, pp. 26-32.

Svoboda, J. and Švarc, V. (2005), “Valík tunnel – the key to the motorway bypass of Pilsen”, Tunel, Vol. 14, No. 1, 2005, pp.18-23.

Valeš, J., Falhar, S. and Kůrková, E. (2015), “Blanka complex of tunnels – construction work overview”, Tunel, Vol. 24, No. 2, 2015, pp. 24-33.

Vítek, J. L. (2003), “Metro tunnels under the Vltava River”, Proc. of the ITA World Tunnelling Congress 2003 “(Re)Claiming the Underground Space”, J. Saveur, edt. Vol. 1, Swets and Zeitlinger.

Vítek, J. L. and Vítek, P. (2017), “Fibre reinforced concrete and its application in tunnels”, Tunel, Vol. 26, No.3, 2017, pp. 48-63.

WHERE NEXT, MAÚT?

Szabolcs NYIRI
Chairman
MAÚT Hungarian Road and Rail Society

ABSTRACT

The MAÚT Hungarian Road and Rail Society has been founded as a social-professional entity in 1994 by the affected stakeholders of the road sector. The scope of activities has been extended to the railway sector in 2014. The fundamental aim was to ensure that the contracts between Client and Contractor are based on generally accepted professional regulations and instructions. The elaboration and maintenance of the up-to-date technical regulation framework shall be the principal common interest and task of all major stakeholders of the road sector. With the consequent application of the well-functioning regulation system, known and recognised by the affected and interested professional players, the tasks of planning, investments, operation and maintenance of the road sector can be performed in an economical, uniform, up-to-date way and in good quality.

The key activity of the Society remained unchanged in its 30 years old history: elaboration and publishing of new and updated technical regulation documents, further the continuous operation and maintenance of the system.

The members of the working committees who are producing the technical regulatory documents, are selected from qualified, experienced and well-known experts of the specific professional field in question. We make every effort to ensure representation of all major stakeholders and players: public investment sector, authorities, scientific professionals, planning, consulting, construction, maintenance and operation experts.

The digital version of the complete system (e-UT® Digitális Útügyi Előírástár – Digital Inventory of Regulations for Roads, started in 2009, and e-VASUT® Digitális Vasútügyi Előírástár – Digital Inventory of Regulations for Railways, started in 2017) is currently used as a subscription-based system by more than 4000 professionals of more than 180 organizations.

Our primary intention is to provide a stable, transparent and up-to-date background and support for all the actors of the road and railway infrastructure sectors through their continuous activities, during the whole life-cycle of the road and railway engineering works.

Facing the challenges of the near future we are committed to the successful and effective handling of the new issues of environment protection and awareness, sustainable development, remunerative innovation, climate change and social responsibility.

NAGYVÁROSI ÉLETMINŐSÉG JAVÍTÁSA A LEGÚJABB MOBILITÁSI TECHNOLÓGIÁK ÖSSZEKAPCSOLÁSÁVAL

IMPROVING THE QUALITY OF LIFE IN BIG CITIES BY CONNECTING THE LATEST MOBILITY TECHNOLOGIES

Üveges Péter Zoltán
Yunex Traffic Kft.
1143 Budapest Gizella út 51-57.

ÖSSZEFOGLALÓ

Az előadás az emberiség előtt álló globális kihívások, azon belül a közlekedés által okozott nagyvárosi problémák szükséges és lehetséges megoldásait mutatja be, amely a kifejlesztett legújabb telematikai technológiák összekapcsolt alkalmazásán alapszik.

Célok a legújabb mobilitási technológiák összekapcsolásával: élhetőbbé tenni a városokat, növelni a közutak biztonságát, tenni bolygónk jövőjéért – klímavédelmi fellépés.

A legújabb informatikai és távközlési keret technológiák alkalmazási környezetével létrehozott újgenerációs környezetorientált forgalom menedzsment rendszer hatékonyan segíti ezen célok elérését, mint a városi úthálózat torlódásainak és közlekedési kibocsátásból származó légszennyezettségének megszüntetésére kifejlesztett megoldás. A rendszer felépítésének, az egyes alrendszerek és alkalmazott technológiák együttműködésének és az általuk elérhető eredményeknek az általános bemutatását követően egy konkrét, valós városi környezetben létrejött torlódási és környezeti határérték túllépési szituációnak a megszüntetését követhetjük nyomon a rendszer gyakorlati alkalmazásával.

SUMMARY

The presentation will introduce the necessary and possible solutions to the global challenges facing humanity, including the problems caused by transport in metropolitan areas, based on the combined application of the latest telematics technologies developed.

The objectives of combining the latest mobility technologies are: to make cities more liveable, to increase road safety, to act for the future of our planet – climate action.

A new generation of environmentally oriented traffic management systems, using the latest IT and telecommunications framework technologies, will effectively help to achieve these goals as a solution to congestion and air pollution from traffic emissions on the urban road network. After a general description of the system architecture, the interaction of the subsystems and the technologies used and the results they achieve, the practical application of the system in a concrete congestion and environmental limit value exceedance situation in a real urban environment will be followed.

1. BEVEZETÉS

Bolygónk és az emberiség nagy kihívások előtt áll, amelyek jórészt a technológia alapú civilizációs fejlődésünk következményei: túlnépesedés, felgyorsult urbanizáció, globális felmelegedés, globális kereskedelmi szállítási igények növekedése, digitális adatrobbanás miatti tárolási igények extrém növekedése és ennek környezeti hatásai, stb.

A közlekedés a globális károsanyag kibocsátás egyik jelentős tényezője. Minden olyan új technológia és az ezeken alapuló mérnöki megoldás, ami hozzájárul a közlekedési kibocsátások csökkentéséhez, hozzásegít bennünket az egészségesebb életminőséghez, a bioszféra és a földi ökoszisztéma megóvásához, végső soron az emberiség hosszútávú túléléséhez. A környezetvédelmi problémák gócpontjai a városok, amelyek száma és népessége az urbanizáció miatt egyre csak nő. A közlekedésből származó károsanyag kibocsátás a városokban koncentráltan jelenik meg, melynek mérséklése részben a járművek alternatív meghajtó rendszereinek (pl. elektromobilitás) fejlesztésével, részben a forgalomirányítás hatékonyabbá tételével oldható meg elsődlegesen. Az előadás a forgalomirányítás ezirányú fejlesztésében elért legújabb eredményeket kívánja bemutatni a városok életminőségének javítása érdekében.

2. A TECHNOLÓGIAI FEJLŐDÉS TAPASZTALATA ÉS KITŰZÖTT CÉLOK A KÖZLEKEDÉS TERÜLETÉN FELLÉPŐ PROBLÉMÁK MEGSZÜNTETÉSÉRE, ILLETVE MÉRSÉKLÉSÉRE

Technológiai fejlődésünk mára exponenciális mennyiségű új technológiát állít elő, amelyek valós problémákat megoldó mérnöki megoldásokká konvertálása egyre nagyobb kihívás. Az innováció akkor valósul meg, amikor a kereslet és a technológiai képességek találkoznak, erre kell törekednünk a közlekedés menedzsment rendszerek fejlesztésében is minél több új mobilitási technológia összekapcsolásával.

Célok a legújabb mobilitási technológiák összekapcsolásával:

- Élhetőbbé tenni a városokat.
- Növelni a közutak biztonságát.
- Tenni bolygónk jövőjéért – klímavédelmi fellépés.

3. A LEGÚJABB INFORMATIKAI ÉS TÁVKÖZLÉSI KERET TECHNOLÓGIÁK

A legújabb informatikai és távközlési keret technológiák, amelyek lehetővé teszik konkrét, valós közlekedési problémák megoldását:

- *Felhő és mikroszolgáltatások:* évente egyszeri szoftver upgrade-k helyett, felgyorsított fejlesztés, több új funkció létrehozása egységnyi idő alatt.
- *Mesterséges intelligencia & adatfúzió:* digitális ikertestvér létrehozása a kereszteződések valós forgalmának megismerése, a forgalomáramlás javítása és a torlódások csökkentése érdekében.
- *5G, IoT & edge computing:* az adatok, az összekapcsolhatóság és a számítási teljesítmény biztosítja, hogy az utak biztonságát új szintre emeljük.
- *Scaled agility & DevOps tech stack:* segítséget ad abban, hogy gyorsabban, több ügyfélértékkel rendelkező, kiváló minőségű szoftvereket lehessen előállítani.
- *Üzleti folyamatok digitalizálása:* automatizált üzleti folyamatok, ami több időt biztosít az ügyfélérték-teremtésre.

4. A KÖZLEKEDÉS MENEDZSMENT PLATFORMOK INNOVATÍV ÚJ GENERÁCIÓJA A KÖRNYEZETORIENTÁLT FORGALOM MENEDZSMENT RENDSZER

A fenti keret technológiák alkalmazása lehetővé tette a közlekedés menedzsment platformok innovatív új generációjának, a környezetorientált forgalom menedzsment rendszernek a kifejlesztését, ami az alábbi legfontosabb jellemzőkkel rendelkezik:

- A torlódások megelőzése és proaktív cselekvés a várható vagy váratlan forgalmi zavarok esetén.

- A károsanyag-kibocsátás folyamatos ellenőrzése és az elfogadható határértékek alatt tartása.
- Az összetett városi mobilitási környezet koordinálása több szereplővel, multimodális környezetben a gyors reagálás és az összes úthasználó biztonságának biztosítása érdekében.
- Az üzemeltető szakértelmére és leleményességére épülő innovatív megoldások tervezése, életre hívása és kivitelezése.

4.1. A rendszer szabályozási és funkcionális felépítése, a felhasználói igények kiszolgálása és moduláris kialakítása

A környezetorientált forgalom menedzsment a szabályozási kör mind az öt fázisának kombinációja, aktív forgalom menedzsment – zárt szabályozási kör, sokféle bemenő adat felhasználásával a hatékony forgalomirányítás érdekében az alacsonyabb kibocsátásokért.

Az összes érdekelt fél és felhasználó (városvezetés/hatóságok, forgalomirányító központ üzemeltető, a közlekedés magán/köz üzemeltetői, rendőrség/tűzoltóság/mentők, városlakók/turisták) igényeinek a kiszolgálása az összekapcsolt alrendszerek (jelzőlámpák, tömegközlekedés, forgalmi mérőhelyek/levegőminőség érzékelők, VJT táblák, V2X eszközök, forgalmi incidensek) adatgyűjtésének felhasználásán és vezérlésén keresztül.

Legfontosabb jellemzői: flexibilis, skálázható, testre szabható, kiterjeszthető, stabil, biztonságos, alkalmazkodó.

A platform összeköti a különböző adatforrásokat, rendszereket és érdekelteket. Egységes „emberi interfész” ahonnan aktívan irányítható az egész hálózat, bevonhatók, integrálhatók további (al)rendszerek, mint pl. csatlakozó autópályák irányítási rendszerei. „Zárt városi szabályozási kör”-ként működik a városi úthálózat aktív üzemeltetése érdekében. Átfogóan és következetesen működő akciótervek használata, környezeti hatással is számoló forgalomirányítás, amely átíveli a közlekedési rendszereket és módokat, előzetes szimulációkkal biztosítja az optimális stratégiát, mindezt magas automatizáltsági szinten.

4.2. A kulcsfontosságú alrendszerek és alkalmazott technológiáik részletes bemutatása

4.2.1. Meteorológiai és környezetvédelmi alrendszer

Átláthatóságot biztosít az aktuális légszennyezettségi és forgalmi szituáció tekintetében.

A légszennyezettségi helyzet teljeskörű áttekintése korlátozott számú levegő-minőség érzékelő használata mellett is lehetséges. A városi úthálózat valós idejű levegőminőség térképét több szintű meteorológiai modellek állítják elő. Az emissziós modell a különböző járműtípusok és motortípusok CO_2- és NO_x-kibocsátását képezi le és validálja az érzékelők adataival összevetve, a diszperziós modell pedig az emissziós modell adatainak felhasználásával a szennyező anyagok térbeli eloszlását a földi validáció, a szél és a topográfiai adatok alapján jeleníti meg egy térképi felületen.

Mivel minden város úthálózata topográfiai adottságai, beépítettsége és meteorológiai mikro környezete különböző, ezért a meteorológiai alrendszer által előállított légszennyezettségi térképhez a meteorológiai modell kalibrálása egy rendkívül összetett több hónapos folyamat. Hatalmas mennyiségű részletes adatgyűjtést igényel a begyűjtött historikus adatok korrelációs elemzésével, melynek segítségével az időjárás és a forgalmi viszonyok együttes egymásra hatásai alapján megállapíthatóak azok a városi gócpontok, ahol nagy a valószínűsége a környezeti határérték túllépések kialakulásának.

Az alrendszer fentiek szerint biztosított output adatai teszik lehetővé a közlekedési kibocsátások befolyásolását forgalmi intézkedésekkel a légszennyezettségi határértékek betartása érdekében.

Az útvonalak aktív befolyásolása jelzőlámpák (intelligens kapuzás), VJT kijelzők és útvonalajánlások segítségével történik meg a kibocsátások alacsony tartományban tartása érdekében.

Az alrendszer legfontosabb jellemzői és előnyei:

- az észlelt környezeti és közlekedési helyzet áttekintése és ellenőrzése, légszennyezési küszöbértékek túllépése esetén az ellenintézkedések megtétele,
- átláthatóság a teljes hálózaton, teljeskörű levegő-minőség érzékelő lefedettség kiépítése nélkül is,
- a forgalom-előrejelzéssel és a szituációkezeléssel elkerülhető a küszöbértékek túllépése,
- a levegőminőség javítása a torlódások elkerülésével az utazók útvonaltervezése által.

4.2.2. Digitális ikertestvér alrendszer

A digitális iker a valós világ infrastruktúrájának, rendszereinek és folyamatainak virtuális reprezentációja, ahol a reprezentáció szinkronban van a valós világgal.

A digitális ikertestvér számos folyamatlépésben helyettesítheti a valós rendszereket a hatékonyság növelése vagy olyan műveletek elvégzése érdekében, amelyek a valós világban nem lennének lehetségesek.

A digitális ikertestvért létrehozó több rétegű szoftver rendszerek segítségével leképezhető egy város komplett úthálózata és annak forgalomtechnikai kialakítása, megtervezhetők, tesztelhetők és optimalizálhatók az új úthálózati elemek, jelzéstervek, tömegközlekedési vonalak és ITS-stratégiák (önállóan és a forgalom menedzsment rendszerbe mélyen integrálva is, pl. a prediktív reagálási tervek értékeléséhez).

Alkalmazása lehetőséget ad összetett forgalomtechnikai feladatok megoldására és a multimodális hálózat működésének optimalizálására, különösen akkor, ha a kapacitásbővítés korlátozott. Továbbá elősegíti a tervezési szabályoknak való megfelelést és a közlekedési intézkedések hatásainak megértését komplex tervezési feladatokon keresztül.

Lehetővé teszi a megtervezett forgalomtechnikai beavatkozások offline szimulációját a jövőbeli mobilitási mintáknak az egyéni igények és a rendelkezésre álló városi szintű közlekedési lehetőségeknek a pontos ábrázolásával. Összekapcsolva a központi forgalomirányítás forgalmi adatgyűjtő rendszerével, a valós idejű forgalmi adatok felhasználásával lehetővé teszi a közlekedés menedzselését nagy területek valós idejű szimulációjával és fejlett adatelemzésével kombinálva, hogy előre jelezze a forgalmi viszonyokat, torlódásokat, mielőtt azok kialakulnának. Emellett segít összehasonlítani és rangsorolni a torlódáskezelési stratégiák hatását.

4.2.3. Központi forgalomirányító és forgalom menedzsment alrendszer

A központi forgalomirányító és menedzsment alrendszer lehetővé teszi egy terület összes jelzőlámpájának vezérlését különböző interfészszabványok segítségével, biztosítja a forgalom folyamatos áramlását, lehetővé teszi a közlekedési jelzések tervezését, konfigurálását és vezérlését egyetlen felületen és zökkenőmentes munkafolyamatokkal. Emellett a forgalomirányítási rendszerelemek meghibásodása esetén azonnali részletes információkat biztosít az üzemeltetés számára a hibák mielőbbi elhárítása érdekében, ezzel lerövidítve a hibák miatti balesetveszélyes állapotot, jelentősen javítva az általános forgalombiztonságot.

Az alrendszer legfontosabb jellemzői és előnyei:

- nagyfokú kompatibilitás és egységes vezérlőrendszer,

- nagyteljesítményű közlekedési infrastruktúra,
- intuitív zöld hullám és közlekedési jelzőlámpa jelzés optimalizálás,
- lehetővé teszi a V2X alkalmazásokat,
- biztonságos naplózás és dokumentáció, valamint a szükséges historikus adatok gyors átadása.

4.2.4. Hálózatba kapcsolt mobilitás (V2X) CMS alrendszer

Az úthálózatok digitalizálása fontos a gazdasági növekedés és az életminőség szempontjából. A járművek összekapcsolása egymással és az infrastruktúrával lehetővé teszi a városok számára, hogy minden eddiginél pontosabban és hatékonyabban kezeljék közlekedési hálózatukat, amely a forgalmi dugók, a balesetek és a károsanyag-kibocsátás jelentős csökkenésével jár.

A hálózatba kapcsolt mobilitás (V2X) lehetővé teszi, hogy a járművek kommunikáljanak az infrastruktúrával, ezáltal növeljék a biztonságot és a hatékonyságot. Mivel minden jármű és infrastrukturális rendszer összekapcsolódik egymással, így a csatlakoztathatóság pontosabb adatokat szolgáltat a forgalmi helyzetről és lehetővé teszi a kétirányú kommunikációt.

A hálózatba kapcsolt mobilitási rendszer három alapvető rendszerelemből épül fel.

Az OBU2X a járművek fedélzeti egysége, amely egyrészről folyamatosan adatokat sugároz a jármű helyzetéről, mozgási irányáról, sebességéről és a jármű kategória besorolásáról (ezzel lehetőséget adva az úthálózati forgalom teljes részletességű elemzésére is), másrészt adatokat fogad az RSU2X útmenti egységektől.

Az RSU2X útmenti egység az úthálózaton meghatározott sűrűséggel és eloszlással kihelyezett kommunikációs eszköz, amely egyrészt fogadja a hatókörzetében jelenlévő járművek adatait és továbbítja a forgalomirányító központ CMS moduljának, másrészt különböző típusú üzenetek formájában forgalombiztonságot és az optimális haladást elősegítő információkat sugároz az egyes járművek számára, amelyeket a CMS modultól kap.

CMS2X központi modul adatokat cserél és konvertál az útmenti egységek (RSU2X) és más központi forgalomirányítási modulok között. Ez lehetővé teszi, hogy az olyan központi modulok, mint az eseményinformációk kezelése, az utazási idő és a forgalmi adatgyűjtő rendszerek használhassák a V2X-funkciókat. A CMS felügyeli és kezeli az RSU2X-kat is.

A hálózatba kapcsolt mobilitási (V2X) rendszer a központi forgalomirányítást olyan korábban elérhetetlen információkkal látja el az úthálózaton közlekedő forgalomról, amely lehetővé teszi a hálózat minden pontján a forgalom teljes részletességű detektálását és elemzését a megfelelő forgalomirányítási stratégiák kialakítása és a hálózati optimum elérése érdekében. Emellett biztosítja, hogy a központban rendelkezésre álló információkat (pl. balesetek, útlezárások és forgalomkorlátozások, veszélyhelyzetek, parkolási információk, stb.) közvetlenül az egyes járművek fedélzetére eljuttassa.

5. VALÓS VÁROSI KÖRNYEZETBEN LÉTREJÖTT TORLÓDÁSI ÉS KÖRNYEZETI HATÁRÉRTÉK TÚLLÉPÉSI SZITUÁCIÓ MEGSZÜNTETÉSE A KÖRNYEZET-ORIENTÁLT FORGALOM MENEDZSMENT RENDSZER ALKALMAZÁSÁVAL

Az előzőekben bemutatott alrendszerek együttműködése teszi lehetővé a környezetorientált forgalom menedzsment rendszer működtetését.

Mindez a gyakorlatban a következőképpen zajlik:

A forgalomirányító központ operátora egy térképi felületen követi nyomon a felügyelt városi úthálózat forgalmi helyzetét, illetve annak egy potenciális gócpontját, ahol egy kialakulóban lévő torlódást észlel. A pillanatnyi forgalmi adatok a központi forgalomirányító alrendszerből (az adott úthálózati rész releváns forgalmi mérőhelyeitől), illetve a hálózatba kapcsolt mobilitás CMS alrendszeréből (a releváns RSU-kon keresztül az egyes V2X képességgel rendelkező járművektől) érkeznek. A környezetorientált forgalom menedzsment rendszer térképi felületén a valós időben beérkező forgalmi adatok alapján az úthálózat egyes szakaszain a forgalomdenzitás mértéke színekkel kerül ábrázolásra. A szabad forgalomáramlás zöld, a lelassult sárga, a torlódó piros színnel.

Az operátor a digitális iker alrendszer segítségével lekérdez egy pl. 30 perces előrejelzést az úthálózatnak erre a részére vonatkozóan, ami a pillanatnyi forgalmi adatokból előállítja a 30 perccel későbbi állapot forgalmi denzitását, ami ténylegesen az úthálózat több szakaszára kiterjedő torlódást mutat.

Az előre jelzett forgalmi állapot nézetből az operátor átvált egy gombnyomással a környezeti határérték állapot nézetre, ami szintén színekkel mutatja be az egyes útszakaszokon a légszennyezettség mértékét. A környezeti határérték túllépés piros, az ahhoz közeli helyzet sárga, a normál határérték alatti állapot zöld. A környezeti határérték állapot adatai a meteorológiai alrendszerből érkeznek. Mivel az előrejelzés alapján több szakaszon is határérték túllépés keletkezne, ezért a beavatkozás mellett dönt.

A forgalomirányító központ előkonfigurált beavatkozási terveiből kiválaszt kettőt, hogy összehasonlítsa őket egymással és azzal a helyzettel, hogyha egyáltalán nem avatkozik be. Ezt a háromféle beavatkozási forgatókönyvet a digitális iker alrendszer azonnal leszimulálja és kiértékeli néhány előre definiált KPI paraméter alapján. Ezek a KPI-k lehetnek például: utazási idő növekedése (%), a tömegközlekedés utazási idejének növekedése (%), hálózati forgalom áteresztő képesség (jármű/h), hálózati átlagsebesség (km/h), hálózati utazási idő (sec/km), hálózati forgalom sűrűség (jármű/km), stb. Ezután a három forgatókönyv közül a számszerűsített összehasonlítás alapján kiválasztható a legkedvezőbb helyzetet eredményező beavatkozási forgatókönyv, amelyet gombnyomásra el lehet indítani.

A kiválasztott beavatkozási forgatókönyvet ezután a forgalomirányító központ szoftver rendszere automatikusan végrehajtja a szükséges jelzőlámpa programok egyidejű módosításával.

Végül a térképi megjelenítő felületen az operátor ellenőrizni tudja a végrehajtott beavatkozási forgatókönyv nyomán előállt valós helyzetet.

6. KÖVETKEZTETÉSEK

A bemutatott környezetorientált forgalom menedzsment rendszer jó példája a különböző mobilitási technológiák összekapcsolásával létrehozható komplex rendszereknek, amely működésével valós kézzelfogható eredményeket produkál a közúti forgalom által okozott légszennyezettség mérséklése érdekében, ezzel jelentősen hozzájárulva a nagyvárosi életminőség javításához.

Az összekapcsolt technológiák alkalmazásával létrehozott komplex rendszerekkel olyan többlet képességeket hozhatunk létre, ami túlmutat az egyes technológiák önálló alkalmazásából származó képességeken. Ezért ezen rendszerek esetében különösen elmondhatjuk Arisztotelész szavaival élve, hogy „az egész több, mint a részek összessége”.

GREEN AND INNOVATIVE APPROACH TO A NEW GENERATION OF ASPHALT PAVEMENT CONSTRUCTION

Zsolt BOROS[1], Filip BUČEK[1]
[1] TPA Society for Quality Assurance and Innovation (member of STRABAG concern)
Mlynské Nivy 61/A, 825 18 Bratislava, Slovak Republic

SUMMARY

In Slovakia, semi-rigid asphalt pavement constructions are still prevalent in new road constructions (highways and expressways). This is due to the high mechanical efficiency of hydraulically bounded base courses as compared to unbounded base courses – case of the flexible asphalt pavement construction. Lower mechanical efficiency of unbounded base courses automatically leads to economically less favourable design of pavement construction based on dimensional calculations. Substantial and decisive problems with later reflective cracks appearing on the surface of semi-rigid asphalt pavements are underestimated and later maintenance costs are not considered in the design phase. For the wider use of flexible pavement constructions in the construction of new roads, one of the options is to increase the design parameters of the unbound base course. From our own experience, we can recognize that by optimizing the grain size distribution of the unbound base course, it is possible to achieve significantly higher values of the design parameters. The way to do this is, on the one hand, the optimal combination of aggregates and the optimum aggregate parameters in the fractions and, on the other hand, the effect of the pozzolan reaction with the volcanic crushed aggregate.

After verifying the theoretical assumptions in the laboratory, it was very important to verify the material in the layer built by real construction technology in a real road construction. Based on experimental experience both from the laboratory and from the building site we deduced modules elasticity for pavement design purposes.

1. OBJECTIVES AND SCOPE OF WORK

The main goal of presented solution is to find the way to increase the mechanical efficiency of the unbound base course for flexible asphalt pavement toward better technical-economic benefits. The strength of base course is achieved partly by mechanical skeleton of the structure and partly by natural bonding of selected aggregate and bond activator.

The Optimisation Development Program of mechanically strengthened base course (MSB) was designed over a two-year period in the following areas:

- Theoretical background of research, determination of research objectives, consultations with experts.
- Evaluation of the pozzolan activity of the dust component of the selected aggregate.
- Selection of material components, optimization of grain size distribution.
- Initial type test for optimized mechanically strengthened base course.
- Verification of the realisation possibilities – building of test section using optimized MCSB as base layer.
- Evaluation of the bearing capacity of existing pavement sections using FWD, where the base course is MCSB-TPA.

- Evaluation of the load-bearing capacity of the built-in optimized MCSB layer expressed by static modulus of elasticity (static load test) and dynamic modulus of elasticity (FWD).
- Analysis of the material during the preparing, mixing, and construction of the developed base course.

2. METHODOLOGY

2.1 Selection of Aggregate

For the research purpose, two quarries “Pohranice” and “Vtáčnik” were selected, the aggregate of which assumed pozzolan reactivity. During the research process, the investigation of the aggregate from the quarry “Pohranice” was cancelled due to lack of pozzolan potential. For the investigation of the pozzolan reactivity we used modified Frattini's test, which is performed on the particle dust component of the stone material.

Calcium Hydrate was used as the activator of the pozzolan reaction. Limestone hydrate is produced by the hydration of high-quality lime. Its advantage is the possibility of its immediate use because it is volumetric stability.

2.2 Frattini´s Test

The pozzolanic reaction is identified as the loss of lime from the reaction mixture containing the test material, water and lime. On this basis, Frattini proposed the original test consisting in the reaction of a mixture of 20 g of pozzolan in 100 ml of water left at 40 °C for eight days and the final determination of total calcium and free alkalinity. The position of the so-called figurative point on the diagram of total calcium concentrations versus total alkalinity, either below or above the solubility curve of calcium hydroxide, made it possible to decide whether the pozzolanic reaction had taken place.

A sample of the aggregate dust component (0–0.063 mm fraction) was taken from the Vtáčnik quarry to determine the pozzolanic activity. The aggregate is of volcanic origin (andesite), it meets the assumptions for the pozzolanic reaction. The aggregate dust component was separated by sieving on a 0.063 mm sieve from the 0–4 mm fraction.

2.3 Proposals for the mix composition of mechanically strengthened aggregate (MSB)

Based on the grain size distribution of individual aggregate fractions was created an initial design of the mechanically strengthened aggregate MSB_A (Version A) in order to fit granularity limits according to STN EN 13285. During this research program in the TPA laboratories were made many different versions of optimized MCSB mixtures in order to find the best combination.

3. LABORATORY RESULTS

3.1 Immediate bearing index IBI

Several tests were executed during the research, the purpose of which was to gradually optimize the composition of the final mixture and to evaluate its parameters, especially in terms of bearing capacity (Fig. 1).

Fig. 1. Test specimens (left – IBI test; right – compressive strength test)

It has been sufficiently demonstrated, how much influence on the bearing capacity cause adding the activator to the mixture, since mixtures without activator have not shown any increase in bearing capacity over time, expressed by the IBI parameter (Fig. 2). In contrast, the IBI parameter increased with the added activator mixture over time. Adding the activator to the mixture increases the IBI bearing capacity parameter immediately after sample production; IBI values for MCSB mixtures with activator added immediately after manufacture ranged from 240% to 340%. For comparison, the same mixture without activator addition achieved IBI values in the range of 150% to 200%.

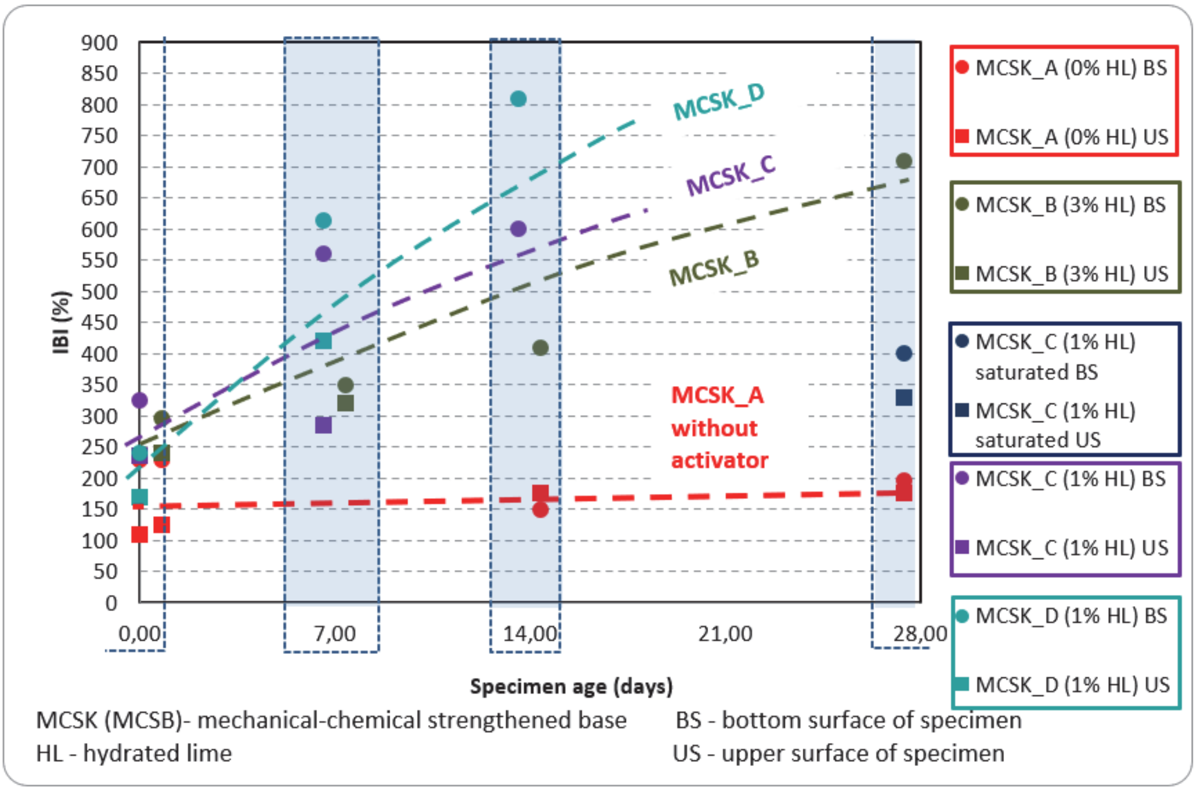


Fig. 2. IBI test of various MCSB mixtures with different % of activator (Laboratory results)

3.2 Compressive Strength – Laboratory Results

The bearing capacity expressed by the IBI parameter were already so high in the 7-day samples, that the samples were more suitable for compression strength test according to EN 13286-41. Based on the values of the compressive strength results of the tested samples, the theoretical curves of the increase in compressive strength over time were drawn. These theoretical curves of the increase in compressive strength over time of the MCSB are similar by its character to the curves of the compressive strength of the concrete, respectively CBGM (Cement Bound Granular Mixture).

The dose of activator in the mixture was reduced from 3% to 1% during the research, making later versions of MCSB more economical. This reduction of the dose did not occur by reducing the strength of the samples.

Optimization also took place on the aggregate selection; two fractions of coarse aggregate from the quarry "Pohranice" were replaced by the aggregate from the quarry "Vtáčnik".

The laboratory results of the compressive strength of the MCSB mixtures showed an increase over time for all variants of the mixture (Fig. 3). The 28-day compressive strength for MCSB_A and MCSB_C has reached 3 MPa on all test samples, and with increased humidity even up to 4 MPa. Satisfactory results were also achieved at 7-day strengths, especially when MCSB_C has a faster start of 7-day strength thanks to a smaller maximum aggregate grain.

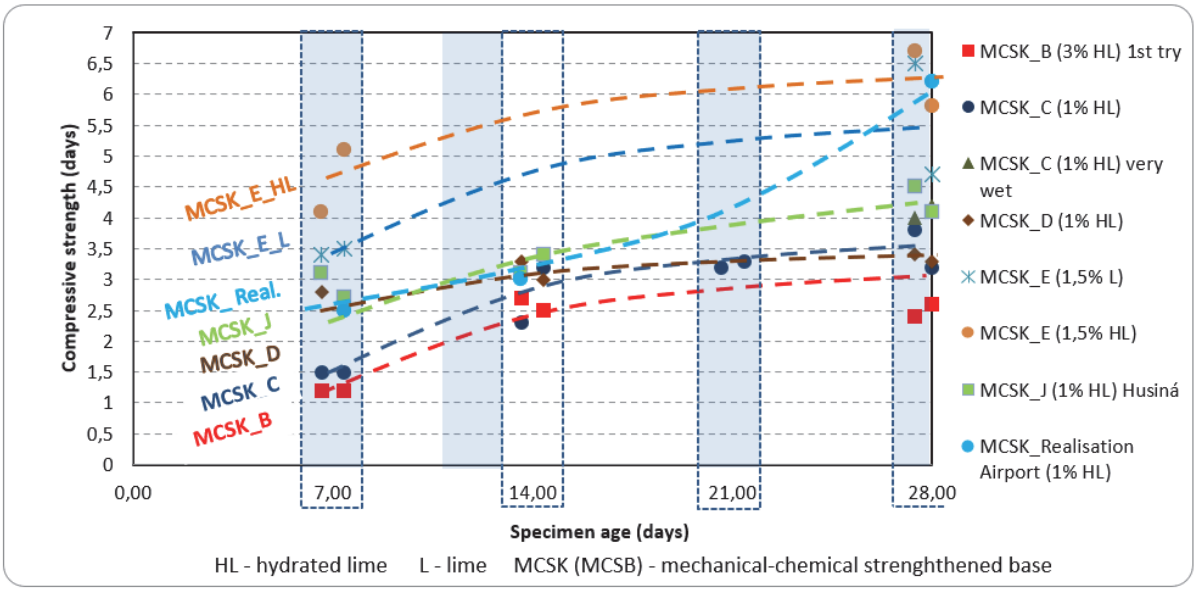


Fig. 3. Compressive strength of various MCSB mixtures (Laboratory results)

3.2 Bulk density of the mixture

The range of bulk density of the mixtures with added activator was from 2300 kg/m^3 to 2350 kg/m^3.

3.3 Modulus of elasticity

Semi-rigid pavement constructions are commonly designed and successfully implemented in various climatic conditions all over the world. However, they have their own laws which require a special approach in the process of designing the pavement structure and also in the process of manufacturing and processing the building mixture. In the design phase of a semi-rigid road design, there are basically three possibilities of the hydraulically bound layer behaviour in the pavement structure, which is mainly the result of a later maintenance method. Taking into account the prevailing types of pavement structures in individual countries, we can distinguish the concept of pavement design with low-tensile strength bonded layer (7-day strengths are less than 2 MPa, the modulus of elasticity is between 1,000 MPa and 2,000 MPa), for example Switzerland; with a medium-tensile strength bonded layer (7-day strengths are between 2.5 MPa and 4.5 MPa, modulus of elasticity from 7,000 MPa to 10,000 MPa), for example Italy; and with a high-tensile strength bonded layer (7-day strengths are greater than 10 MPa, the modulus of elasticity is from 15,000 MPa to 30,000 MPa), for example France. The most widespread method of designing a semi-rigid construction of asphalt pavements considers both bonded layers (asphalt and hydraulically) to the bending stiffness of the pavement. In the design concept, an important (economical-technical) criterion is the copying (reflection) of thermal cracks from the bonded layer to the pavement surface. Reflex cracks can be delayed by selecting a hydraulic binder, by combining layer thicknesses, or simply by accepting these cracks and systematically treating them for pavement life. In Slovakia dominates the design concept of the bonded base layers with lower strengths and elastic modules with overlap of these layers by a relatively thick asphalt layers to delay the cracking time.

In the case of MCSB_A, the elastic modulus according to STN EN 13286-43 was laboratory tested by an external TSÚS laboratory. The modulus of elasticity of MCSB_A was 1,000 MPa.

4. REALISATION

In the second half of year 2018, the construction of new airfields of Prievidza Airport was carried out by STRABAG operational units. In cooperation with the designer, the originally considered CBGM as a base layer was replaced by MCSB_D (also called MCSB-TPA, Mechanical-Chemical Strengthened Aggregate – TPA) at the same thickness. During the construction, approximately 4,700 m^3 (10,900 tons) of the MCSB-TPA mixture was laid on all areas of "Prievidza" Airport (Fig. 4).

Fig. 4. Laying of MCSB-TPA base course ("Prievidza" Airport)

4.1 Parameters of finished layer

During and after the realisation of construction works on the airfield's areas of "Prievidza" Airport, several tests were carried out to determine the strength and elastic characteristics of the MCSB-TPA base layer. Test samples were taken to determine compressive strength and FWD measurement of elastic parameters of pavement layers were executed (Fig. 5).

Fig. 5. FWD measurement ("Prievidza" Airport)

4.2 Compressive strength – "Prievidza" Airport

Test samples for compressive strength test were manufactured from mixture taken directly from trucks on the building site. In this case, also 1-day compressive strength was determined. It was achieved a value of 2.5 MPa, which means that a significant increase in compression strength is performed in the first 24 hours after laying the mixture.

28-day compressive strengths reached 6.2 MPa, which means a considerable difference over the compressive strengths measured in laboratory conditions (Fig. 3).

4.3 Elastic modulus of the pavement layers based on FWD measurements

Elastic Modules were calculated from road surface deflection measurements using the Dynatest 8012 FastFWD. From back-calculation, a modulus of elasticity was determined for the MCSB-TPA base layer in the range of 1,000 MPa to 1,600 MPa (Figures 6.a and 6.b).

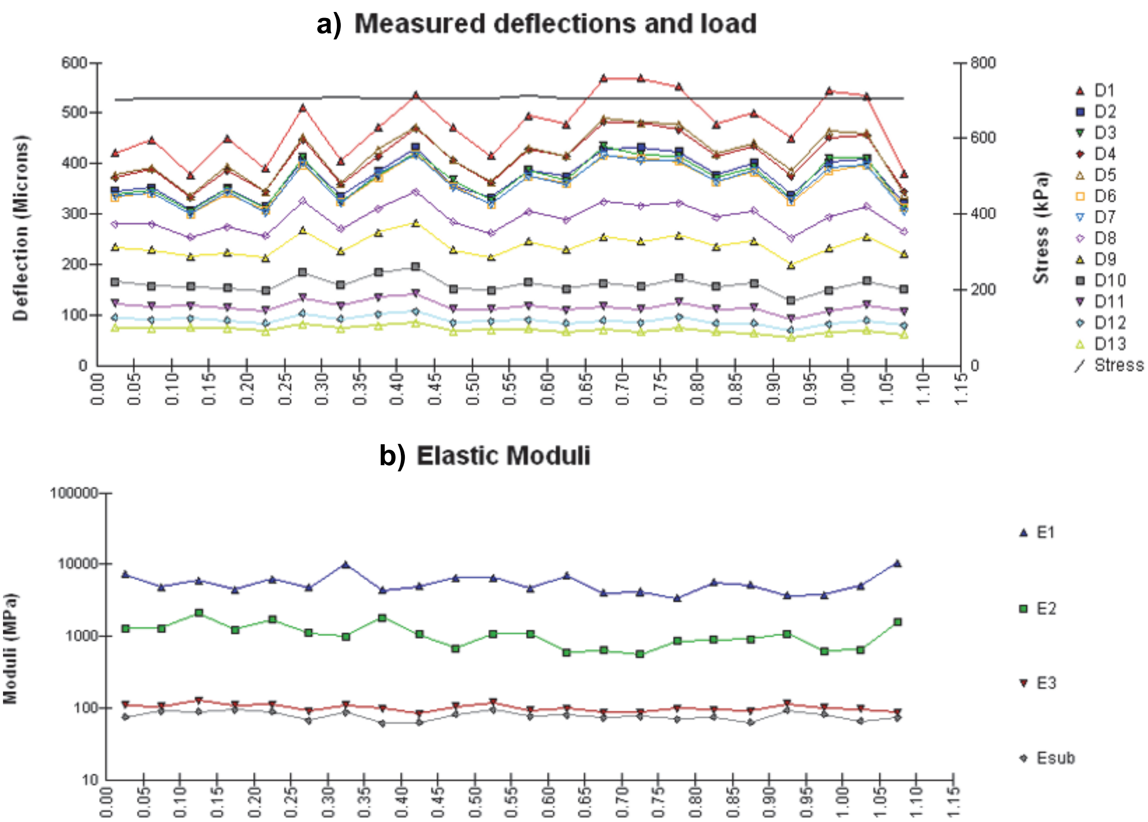


Fig. 6. Results of FWD measurement and back-calculation (RWY, lane 2, Prievidza Airport)

5. CONCLUSIONS

From the results of the material tests in the laboratory and field tests made on the construction of real site, the hypotheses on the possibility of designing the material for pavement base course, which design parameters (modulus of elasticity) are between the mechanically strengthened aggregate (MSB) and the cement bound granular mixture layer (CBGM), were confirmed.

In addition, it is also possible to fine-tune the mechanical parameters of the base layer according to the designer's intention and the type of aggregate, which is locally available through experimental design of the composition of the mixture in the laboratory.

A substantial part of the stiffness of the base course is obtained from the skeleton of the aggregate, but to the stiffness also significantly contributes the pozzolan bonding.

It looks realistic that the MCSB (Mechanical-Chemical Strengthened Base) layer can replace the use of mechanically stabilised layers as well as hydraulically bounded layers on Slovak motorways.

In the case of innovative solutions, it is typical that these are not yet captured in standards and technical regulations, making it difficult to use them in practice. By legalizing the solution, however, the author of the solution loses the market advantage. In our case, we have proceeded to 'legalize' this layer for implementation on national roads by a technical assessment by a notified body.

6. REFERENCES

Boros, Zs. et al. (2022), "Mechanical-chemical strengthened base course (MCSB-TPA) – a green and innovative approach to a new generation of asphalt pavement construction", ICMPA 2022 – 11th International Conference on Maintaining Pavement Assets, Chicago, USA.

Boros, Zs. (2019), "Mechanical-chemical strenghtened base course MCSB-TPA", SID19 STRABAG Innovation Day, Stuttgart, Germany.

Boros, Zs., Dancs, N. and Benkó, Zs. (2015), "Evaluation of asphalt pavement with bounded and unbounded base courses after 15 years of exploitation under real load and climate condition", XXV. World Road Congress Roads and mobility creating new value from transport, Article 0010, Seoul.

Boros, Zs., Dancs, N. and Benkó, Zs. (2015), "Netuhé vozovky v reálnych podmienkach na Slovensku (Flexible pavements in real conditions in Slovakia)", VI. Konferencia nestmelené a hydraulicky stmelené vrstvy vozoviek (VI. Conference – Unbound and hydraulically bound pavement layers), Podbanské, Slovak Republic.

Bonnot, J. et al. (1991), "Semi-rigid pavements", PIARC report no. 08.02.B.

Fiedler, J. and Bureš, P. (2015), "Zohlednění vlastností nestmelených vrstev při navrhovaní vozovek s využitím laboratorních a polních zkoušek (Influences of properties of unbound layers when designing pavements using laboratory and field tests)", VI. Konferencia nestmelené a hydraulicky stmelené vrstvy vozoviek (VI. Conference – Unbound and hydraulically bound pavement layers), Podbanské, Slovak Republic.

Komačka, J. and Benkó, Zs. (2011), "Diagnostika únosnosti asfaltových vozoviek deflektometrami FWD (Diagnostics of the bearing capacity of asphalt pavements using FWD deflectometers)", EDIS, Žilina, Slovak Republik.

Slovak Road Administration (2009), "TP 033 – Design of flexible and semi-rigid pavements. Technical conditions".

TSÚS – Building testing and research institute (2018), "Report of pozzolanic reactivity results from quarry Vtáčnik", Slovak Republic.

TPA Society for Quality Assurance and Innovation (2018), "Type test – unbound material MCSB", Slovak Republic.

RESEARCH AND DEVELOPMENT IN THE CONSTRUCTION INDUSTRY FROM A SOCIALLY RESPONSIBLE PRESPECTIVE

Dipl.-Ing. Jens Hoffmann
STRABAG AG
Donau-City-Strasse 9
1220 Vienna, Austria

SUMMARY

Construction has seen little change over the past 150 years leading to declining productivity, and challenges such as a shortage of skilled labour as well as climate change. Traditional construction methods cause significant environmental impacts. The EU's Green Deal and STRABAG's strategic climate neutrality goal highlight the necessity for sustainable digital construction practices. Digitalisation and sustainability are synergistic: more efficient construction processes and reduced resource usage are enabled by digital technologies, as well as new building materials and methods. With approximately 400 current development projects, STRABAG significantly promotes innovation with people remaining central to the success of these developments. Additionally, modular construction has the potential to be a true game-changer in the construction industry. It offers considerable ecological and economic benefits but requires measures for broader societal acceptance.

1. RATIONALE

For more than 150 years, construction has not experienced any fundamental changes. While machinery on construction sites has reduced the amount of manual labour, labour-intensive methods such as brick laying and in-situ concrete construction continue to dominate individual building projects. Compared to other industries, the construction sector has seen a steady decline in productivity for decades (Fig. 1). Additionally, a shortage of skilled labour, raw material scarcity, and supply chain issues exacerbate these challenges. From an economic perspective alone, these factors justify significant investments in research and development initiatives to make construction future-proof. However, the challenges of climate change significantly increase the urgency for action. The global construction industry, with its conventional methods, is responsible for 40 to 50 percent of today's energy and resource consumption, 60 percent of worldwide transport, 40 percent of current waste generation, and 38 percent of all energy-related greenhouse gas emissions. Therefore, making construction more sustainable and digital, and in some parts rethinking it entirely, is a societal obligation.

As part of its Green Deal, the European Union has set the goal of achieving climate neutrality by 2050 (European Commission, 2019). Accordingly, regulations and directives are rapidly being implemented that will directly impact industry, especially the construction sector. In response, STRABAG, as part of its company-wide Strategy 2030, has committed itself to achieving its own climate neutrality by 2040.

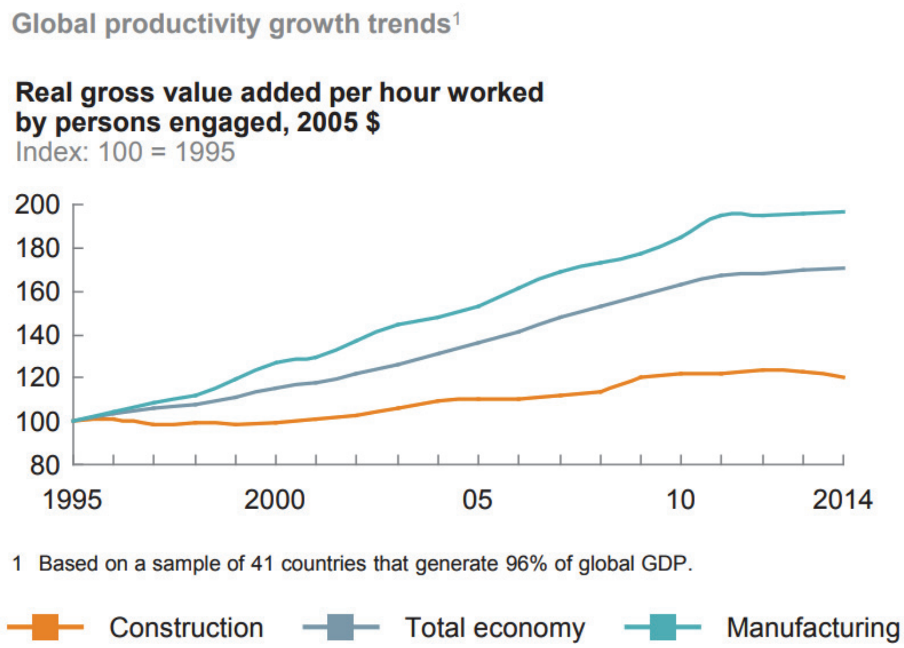


Fig. 1. Globally, labour-productivity growth lags behind that of manufacturing and the total economy, (Barbosa F. et al., McKinsey & Company, 2017).

2. SUSTAINABILITY AND DIGITALISATION – NO CONTRADICTION

Sustainability and digitalisation are less a contradiction and more a synergy. Digitalisation in construction is crucial for implementing sustainability and achieving climate goals. Without digital technologies, methods, and ultimately high-quality data, it will not be possible to make the planning, execution, and operation of buildings more efficient, and thus more sustainable. Digitalisation enables optimised construction and management processes and, therefore, the use of fewer resources. Digital models refine planning in its early stages, create transparency, and provide the necessary data basis to evaluate and optimise material selection, procurement, manufacturing, and logistics processes so enabling improved sustainability and cost saving throughout the entire construction process. Conversely, the sustainability of digitalisation offers an equally necessary limitation. The well-known quote by Deutsche Telekom CEO T. Höttges (2015): "Everything that can be digitised will be digitised. And everything that can be networked will be networked. This applies to people, machines, and products alike" will also apply in the construction industry, potentially increasing resource- and energy consumption without sustainability constraints. Moreover, productivity increases associated with the digitalisation and automation of construction processes will also economically support the argument for increased sustainability. Sustainability in construction will not establish itself in the mid- and long term unless these changes also make financial sense.

3. RESEARCH AND DEVELOPMENT – LIFECYCLE ORIENTATION

The message about the need to modernise construction, and the associated business potential which comes with this modernisation has also reached global hardware and software industries. In recent years, as an industry, we have been faced in recent years with a steadily growing number of new market products and methods. Many of these originate from the professional fields of BIM, sensors, robotics, cloud services, or AI, to name a few. For a diversified company like STRABAG, it is essential to maintain an overview of all these market developments, and centrally steer the multitude of its own R&D activities. To achieve this, STRABAG Innovation

& Digitalisation (SID) was founded in 2020. SID enables the establishment and implementations of company-wide innovation projects and comprising of approximately 400 experts in digitalisation and sustainability.

The vast majority of STRABAG's innovation projects focus on the core business of planning, constructing, and operating building structures. However, the methods and tools being tested or developed often target specific tasks within individual trades, such as scheduling in construction or surveying in pipeline construction. While these incremental improvements, by definition, are not innovations, they have been and will continue to make valuable contributions to advancing construction. Their potential for significant changes, whether in terms of sustainable construction, substantial efficiency gains, or even new business models, is nevertheless limited. Achieving such changes requires broader considerations spanning entire process chains and involving multiple trades and phases of a construction project, up to a multi-project perspective (think Urban Mining –valuable materials from old buildings and infrastructure for reuse in new construction projects.).

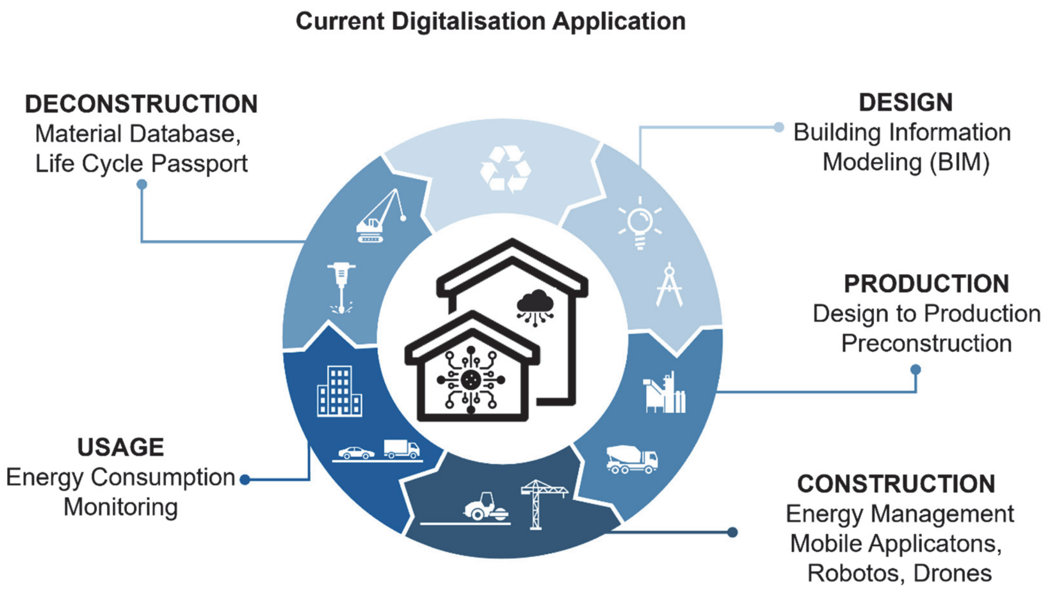


Fig. 2. Schematic Diagram of a Construction Project Lifecycle (Wall, J., Dallinger, C., Trauninger, D., 2023)

Innovating around the lifecycle of a construction project has proven to be practical (Fig. 2). In depth examination within this lifecycle reveals preceding and subsequent sub-processes that need to be interconnected. Often, these considerations serve as starting points for further developments and innovations. Comprehensive assessments enable the development of data-driven processes, allowing data from the planning phase to be utilized during manufacturing in the factory, and during construction on-site. This requires seamless integration of workflows and tools, resulting in consistently available and analysable validated data (think Big Data). Cloud-enabled software products with open data interfaces (APIs) are becoming indispensable. STRABAG already extensively implements API-capable software, and API capability is a key objective of the corporation's digital and data strategy, and a major factor in shaping the selection of future software products, and partners (Sprenger, W., Schley, F., Hoffmann, J., 2023).

4. THE HUMAN FACTOR

The challenge in digitalization is less technical and more human in nature. If employees are not on board, feeling involved as active participants in the change, even the best developments won't succeed in the real construction world. STRABAG has also faced these challenges and learned significantly in recent years. Through two internal programs, *ideas@strabag* and *AdASTRA*, employees at all levels can contribute innovative ideas that either improve their daily work or offer creative approaches for new initiatives. These ideas are picked up, evaluated for feasibility, and integrated into development projects. The idea generators themselves are part of interdisciplinary development teams. Management must not only allow employees to come up with ideas, but rather actively encourage it, and demonstrate this encouragement through open communication. Failures, which are integral to any innovation process, should be viewed as learning opportunities and thus gains. This mindset, fundamentally at odds with construction's focus on risk avoidance in the pursuit of robustness and safety, must be nurtured.

Once brainstormed ideas evolve into development projects with initial outcomes, the work has usually just begun. Results are tested through Proof of Concept (PoC) phases and subsequently in pilot projects within real project environments. These tests require close monitoring, involving on-site technical expertise, and change management. They uncover not just technical aspects needing improvement but also the impacts these innovations have on employees in their daily tasks. Developments which directly enhancing an employee's work routine generally gain acceptance quickly. Challenges arise, however, with innovations affecting individual roles and responsibilities, where tasks shift to others or machines, with benefits manifesting in subsequent processes or overall outcomes. Clarifying the "why" is crucial here, thus highlighting the vital importance of professional change management, and effective communication.

Ultimately, humans are at the core of innovation and change processes in construction and will remain so. The right mix of creativity, leadership by example, collaboration, and adaptability is crucial for successfully implementing innovations and ensuring long-term success. As part of its 2030 strategy, STRABAG deliberately prioritizes the human element.

5. MODULARITY – THE FUTURE OF CONSTRUCTION

The concept of modular construction refers to a method where buildings are predominantly made from prefabricated modules, designed and assembled off-site. These modules are produced serially in decentralized factory environments by specialized teams, pre-assembled there, transported to the construction site, and then final assembled on-site. The size of the modules varies but is primarily limited by their transportability and assembly capability (Fig. 3).

Modular construction offers numerous advantages over predominantly individual, mostly manual on-site manufacturing, including faster construction times with less noise pollution on-site, cost-efficiency, high execution quality, and a proactive solution to the skilled labour shortage in construction. Given the increasing urbanization and resulting demand for affordable housing, the importance of modular construction will significantly grow in the future. While the concept of industrially manufactured buildings in series is not new, this renaissance will also contribute significantly to the sustainability of this building method. Modular construction is dismountable and reusable, making it resource efficient. Planning and manufacturing data essentially provides the dismantling instructions. Used modules can be dismantled at the end of a building's life, recycled into their base materials, or upcycled for reuse. Additionally, less waste is generated during factory production compared to conventional construction sites. As already stated above, the construction industry is responsible for up to 40% of global waste; the increased use of modular construction has the potential to reduce this figure significantly.

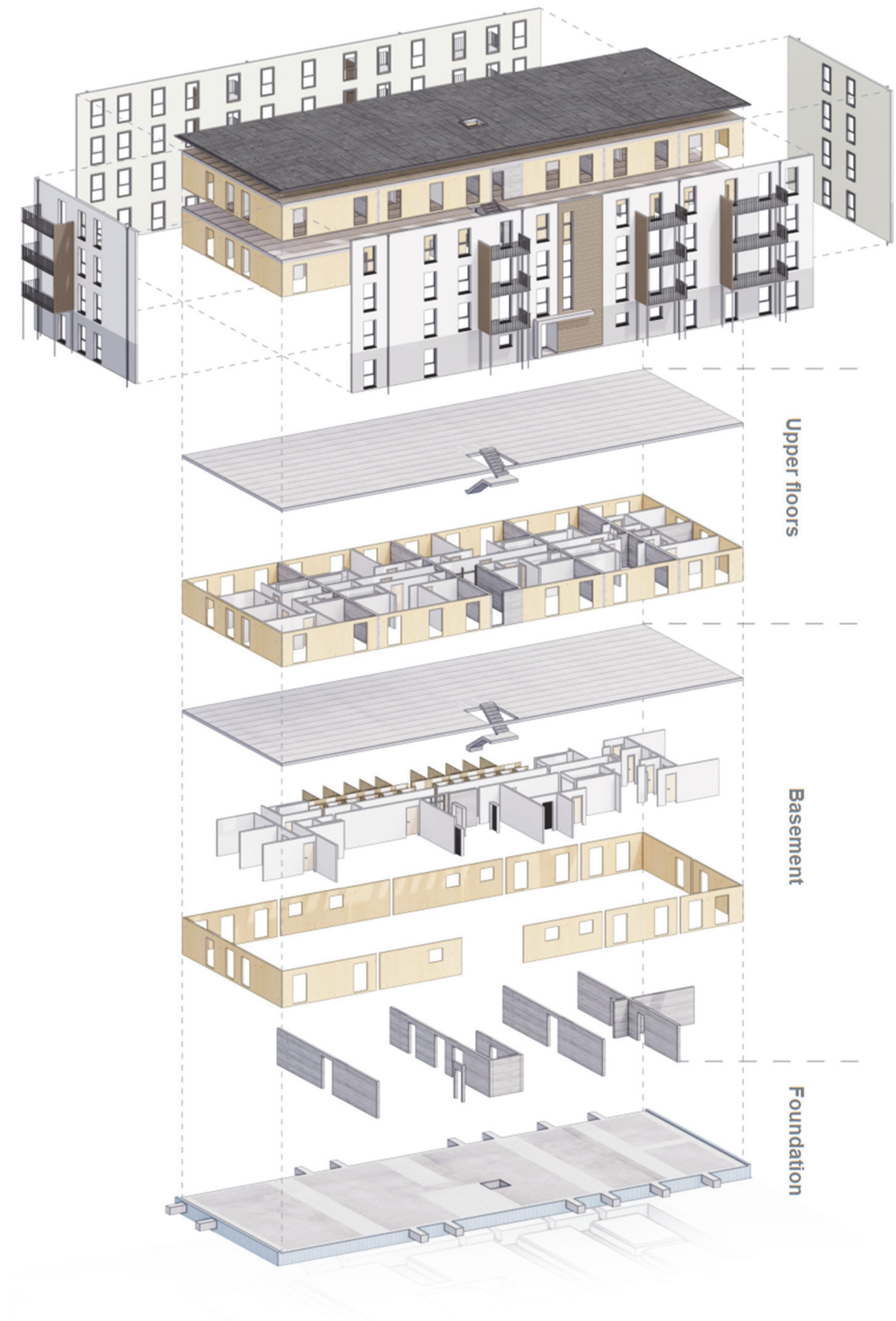


Fig. 3. Isometric representation – Modular construction principle in residential construction (STRABAG AG, 2024)

Regarding environmental responsibility, 20-50% of total building lifecycle emissions are attributable to the construction phase and later demolition. Therefore, the environmental advantages described for modular construction address critical areas, although not the significant factor of client's aesthetic preferences and individual requirements. Prefabricated construction often suffers from a negative image in Central Europe, partly due to monotonous prefabricated panel housing estates on urban peripheries. However, digitalization now offers a tangible opportunity to achieve modular construction with a significantly higher degree of individuality. Using algorithm-based Generative Design, prefabricated building kits can be more extensive yet manageable in planning. The resulting model data (digital twins) allow customers to experience and actively participate in shaping the building in earlier planning phases. The combination of digitalization and modular construction thus presents an opportunity to disrupt the construction industry in positive way.

6. CONCLUSIONS

Given stagnating productivity and significant environmental challenges, it is essential to modernise the construction industry, and in some areas, even fundamentally rethink it. With its Strategy 2030, STRABAG focuses on digitalised construction processes, new materials and methods, as well as more efficient resource utilisation. Modular construction has the potential to be a game changer for the industry. Generative design enables an unprecedented level of adaptability to individual customer requirements, which will hopefully make modular construction more widely accepted than ever before.

The human factor remains central: the involvement and active participation of employees are crucial for the success of innovation processes. At the same time, courage is required to embrace change and explore new paths. This courage to innovate is indispensable for achieving long-term success and driving transformation in the construction industry.

7. REFERENCES

Barbosa, F., Woetzel, J., Mischke, J., Ribeirinho, M. J., Sridhar, M., Parsons, M. and Bertram, N. (2017), “Reinventing Construction: A Route to Higher Productivity”, McKinsey & Company. Available at: https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/Operations/Our%20Insights/Reinventing%20construction%20through%20a%20productivity%20revolution/MGI-Reinventing-Construction-Executive-summary.pdf

European Commission (2019), “The European Green Deal”, p. 5. Available at: https://ec.europa.eu/info/sites/default/files/european-green-deal-communication_en.pdf

Sprenger, W., Schley, F. and Hoffmann, J. (2023), “BIM und Datenintegration”, In: Hofstadler, C., Motzko, C. (eds) Agile Digitalisierung im Baubetrieb. Springer Vieweg, Wiesbaden. https://doi.org/10.1007/978-3-658-43247-8_11

Wall, J., Dallinger, C. and Trauninger, D. (2023), “Digitalisierungsprozesse für die klimaneutrale Baustelle”, In: Hofstadler, C., Motzko, C. (eds) Agile Digitalisierung im Baubetrieb. Springer Vieweg, Wiesbaden. https://doi.org/10.1007/978-3-658-43247-8_33

PROGRAM **2024. október 1. (kedd)**	PROGRAMME **1 October 2024 (Tue)**
9:00–9:05 Köszöntő Nyiri Szabolcs, elnök, MAÚT	9:00–9:05 Welcome Speech Szabolcs Nyiri, Chairman, MAÚT
9:05–9:15 Miniszterhelyettesi köszöntő Csepreghy Nándor, miniszterhelyettes, ÉKM	9:05–9:15 Welcome Speech Nándor Csepreghy, Deputy Minister, ÉKM
1. SZEKCIÓ – Szabályozás Szekcióvezető: Dr. Michael Rohleder (D) Társ-szekcióvezető: Bortei-Doku Shaun (HU)	**SESSION 1 – Technical Regulation** Chair: Dr. Michael Rohleder (D) Co-Chair: Bortei-Doku Shaun (HU)
9:15–9:55 Szakpolitikai összefüggések Bartal Tamás, ÉKM	9:15–9:55 Contest of policy Tamás Bartal, ÉKM
Közlekedési szakigazgatási kérdések Kerékgyártó János, ÉKM	Transport Administration Issues János Kerékgyártó, ÉKM
9:55–10:25 Klíma-Check – Dekarbonizáció az osztrák útügyi műszaki előírásokban Dr. Martin Fellendorf (A)	9:55–10:25 Climate Check – Decarbonization in Austrian Road Guidelines Dr. Martin Fellendorf (A)
10:25–10:55 Az Európai Unió vasúti rendszerének evolúciója a szabályozás nézőpontjából Dr. Josef Doppelbauer (A)	10:25–10:55 The Evolution of the Railway System of the European Union from a Regulatory Perspective Dr. Josef Doppelbauer (A)
10:55–11:25 Kávészünet	10:55–11:25 Coffee Break
2. SZEKCIÓ – Megtérülő innováció 1 Szekcióvezető: Thoroczkay Zsolt (HU) Társ-szekcióvezető: Győri Enikő (HU)	**SESSION 2 – Remunerative Innovation 1** Chair: Zsolt Thoroczkay (HU) Co-Chair: Győri Enikő (HU)
11:25–11:50 Digitalizáció, automatizáció és mesterséges intelligencia Aleksander Zborowski (PL)	11:25–11:50 Digitalization, Automatization and Artificial Intelligence Aleksander Zborowski (PL)
11:50–12:15 Érdesítőszerek környezeti hatásainak minimalizálása a téli útfenntartás során Dr. Peter Nutz (A)	11:50–12:15 Minimising the Environmental Impact of the Use of Gritting Agents in Winter Road Maintenance Dr. Peter Nutz (A)
12:15–12:40 Útfenntartás a XXI. században Koch Domonkos (HU)	12:15–12:40 Road maintenance in the 21th Century Domonkos Koch (HU)

12:40–13:05 Megtérülő innováció a szerkezetépítés területén
Dr. Balázs György (HU)

13:05–14:30 Ebédszünet

3. SZEKCIÓ – Megtérülő innováció 2
Szekcióvezető: Szerencsi Gábor (HU)
Társ-szekcióvezető: Szinvai Szabolcs (HU)

14:30–15:00 A szerkezeti betonok, a mérnökök és a tervezők jövőjének néhány kérdése
Michel Virlogeux (F)

15:00–15:30 Hídépítést támogató kutatások a Műegyetemen
Dr. Dunai László (HU)

15:30–16:00 Földművek teherbírásának és terhelés okozta alakváltozások vizsgálatának hazai eredményei
Dr. Szendefy János (HU)

16:00–16:30 Beton alagútbélések építési technológiái Csehországban
Jan L. Vítek (CZ)

16.30–17.00 Hogyan tovább, MAÚT?
Nyiri Szabolcs (HU)

19.30–22.30 Díjátadás, Gálavacsora
Díjátadás: Wagner Ernő, MMK, Scharle András
Gálavacsora megnyitó beszéd: dr. Fónagy János

12:40–13:05 Remunerative Innovations on the Field of Structural Engineering
Dr. György Balázs (HU)

13:05–14:30 Lunch Break

SESSION 3 – Remunerative Innovation 2
Chair: Gábor Szerencsi (HU)
Co-Chair: Szabolcs Szinvai (HU)

14:30–15:00 Some Questions About the Future of Structural Concrete and of Engineers and Designers
Michel Virlogeux (F)

15:00–15:30 Bridge Research Activities at the Budapest University of Technology and Economics
Dr. László Dunai (HU)

15:30–16:00 Domestic results of investigations into the load bearing capacity and load-induced deformation of earthworks
Dr. János Szendefy (HU)

16:00–16:30 Technologies for Construction of Concrete Tunnel Linings Used in Czechia
Jan L. Vítek (CZ)

16.30–17.00 Where Next, MAÚT?
Szabolcs Nyiri (HU)

19.30–22.30 Awarding Ceremony, Gala Dinner
Awarding: Ernő Wagner, MMK, András Scharle
Gala Dinner Opening Speech, dr. János Fónagy

2024. október 2. (szerda)	2 October 2024 (Wed)
4. SZEKCIÓ – Társadalmi felelősségvállalás, fenntarthatóság 1 Szekcióvezető: Szilvai József (HU) Társ-szekcióvezető: Arnóczki Flóra (HU)	**SESSION 4 – Social Responsibility, Sustainability 1** Chair: József Szilvai (HU) Co-Chair: Flóra Arnóczki (HU)
9:00–9:10 Az építésgazdaság aktuális helyzete Koji lászló (HU)	9:00–9:10 Current situation of the constructions economy in Hungary László Koji (HU)
9:10–9:30 Energiafelhasználás csökkentése, recycling, zajcsökkentés Dr. Füleki Péter (HU)	9:10–9:30 Energy Construction Reduction, Recycling, Noise Mitigation Dr. Péter Füleki (HU)
9:30–9:50 Körforgásos gazdaság a vasútépítés területén Urvald Krisztián (HU)	9:30–9:50 Circular Economy in the Railway Construction Sector Krisztián Urvald (HU)
9.50–10:10 Nagyvárosi életminőség javítása a legújabb mobilitási technológiák összekapcsolásával Üveges Péter (HU)	9.50–10:10 Improving the Quality of Life in Big Cities by Connecting the Latest Mobility Technologies Péter Üveges (HU)
10.10–10.30 Holland tanulmányok az elektronikus közúti rendszerek területén Dr. Lóránt Tavasszy (NL)	10.10–10.30 Studies on Electric Road Systems in the Netherlands Dr. Lóránt Tavasszy (NL)
10.30–10.50 Egy zöld és innovatív megközelítés az aszfaltburkolatok új generációjához Boros Zsolt (SK)	10.30–10.50 Green and Innovative Approach to the New Generation of Asphalt Pavements Zsolt Boros (SK)
10.50–11.10 Kutatás és fejlesztés az építőiparban a szociális felelősség nézőpontjából Jens Hoffmann (A)	10.50–11.10 Research and Development in the Construction Industry from a Socially Responsible Perspective Jens Hoffmann (A)
11:10–11:30 Kávészünet	11:10–11:30 Coffee Break

5. SZEKCIÓ – Társadalmi felelősségvállalás, fenntarthatóság 2
Szekcióvezető: Jan Sedivy (SK)
Társ-szekcióvezető: Szakonyi Petra (HU)

11:30–13:00 Panelbeszélgetés
Moderátor: Pásztor Zoltán (HU)

Résztvevők:
Biczók Péter (HU)
Dr. Kiss János Péter (HU)
Dr. habil. Szalkai Gábor (HU)
Kiss László (HU)
Dr. Szakonyi Petra (HU)

13:00–14:30 Ebédszünet

6. SZEKCIÓ – Generációváltás
Szekcióvezető: Pásztor Zoltán (HU)

14:30–16.30 Fiatalok bemutatkozása és szakmai programja
NextGen

SESSION 5 – Social Responsibility, Sustainability 2
Chair: Jan Sedivy (SK)
Co-Chair: Petra Szakonyi (HU)

11:30–13:00 Panel Discussion
Moderator: Zoltán Pásztor (HU)

Participants:
Péter Biczók (HU)
Dr. János Péter Kiss (HU)
Dr. habil. Gábor Szalkai (HU)
László Kiss (HU)
Dr. Petra Szakonyi (HU)

13:00–14:30 Lunch Break

SESSION 6 – The Next Generation
Chair: Zoltán Pásztor (HU)

14:30–16.30 Introduction and Professional Program of the Next Generation
NextGen

MAÚT 30

30 ÉVES A MAGYAR ÚT- ÉS VASÚTÜGYI TÁRSASÁG

ISBN 978-615-82475-2-8