

Brief Summary of Current Research Activities of Centre for Effective and Sustainable Transport Infrastructure (CESTI)

April 2015

1. WP1: Roads – Smart, Long-Lasting and High-Performance Technological Solutions

1.1 Asphalt layers for high-performance roads

Work task deals with new technical solutions for semi-warm asphalt mixes, validation of new set of performance tests or development of new mixes for durable asphalt layers. Main activities and conclusions:

- Mechanical activation of recycled materials by high-speed disintegration was tested. It was proved that this technique increases hydraulic activity of the material.
- ACO and ACL mixes with substitution of filler by fluidic fly ash were tested (compatibility of filler with asphaltic binder, determination of adhesion of asphaltic binders to aggregate).
- Optimization of semi-warm asphalt mixes was conducted. Suitable solution for decreasing processing temperature below 200 °C was found.
- Set of performance tests of asphalt binders was conducted. One of the objectives is to define conditions for repeatability of the tests.
- Uniaxial shear testing device for determination of shear properties of asphalt paving mixes was developed in cooperation with University of Berkeley, USA. Patent application was filed in both the Czech Republic and USA.
- Vast experimental program aimed at the effect of selected additives on processing temperatures of SMA-type and HMAC-type mixes was carried out. The results showed that it is possible to decrease the temperature by 20 °C without any negative effects on the properties of the material.
- Specification of mixes for durable asphalt layers (with higher stiffness modulus or increased fatigue resistance – e.g. RBL mixes) was created, effect of adjustment of parameters was verified by comparative calculations.

The results will allow to use the new types of paving mixes in larger scale. Decreased processing temperatures will yield significant economical and environmental benefits (savings of energy required for heating of the mix, reduced pollution of air by toxic gases from asphalt processing, mitigation of impacts on health of construction workers). Exploitation of durable asphalt layers will reduce maintenance costs of roads.

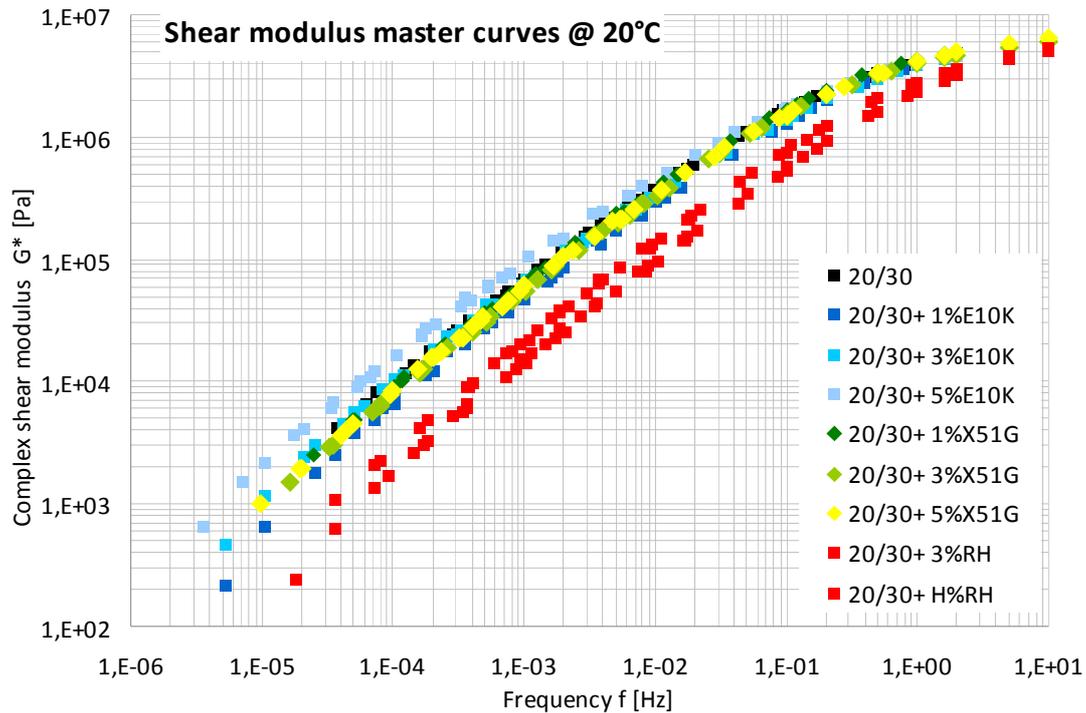


Fig. 1 Performance tests of asphalt binders – example of results.

1.2 Durable concrete pavements with innovative binders, application for fast repairs

Work task deals with issues of technical design of concrete roads, prediction of degradation of concrete roads and development of new types of road concretes with blended cements and energy production by-products. Main activities and conclusions:

- Numerical model of segment of concrete road on soft subsoil was tuned in ABAQUS program. The reason was to correct deficiencies in design procedure for concrete roads included in TP170 specifications of Ministry of Transport of the Czech Republic. A set of influence coefficients was defined, software CB_Design was developed for calibration of these coefficients.
- Trial segments of roads made from concrete with ground granulated blast-furnace slag were constructed in Skanska complex in Uherské Hradiště. Effects of traffic and environmental loads on properties of the structure will be evaluated in regular intervals.
- Road concrete mixes with fly-ash were proposed. First set of tests have shown general compliance with requirements, testing will continue.

Precision of TP170 will allow to better account for load-bearing capacity of the subsoil, enabling more precise design of road slab. Concrete mixes exploiting energy production by-products will significantly reduce the amount of primary raw materials required for construction of concrete roads. With millions of tons of concrete used for roads every year, financial and environmental savings will be of substantial extent.

1.3 Technical solutions for rehabilitation and continuous maintenance based on the concept of fully recyclable road

Work task is aimed at energy saving asphalt paving mixes with increased contents of R-material, cold recycling of asphalt pavements and multiple recycling of pavement structures. Main activities and conclusions:

- Influence of use of up to 30 % of R-material on 8 types of VMT asphalt paving mixes was studied, including effects of rejuvenating or temperature reducing admixtures. The most suitable mixes with minimum negative impacts on mechanical properties and durability were identified.
- The use of recycled concrete in cemented subgrade layers was investigated as well as the use of recycled concrete aggregate for asphalt paving layers. Materials for subgrade layers are ready for practical application, further research is needed for paving materials.
- Multiple recycling was tested on laboratory specimens. Prepared specimens were artificially aged, ground and reused in new cold recycling mixes. Some problems with strength characteristics were identified, probably caused by asphalt layer on the surface of recycled aggregate. The research will continue in following years.
- Technology of cold emulsified asphalt mix was verified on trial structure – 1.8 km long section of road near Moravský Beroun. The technology will be further utilized by TOTAL company and offered to other major producers of asphalt pavements (Skanska, Eurovia). Estimated savings are 0.9 – 1.1 € per ton of asphalt mix compared to traditional warm mixes.

The topic of recycling existing asphalt roads is very thorny, as many structures subjected to first cold recycling 15 years earlier will require another maintenance in the near future. Therefore, it is necessary to prepare reliable technologies and specifications for exploitation of multiple recycled materials.



Fig. 2 Application of cold emulsion asphalt paving mix (left), specimens for laboratory tests (right).

1.4 Design processes for roads with the use of probabilistic prediction models and performance parameters

Work task solves the questions of 3D modelling of roads and development of degradation models and tools for simulation of degradation. Main activities and conclusions:

- Analysis of use of 3D scanning, exploitation of point cloud data for surface creation, utilization of 3D models for construction machinery control and analysis of possible advantages and disadvantages of BIM approaches in transport construction engineering is conducted. At the same time, negotiations with public authorities regarding standardization and normalization in this area are in process. Application of 3D technologies on selected projects is expected in coming years.
- Data collection from fatigue behavior tests and analysis of current degradation models was performed. In the following years, development and validation of degradation models is planned, with special focus on the area of cold recycling materials where current level of knowledge is very low.

BIM processes and connected 3D modelling techniques will become more and more common in transportation engineering in the near future, because they present a robust tool for effective design and operation of infrastructure. BIM model is a database where all the data about the structure can be stored. Such a database is a necessary precondition for efficient application of LCCA methods which must be adopted for planning of key transport infrastructure objects if sustainable development shall be secured.

1.5 Systems and innovative solutions for water drainage

Work task deals with problems of water drainage of road structures. Main activities and conclusions:

- Works on the catalogue of failures of water drainage systems were started. The catalogue will provide description of typical failures, measures for prevention and techniques for repair of the failures.
- Laboratory geotechnical field of Transport Research Centre (CDV) was adjusted for monitoring of movements of water in road structure. This will facilitate the solution of problematic details of water drainage systems.

Poor water drainage can significantly reduce service life even if the road structure is otherwise perfectly built. Therefore, catalogue enabling correct design of water drainage systems will enable tremendous savings of maintenance costs in all types of roads.

2. WP2: Progressive Approach to Technical, Technological and Cost Aspects of Railway and City Rail Infrastructure

2.1 Description of key aspects influencing total costs, definition of technical problems and their causes

Work task is focused on preparation of state-of-the-art reviews dealing with technical and economic problems of railway infrastructure, monitoring of existing railway structures and evaluation of data from monitoring. Main activities and conclusions:

- A report defining decisive cost factors for railway infrastructure was prepared. Databases of national owner and operator of the railways in the Czech Republic (SŽDC) were analysed.
- A report on application of progressive geosynthetic materials in railway substructure was prepared.
- Comparison of technical solutions of transition area of railway bridges used by various European railway owners (Czech, Slovak, Austrian, German, French, Swiss) was carried out.
- General mechanism of rail corrugation was described. The information will be used for proposal of new technical solutions.
- Regular monitoring of more than 50 railway structures is performed. Results will be exploited in recommendations for design of new structures.

Although the activities of this work task have no direct economic contribution, their importance for design of new effective and sustainable technical solutions is indisputable.

2.2 Static and dynamic analyses of railway structures, modeling of structures and elements of tracks

Work task is focused on definition of requirements and parameters for static and dynamic analyses and preparation of advanced numerical models. Influence of parameters of railway substructure and superstructure on dynamic parameters of behavior of the track is investigated. Main activities and conclusions:

- A report summarizing requirements on parameters of static and dynamic analyses was prepared.
- Optimal setup of dynamic penetration test is being sought. Several adjustments were made to penetration rods. The result will be a methodology for setup and evaluation of the test.
- Advanced numerical model of railway ballast bed is under development. The work attains a lot of interest on international conferences.
- Mathematical model of a dynamic system composed of railway vehicle and track was prepared. As a result of solution of this model, description of the effect of relative damping and critical velocity on deflections of the track was obtained.

Developed mathematical models will allow more effective prediction of service life of railway structures. This will enable to define optimum maintenance intervals. By regular maintenance, expensive reconstruction can be avoided.

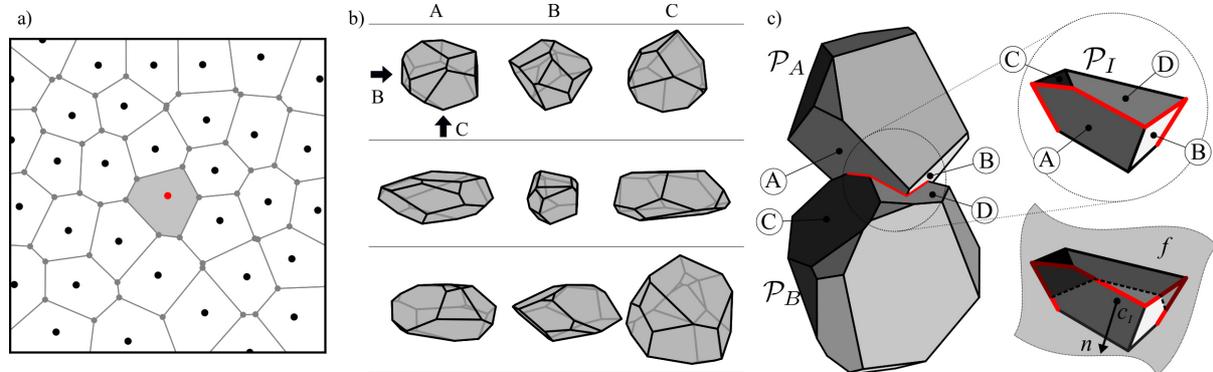


Fig. 3 Mathematical model of railway ballast bed. Voronoi tessellation in 2D (left), grains with various shape factors and random geometry (center), two polyhedrons and their intersection (right).

2.3 Construction and maintenance management – development of advanced technological approaches and strategies

Work task aims at defining strategies for long-term investments and maintenance, optimization of relations between owners, operators, administrators, producers and vendors. Main activities and conclusions:

- Analysis of public procurement, issues of low bidding prices according to Public Procurement Act, evaluation of railway infrastructure projects.
- Analysis of changes during construction, additional works and cancelled works from the point of view of national and European law.
- During reconstruction of Hodonín – Rohatec railway in 2014, different methods (with and without removal of track gird) were used for each track. Measuring polygon for continual monitoring of changes on individual tracks was established.

Analysis of legislative requirements for construction of railways is important for identification of problematic areas, where strict directives prevent application of progressive and more efficient technical solutions. Use of reconstruction method without removal of track grid could significantly decrease maintenance costs, if the long-term monitoring rules out possible adverse effects on mechanical parameters and durability of the track.

2.4 Design of new structures and elements for railway structures

Work task is focused on design of new technical solutions for railway structures, including the use of recycled materials. Main activities and conclusions:

- New type of prestressed railway sleeper was developed and patented. According to calculations, the new solution will increase the service life of railway sleepers from 30 to 40 years while the price of one sleeper remains unchanged.

- Railway switch for high-speed tracks (more than 160 km/h) is under development. Prototype is already installed in complex of DT Výhybkárna company, tuning of specific parts (displacement system, safety system) continues.
- Development of new technological and material solutions for crossings is in process.
- New arrangement of sleeper pads for railway switches 1:9-300 with transition area before the trough sleepers was developed and will be patented by the end of 2015.
- Possibilities of use of recycled materials in railway track bed (reclaimed asphalt pavement, crumb rubber from scrap tyres, fly ash, mechanically activated recycled concrete for old railway sleepers) are investigated by means of 1:1 scale laboratory experiments. Experiments with 100% recycled asphalt mixtures made exclusively from reclaimed asphalt pavement have proven significant increase of load-bearing capacity compared to traditional solution, long-term deflection effects will be evaluated in following years.

Although the primary costs of new technical solutions are often higher, total life-cycle costs are decreased thanks to prolonged service life. In case of new railway sleeper, another contribution can be found in increasing competitiveness on the railway sleeper market in the Czech Republic. Currently, there is just one monopoly producer; after introduction of new railway sleeper, railway track owner will have a possibility to negotiate about the price and save public money.

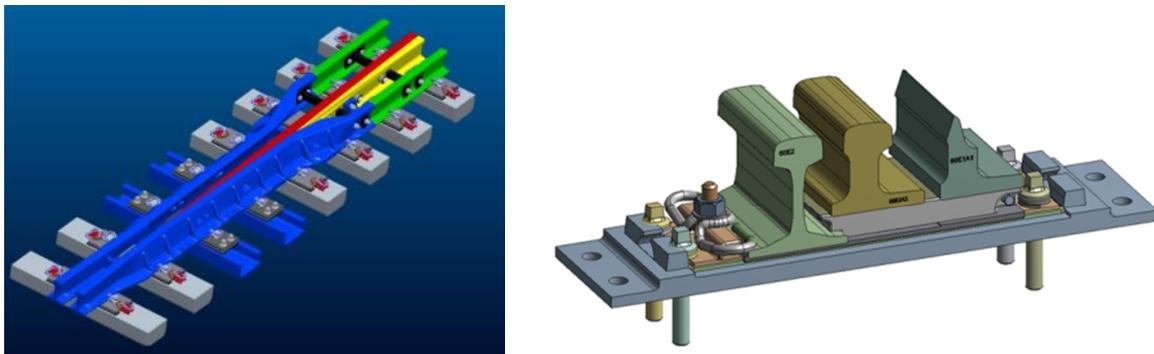


Fig. 4 FEM models of segments of railway switch.

2.5 Implementation of new structures, elements, technologies and strategies for railway structures

Work task is focused on implementation of new technical solutions developed in the previous work task. Representatives of Czech railway track owner (SŽDC) regularly take part in WP2 meetings to be informed about the results of CESTI. Especially the negotiations about application of new railway sleeper are very promising – required certificates were issued, application in trial track is expected in 2015.

3. WP3: Bridges – Cost Effective Structures with Increased Durability and Longer Service Life

3.1 Evaluation of methods for bridge diagnostics including principles of static loading tests

Work task was focused on creation of methodology for diagnostics of existing bridges. The methodology created in 2013 contains description of both destructive and non-destructive testing methods for concrete, steel, timber and masonry bridges, road and railway bridges as well as footbridges. Guidelines for the use of static loading tests and modal analysis are provided. In 2014, conformity of the methodology with European standards, directives of The Railway Infrastructure Administration (SŽDC) and Road and Motorway Directorate of the Czech Republic (ŘSD ČR) was certified by TÜV SÜD international certifying organization.

The methodology provides instructions for selection of suitable diagnostic methods for responsible government officials. Correct selection of the method and evaluation of results of diagnostics is crucial for the right decision about maintenance or reconstruction of a bridge.

3.2 Development and testing of new materials for bridges

Work task is focused mainly on development of new types of (ultra-)high performance concrete ((U)HPC) mixes. Main activities and conclusions:

- Cohesion between HPC and prestressing tendons was experimentally verified. Substantial shortening of anchorage lengths thanks to high compressive strength of the material will allow the use of smaller structural details.
- A new type of connection of precast concrete members with the use of UHPC was designed. The connection is characterized by minimized dimensions and simple detailing of reinforcement. Technical solution will be used by Metrostav company, which expects the savings between 70 and 100 thousand € for a smaller bridge.
- Technology for precast HPC members developed in laboratories of Czech Technical University in Prague was transferred to production plant of SMP CZ company. Technology can be utilized for bridge segments, tunnel lining segments or permanent formwork members. SMP CZ plans to produce at least 3000 m² per year of HPC permanent formwork.
- Composition of UHPC made of local and recycled materials that prevents settling of fibres to the bottom of concrete element was patented in the Czech Republic, patent applications were submitted in Germany and Slovakia.
- UHPC was successfully applied in footbridge in Čelákovice under supervision of CESTI participants (Czech Technical University, Pontex and Metrostav).

A new type of steel-timber composite panels was also developed. This resistant, but at the same time lightweight structure will find its place mainly in temporary bridges in remote regions. Savings in the order of tens of thousands of € per one bridge compared to traditional heavy-weight structures can be estimated.

3.3 Preparation of guidelines for assessment of existing bridges

Work task is a follow-up of the Methodology for diagnostics of existing bridges. Guidelines for complex assessment of existing bridges are being prepared. Experiments were conducted to support the theory by real data. Main activities and conclusions:

- A number of specimens from existing structures were taken for laboratory examination of influence of corrosion on parameters of the material. Steel, concrete and reinforcement samples were studied, in some cases significant influence of corrosion was identified.
- A method for verification of composite action of separated parts of a vaulted bridge was developed together with special measuring device for this technology – so called “centring amplifier”.

Proper diagnostics can save large amounts of money. For example, using the method for vaulted bridges, it can be proved that the structure which visually appears to be largely disturbed by cracks is in fact still in quite good condition. As a result, the scope of reconstruction can be smaller and the cost savings can reach hundreds of thousands of €.

3.4 Long-term monitoring of bridges

Long-term monitoring is performed on several major bridges (elevated railway across Masaryk railway station in Prague, Oparno bridge, steel-concrete composite bridge on K Barrandovu street in Prague, bridge in Trenčín in Slovakia). This work task does not produce any direct economic benefits, but the results give plenty of priceless information for elimination of mistakes in design of new bridges. The results will be also exploited in previous work task.

3.5 Validation of materials for repair and reconstruction of bridges

Work task is closely related to the one discussed previously in section 3.23.2. Technical solutions suitable for repairs of bridges are investigated. Main activities and conclusions:

- Progressive technology of permanent formwork filigree panels for composite steel-concrete bridges was developed and tested on two bridges in Ústí nad Orlicí built by CESTI participant Eurovia in 2014. Significant time and financial saving were identified thanks to elimination of most of supporting structures. The developed panel was submitted for patenting in 2015.
- Permeable bridge deck panel made of fibre reinforced polymers (FRP) was patented in 2013. This lightweight and durable structure is ideal for temporary bridges.
- GFRP bridge deck panel from I-shaped trusses was developed. Road and Motorway Directorate of the Czech Republic (ŘSD ČR) ordered several trial panels in the beginning of 2015, the panels will be applied on real structure in the near future.

Both types of FRP panels are clear examples of the fact that life cycle costs should be taken into account instead of primary costs of technical solution. The price of 1 m² of GFRP

bridge deck panel is circa 500 €/m² compared to approximately 170 €/m² for traditional timber bridge deck panels. However, most timber decks have to be completely changed after 5 years of use, while the estimated service life of GFRP decks is at least 20 years. If the GFRP panels were used for 50 % of temporary bridges operated by Road and Motorway Directorate of the Czech Republic (ŘSD ČR), the savings would reach more than 1 milion € in 20 years.



Fig. 5 FRP permeable bridge deck panel applied on temporary bridge (left). Permanent formwork filigree panels prepared for concreting on one of the bridges in Ústí nad Orlicí (right).

3.6 Preparation and construction of UHPC trial structure

Work task is focused on preparation of large-scale structure made from ultra-high performance concrete. Main activities and conclusions:

- Four pieces of prestressed UHPC girders were produced. Two of them were subjected to load-bearing capacity tests, remaining two specimens were permanently loaded for monitoring of creep and shrinkage effects. The results reached so far are encouraging, application in real structure is planned for 2015.
- Technology for concreting of UHPC bridge segments was verified during construction of footbridge in Čelákovice. The footbridge was opened for public in 2014.

Even though the unit cost of UHPC is at least three times more than for normal strength concrete, leading construction companies (Skanska, Metrostav, Pontex) are interested in this material because of its high durability and increased mechanical parameters that enable construction of more subtle structures. Thanks to reduced self-weight of the bridge, money can be saved also on foundation structure and transport of material.

3.7 Development of approaches for maintenance and repair of common defects of small bridges

Work task is aimed at preparation of guidelines for maintenance and repair of small bridges. Main activities and conclusions:

- Overview of typical claimed defects of new bridges was prepared based on databases of two major construction companies from the last 10 years. 233 claims were analysed and classified in several categories.
- Outline of the guidelines was prepared.

- Technology for cheap and fast reconstruction of small-span bridges is under development. The idea is to come up with a solution which will eliminate formworking and finishing. Results of calculations are promising, experimental verification is planned in 2015. Application for reconstruction of a bridge in Sázava city is being discussed.

There are several tens of thousands of small bridges in the Czech Republic, therefore unification of approaches to their maintenance has a potential of saving millions € per year.

3.8 Issues of numerical modeling of complex structures

Work task deals with the use of FEM methods for modeling of bridges or bridge equipment. Main activities and conclusions:

- Numerical model of bridge crash barrier is being developed. The model will allow to reduce the number of required crash tests. Cost of one crash test is 40 thousand € or more.
- Simple but efficient method for calculation of effects of rheology and change of static scheme on deflections of concrete bridges was developed. The method combines traditional longhand calculation methods with commercially available FEM programs. Effects such as shear lag, distortion or warping are taken into account.

3.9 Development of structural details for reliable and durable bridges

Work task is dedicated to design of efficient details for modern bridges. Main activities and conclusions:

- Experimental device for investigation of various types of transfer areas of integrated bridges is under construction. Launching is planned by the end of 2015. Transfer areas are common source of problems in integrated bridges that can result in expensive reconstruction.
- A new type of anchorage for composite steel-concrete structures made from reinforcement bars was developed, tested and prepared for practical application.
- New optimized shape of culvert face was designed for minimization of consequences of impact on passengers of a vehicle. The invention should be patented by the end of 2015.

The last result clearly shows that in many cases, even though a new solution brings indisputable benefits, economic savings can not be simply evaluated.

3.10 Development of advanced technologies for construction of bridges

Work task deals with development of new technologies for construction of bridges. Main activities and conclusions:

- New technology for construction of segment bridges with long-span cantilevers supported by precast struts was proposed. Economical evaluation is in process.

- Fibre-reinforced concrete permanent formwork panels were proposed and tested. The results have shown that the panels could be used for spans up to 3 m without any temporary supports. Hybrid reinforcement is used, therefore cover depth is not an issue. Thanks to dispersed reinforcement, cracking of cover layer is eliminated and durability of the structure is significantly increased.

3.11 Preparation of guidelines for railway tracks on bridges

Work task is focused on evaluation of various technical solutions for railway track on bridges. The research should result in technical guidelines. Main activities and conclusions:

- Experiments aimed at derivation of dependence between longitudinal resistance of continuous welded rail and relative deflection of bridge structure were started for various types of railway superstructure (rail bed, directly fastened rail, continuously fastened rail).
- Based on measurements on railway bridge in Děčín, functions describing behavior of rail bed in structure with continuous welded rail were obtained. The results were applied in design of railway bridge in Hodějovice.
- A testing device for analysis of bridge-track interaction for direct fastening of continuous welded rail on railway bridges was developed.

If current simplified design methods are used, application of continuous welded rail with direct fastening is impossible on many bridges. Results obtained from the proposed testing device will enable the use on increased number of bridges. The main advantage of discussed technical solution, besides reduced construction depth, is elimination of rail expansion devices. Cost of one rail expansion device is approximately 100 000 €. It can be assumed that after finishing the guidelines for design, continuous welded rail with direct fastening will be used on 10 bridges every year, resulting in 1 million € savings for the budget of The Railway Infrastructure Administration of the Czech Republic.

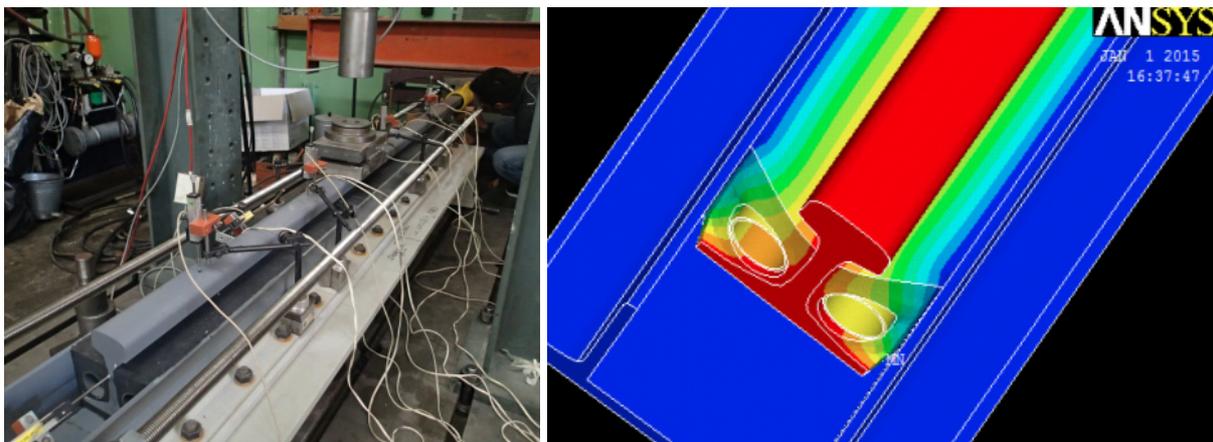


Fig. 6 Testing device for analysis of bridge-track interaction for direct fastening of continuous welded rail (left) and numerical model (right).

4. WP4: Tunnels – Advanced Technologies and Smart Solutions

4.1 Preparation of guidelines for risk management in tunnel construction design

Work task is focused on the area of risks in both mined and cut and cover tunnels. Main activities and conclusions:

- Analysis of tunneling methods, their advantages, disadvantages and risks was conducted.
- Analysis of accidents during construction of both Czech and European tunnels was carried out. Data about approximately 20 representative events were put together and evaluated.
- Methodology for evaluation of risks in tunnel design and construction was created. The document can be used for quantitative assessment of risks prior to the beginning of the construction and minimization of risks.
- Analysis of the effects of geomonitoring and geotechnical survey on risks in tunnel construction was conducted separately as these activities play a key role in preparation of all types of tunnels.

All the works are aimed at preparation of unified technical guidelines for minimization of risks in tunnel construction. Each accident in tunnel has large consequences – delay in the working schedule, lots of additional works and in the worst case, damage to health or even life of construction workers. Proper risk management can save millions of € per each prevented accident.

4.2 Development and in-situ verification of fiber-reinforced concrete for tunnel lining

Work task is focused on preparation, laboratory testing and in-situ verification of fibre-reinforced concrete (FRC) for tunnel linings. Main activities and conclusions:

- Based on extensive experimental program, most suitable composition of steel fibre-reinforced concrete for tunnel linings was selected. Several dozen specimens (standard cubes and beams) were tested in the phase of material optimization.
- Special software for verification of homogeneous distribution of steel fibres in the material was programmed. This utility can be used for quick and unbiased evaluation of quality of the material and suitability of mixing process. Several companies outside the centre claimed their interest in the program, negotiations are in process (SUDOP, Metroprojekt, Satra).
- Large-scale loading tests of tunnel lining segments were conducted to verify the characteristics of the material in real-scale members.
- Loading tests of connecting pins in biaxial bending and shear were conducted to verify the reliability of anchorage between the segments.
- A new testing method for determination of effect of fibres on deformation characteristics of FRC subjected to long-term flexural loading was patented. The method can be utilized for prediction of creep and shrinkage effects on FRC structures.

- Demanding large-scale experiment focused on detailed investigation of shear behavior of FRC was prepared. The experiment will provide unique set of data for numerical modeling of FRC. Execution is planned in the middle of 2015.
- The results of all the tests are encouraging, application of fibre-reinforced tunnel lining in Ejpovice tunnel is planned in 2015. This is going to be the first application of FRC lining in the whole tunnel in the Czech Republic.

The use of FRC in tunnel linings is very desirable, mainly because of the capability of this material to prevent crack propagation and therefore water leakage. Service life of such a tunnel will be significantly prolonged.

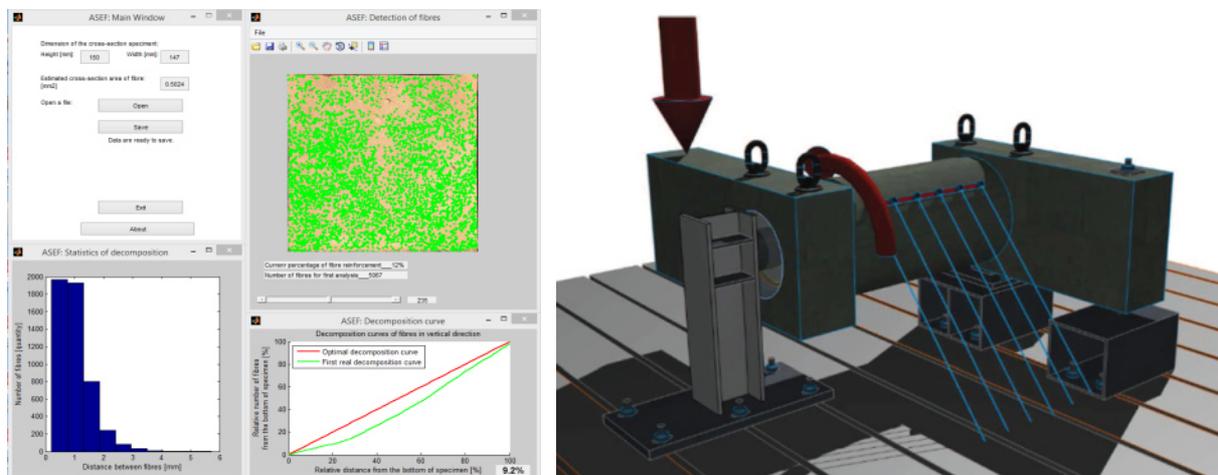


Fig. 7 Software for evaluation of distribution of steel fibres in the specimen (left). Scheme of unique experiment focused on shear behavior of FRC (right).

4.3 Development of water-tight tunnel lining

Work task is dedicated to defining of suitable concrete mix compositions, technical conditions and technology methods for water-tight linings. Main activities and conclusions:

- Experiments focused on the effect of cement type on the development of hydration temperatures of concrete were conducted. Too high hydration temperatures can lead to occurrence of cracks which are fatal for leaktightness of the material.
- Experiments aimed at the behavior of various types of concretes for tunnel linings during fire accidents were prepared and will be performed in 2015. Environmentally friendly concretes with fly-ash and reduced cement contents will be included in the experiments.
- Sealing of joints is usually the biggest problem for watertightness of tunnel linings. Unique experiment for verification of performance of various types of sealings (metal sheets with crystallization materials, asphalt sealings, joints without sealing) exposed to water under pressure have been started and will be continued in 2015. Concrete water tank with the sealing in the bottom of the wall is pressurized to the pressure ranging between 0,1 – 3 MPa, the behavior of the sealing in the course of certain period of time is observed.

The final material – technical guidelines for water-tight tunnel linings – should be prepared in the beginning of 2017. The influence of torrential rainfall on tunnel can be best described on the example of Blanka tunnel in Prague. Direct losses on technological equipment of the tunnel can be estimated in tens of millions of €, the loss caused by estimated one year delay of opening of the tunnel is hardly computable.



Fig. 8 Load-bearing test of FRC tunnel lining segment (left). One of the water tanks for experimental verification of performance of various types of sealings – prior concreting (right).

4.4 Development of coupling of the primary and secondary lining

Work task seeks answers to questions of composite action of primary and secondary tunnel lining, mainly in the area of prediction of material parameters and numerical modeling. Main activities and conclusions:

- A review focused on degradation of concrete in tunnel linings exposed to aggressive environment was created.
- Research aimed at investigation of effects of chlorides, sulphates and low-pH waters on mechanical properties of concrete of primary lining was started; to verify the conclusions, reference samples from old structures such as Desná dam (100 years old) or Brno collectors will be taken in 2015.
- Mathematical modelling of contacts between primary and secondary tunnel lining as well as between primary lining and earth was started.

If primary lining is considered as a part of permanent load-bearing structure, secondary lining can be substantially more slender, resulting in large financial savings thanks to smaller volumes of concrete, shorter time of concreting and increased durability.

5. WP5: Environment Protection and Green Transport Infrastructure

5.1 Tools and technical solutions for reducing traffic noise and vibrations

Work task is focused on evaluation of efficiency of various noise reducing technical measures and preparation of methodology for noise and vibrations measurements and analysis. Main activities and conclusions:

- Comparative measurements of Czech and French noise measuring devices according to CPX method were carried out, the reason was to draw comparison between the results obtained by the two instruments.
- Set of measurements focused on noise-reducing asphalt pavements was conducted. Time development of properties as well as efficiency of regular cleaning of pavements were observed.
- Evaluation of efficiency of low noise barriers along railway tracks was performed on one of the two trial tracks existing in the Czech Republic. Decrease in noise intensity level of 6,5 dB(A) was identified.
- Measurements of noise in vicinity of a steel bridge that is about to be reconstructed in 2015 were conducted; the objective is to compare acoustic properties of old and new type of structure.
- First part of methodology for measurements, analysis and evaluation of durability of noise reducing measures was prepared.

Traffic noise has wide socio-economic impacts. It negatively influences psychology of an individual, decreasing his productivity in work as well as quality of his personal life.

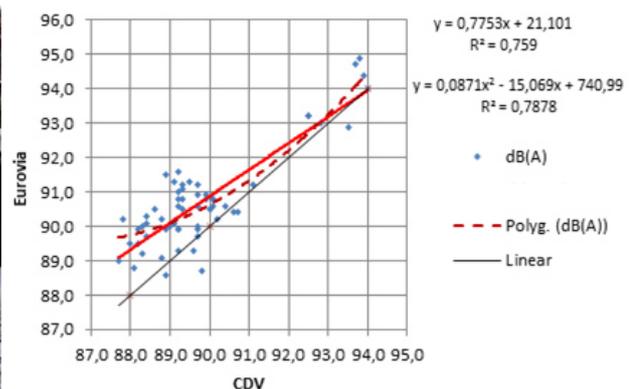


Fig. 9 Low noise barriers (left). Comparison of road noise measurements carried out by French (Eurovia) and Czech (CDV) devices (right).

5.2 Air pollution and water pollution – measuring methods

Work task deals with long-term monitoring of air pollution caused by traffic in dwelling areas or by construction of roads, contamination of the environment by chemical agents used for maintenance of roads in winter or quality of water drainage systems in tunnels. Main activities and conclusions:

- Vast monitoring program focused on contamination of soils and ground waters by transport was started. 18 model locations were selected, more than 100 samples were taken so far. The analysis will be mainly focused on heavy metals and persistent organic agents and their effects to sensitive ecosystems. Methodology for objective taking of the samples was worked out.
- Measurements of concentrations of detrimental agents in the air in dwelling areas were performed in different seasons. The results indicate that other factors (mainly combustion processes connected with heating of buildings) are in many cases more important than transport.
- Samples of the air were taken during construction of asphalt pavements in Blanka tunnel in Prague and evaluated with respect to the effects to health of the workers. The main problem identified was ambiguity and incompleteness of existing directives – limits are missing for some types of agents, for others different limits are specified in different directives.
- Monitoring of water drainage systems in tunnels (e.g. Panonská tunel in Bratislava) was started. Based on the results, methodology for monitoring and maintenance of these systems will be created.

The results will be useful for identification of environmentally friendly approaches to construction and maintenance of transport infrastructure. Safety of the workers is another important issue that is often overlooked, although the consequences of damage of health are hardly quantifiable.

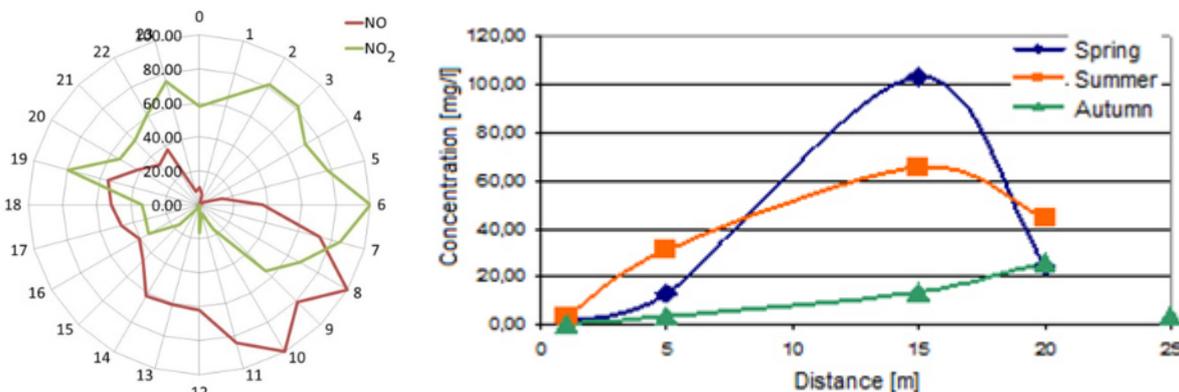


Fig. 10 Concentrations of nitrogen oxides in % during selected day in Okříšky village (left). Chloride concentrations in soil based on the distance from the road in the depth of 5 cm (right).

5.3 Tools and methods for modeling impact of transport and transportation structures on the environment

Work task aims at life cycle cost analysis of environmental impacts of traffic infrastructure. Main activities and conclusions:

- Development of carbon footprint calculator for roads.
- Implementation of life cycle assessment of product flows of the main construction materials (concretes, asphalt mixes, aggregates).

- Development of complex tools for life cycle assessment of environmental impacts of traffic infrastructure.

Outputs of this work task will be applicable for quantification of economic consequences of various technical solutions on the quality of the environment.

5.4 Locally accessible materials, construction waste, by-products of industrial and energy production in transportation engineering

Work task is focused on the assessment of impacts of the use of recycled materials in transport infrastructure on the environment. Main activities and conclusions:

- Field tests of leaching of toxic agents from the asphalt pavement waste material stored for further use were conducted. In the first campaign, no detrimental effects on living organisms were identified.
- A question of abrasion of roads made of different materials is investigated. The aim is to determine the contribution of abrasion to the total concentrations of particulate matter (PM) for different types of road surfaces.
- Database of available construction waste materials and industrial by-products used for construction of transport infrastructure was created. The database contains description of individual materials and list of possible applications.

Maximum possible use of industrial by-products is highly desirable. However, it mustn't be balanced by environmental damage due to the release of harmful substances from recycled materials.

6. WP6: Safety, Security and Diagnostics of Structures

6.1 New and progressive diagnostic methods

Work task is focused on investigation and implementation of new and progressive methods and providing guidelines for their effective exploitation. Main activities and conclusions:

- Database of almost 20 non-destructive diagnostic methods was prepared. The document contains description of the methods, instructions for their application and evaluation of results. Practical examples were given for all the methods, traffic speed deflectograph (TSD), termography, fotogrammetry, radar interferometry, georadar and laser scanning methods were selected for further detailed examination.
- Device for automatic movement of antennas during measurement carried out with dual-channel ground penetrating radar was developed and will be patented in 2015.
- Comparative measurements of Czech falling weight deflectometer (FWD) and Italian TSD device used for evaluation of load-bearing capacity of roads were performed.
- New model of TRT device for measuring of skid resistance of pavement surfaces was developed and constructed. The vehicle will be subcontracted by road construction companies and road administrators.

Diagnostic methods can bring significant financial savings in many areas. Mainly, they are irreplaceable in the process of decision making during planning of maintenance and reconstructions of existing structures. Data gained by diagnostics provide background for selection of the most appropriate and economical way of reconstruction based on the extent and severity of the damage revealed. Non-destructive methods can be used by government authorities in lawsuits regarding quality of construction works, thus helping them to save large amounts of public money.



Fig. 11 Termography of the head wall showing problematic areas with disturbed water-proofing (left). Device for automatic movement of antennas during measurement carried out with dual-channel ground penetrating radar (right).

6.2 Weigh-in-motion (WIM)

Work task is dedicated to research and implementation of weigh-in-motion (WIM) systems. Main activities and conclusions:

- Database of available WIM sensors and systems was created, containing description of the sensors, overview of related domestic and foreign legislative, analysis of possibilities of implementation of WIM systems in the Czech Republic, analysis of estimated impacts of implementation and analysis of results after implementation of WIM in other countries.
- Methodology for design and operation of WIM systems was worked out, containing requirements on technical parameters of WIM station and documentation of measurements results. Instructions for practical execution of control will be finished after approval of related legislation by the Parliament (expected in 2015).
- Special workshop on WIM for government officials, police and users of WIM systems was organized in 2014.
- Controlling measurements on trial WIM stations were performed with the participation of the police and Ministry of Transport.
- Technical description of model WIM station was prepared, including among others information about configuration of sensors, execution and evaluation of measurements.

Overloaded vehicles are a source of damage and decrease in service life of the roads, they jeopardize road safety. All these facts lead to unnecessary spending of public finances. According to experience from many countries (Switzerland, Netherlands, Australia, Singapur or Malaysia), WIM systems are very effective tools for both prevention and repression. Their performance is incomparably higher in comparison with traditional random controls.



Fig. 12 WIM station (left). WIM sensor (insert in the left figure). New TRT vehicle (right).

6.3 Comprehensive systems for continual monitoring of transport infrastructure objects

Work task is aimed at preparation and implementation of systems for continual monitoring of transport infrastructure, for example monitoring of traffic intensity, temperature of roads or structural behavior of selected objects. Main activities and conclusions:

- Database of existing types of sensors for continual monitoring was created, methodology for design and operation of continual monitoring systems will be finished in 2015.
- Trial structures for assessment of functionality and durability of various types of sensors (temperature sensors, tensometers) were constructed in precincts of CDV and Firesta Fišer company (external partner) and also in D1 motorway resting place near Kroměříž. Influences of ambient temperature, relative humidity or stiffness of the road on measured values is studied.
- Trial application of sensors in structure exposed to real traffic is planned in 2015 (most probable in one of the modernized parts of D1 motorway).
- Workshop on continual monitoring systems was organized in 2014.

Continual monitoring systems are crucial part of modern intelligent transport infrastructure. They provide the information about current state of TI to the administrators; by proper maintenance, risks of traffic accidents or congestions are minimized. According to the analysis made by Transport Research Centre (CDV) in 2012¹, average total costs of 1 accident without an injury are circa 10 000 €, with minor injury the amount is 24 000 €, for serious injury the costs are increased to 140 000 € and in case of death of a person, the amount reaches 630 000 €.

6.4 Fire accidents in tunnels – verification and design of escape scenarios

Work task is dedicated to definition of required parameters, preparation of numerical models, design and verification of escape scenarios for fire accidents in tunnels. Main activities and conclusions:

- Literature review containing models for simulation of fire propagation and spreading of toxic gases, overview of technologies for fire protection and tunnel ventilation and principles of fire experiments was prepared.
- Requirements on input parameters for numerical models were specified.
- First numerical models were prepared for selected types of tunnels and fire scenarios. FDS software based on computational fluid dynamics (CFD) method was applied. The models are very demanding, calculation of one model takes several weeks even with the latest computer equipment.
- Experiment simulating evacuation of people from 250 m long railway tunnel was performed in building EXODUS software. The results have shown that well-timed

¹ <http://www.czrso.cz/clanky/skody-pri-dopravnich-nehodach-na-silnicich-cr-dosahuji-1-5-hrubeho-domaciho-produktu/>

information and well-developed evacuation plan are crucial for successful evacuation.

Fire accidents in tunnels are extremely dangerous, losses caused by each such accident can be huge. By understanding possible ways of development of the fire, we can optimize the fire protection measures, design clear and efficient escape scenarios and minimize the damage.

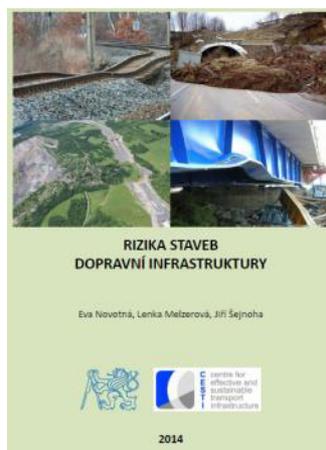
7. WP7: Systems of Management, Durability Assessment and Life Cycle Cost Analysis in Transport Infrastructure

7.1 Analysis of state-of-the-art of management systems

Work task is focused on analysis of current management systems and legislative requirements as well as issues of risk management. Main activities and conclusions:

- Current legislation related to public procurement and operation of transport infrastructure in the Czech Republic was analyzed, including directives, laws, standards, documents of Ministry of Transport of the Czech Republic, The Railway Infrastructure Administration (SŽDC) and Road and Motorway Directorate of the Czech Republic (ŘSD ČR).
- European Parliament and European Commission directives related to public procurement (2004/18/ES, 2005/51/ES and others) were analyzed.
- A monography containing case studies of risk management of particular construction projects and describing possible approaches to risk management was published
- Database of risks of transport infrastructure constructions was compiled. The database contains a list of hazardous factors in all phases of construction, operation and maintenance of structures. The risks are divided in 5 basic categories (constructional and technological risks, strategic risks, credit and market risks, external risks, operational risks), each category is further divided in several subcategories.
- The database is worked out separately for roads, railways, tunnels and bridges. For example, 131 possible risks are defined for tunnels in the category of constructional and technological risks. The evaluation of risks is based on risk priority number (RPN) approach. The database was published and attracted attention of many construction companies, investors and public authorities (e.g. Skanska, Hochtief, Erste Group, Ernst&Young, Association for Development of Infrastructure (ARI), Ministry of Transport etc.).
- Software tool PREV was updated for evaluation of risks defined in Database of risks.

Legislative issues belong to the most important obstacles in the whole process of preparation, construction and operation of transport infrastructure. Even if appropriate technical solutions are available, their implementation is often limited by inflexible legislation. Therefore, sufficient knowledge about the legislation is crucial for effective management of the infrastructure as well as elaborated risk management system that allows to identify all possible risks soon enough to prevent them and to eliminate subsequent economical losses. Savings yielded by proper risk management, for example with the help of developed Database, can be estimated in average as 5 – 10 % of total costs of a structure.



KATALOG NEBEZPEČÍ - Silniční stavby		Sv - závažnost (severity) stupnice 1, 2, 3, 4, 5		Lk - věrohodnost (likelihood) stupnice 1, 2, 3, 4, 5		Dt - zjistitelnost (detection) stupnice 1, 2, 3, 4, 5		RPN = Sv x Lk x Dt Risk Priority Number	
A Stavebně-technologická a projekční rizika									
A1 - Stavební a projekční rizika									
A1.1 - Projektová dokumentace - nesplnění očekávání kladených na projektovou dokumentaci									
zdroj nebezpečí = antropogenní/přírodní									
Typ rizika/nebezpečí	zdroj neb.	Následky výskytu nebezpečí	Sv	Lk	Dt	Opatření	Datum		
01 Rizika projektu nejsou jasně rozdělena, není jasné, na koho jsou přenesena									
02 Návrh nemá potřebnou kvalitu									
03 Návrh není podložen relevantními informacemi									
04 Návrh není standardní (má prvky originality)									
05 Konstrukce je citlivá na základové podmínky									
06 Požadavky na sednutí, popř. deformace stavby i okolí nejsou jasně specifikovány									
07 Součinitele bezpečnosti (obvyklé, mimořádné)									
08 Návrh je obtížně realizovatelný									
09 Nedostatečná diagnostika (u oprav a rekonstrukcí)									
10 Nepřiznivé geotechnické podmínky									
11 Odhad rizika stavby není znám									
12 Nejsou definovaná všechna užitná zatížení									

Fig. 13 Database of risks – cover (left), example of a part of database for roads (right, in Czech).

7.2 Models and tools for management systems

Work task is focused on increasing efficiency of planning and construction of transport infrastructure objects (mainly the ones financed by public contractors) by preparation of tools, guidelines and standards. Main activities and conclusions:

- Cost analysis of important objects of transport infrastructure was performed, points critical for increase of costs were identified.
- Operational manual for management of preparation and construction of transport infrastructure by public authorities was prepared. The material deals mainly with issues of financing of infrastructure, claims, project control, crisis communication and implementation of modern planning approaches such as building information modeling (BIM).
- Operational manual for selection of suitable materials and structural solutions was created. The material contains guidelines for definition and assessment of evaluation criteria.
- Methodology for selection of the type of noise barriers used in road structures was prepared and certified by Road and Motorway Directorate of the Czech Republic (ŘSD ČR).
- Software tool MOST for rough calculation of costs of a bridge structure was created. The tool can be used for preliminary assessment of offers in public procurement.
- A series of meetings regarding exploitation of BIM methods in transport infrastructure planning was organized. Construction projects suitable for trial applications were identified, tutorials for designers, engineers and workers were organized. Pilot projects are expected in 2015. Efficiency of the use of BIM processes compared to traditional methods of planning will be evaluated based on the experience gained in these projects.

All the materials should help mainly government officers in the phase of planning of transport infrastructure. BIM is already successfully being applied in the area of building structures, CESTI is trying to objectively assess possibilities, benefits and drawbacks of BIM

in transport infrastructure. In general, BIM should be understood not just as 3D modelling tool, but mainly as an instrument for LCC assessment, long-term storage and administration of data about the structure and efficient facility management.

7.3 Verification and validation of models and tools for management systems

Work task is dedicated to preparation, verification and validation of tools for management systems, with the aim on the instruments focused on technical aspects of decision making process. Main activities and conclusions:

- Database of diffusion coefficients of aluminosilicate building materials, hydration model, deterministic and probabilistic 1D model for prediction of carbonation and chloride ingress in cracked concrete structures were prepared and implemented in CarboChlorCon software.
- Hydration model was used by Skanska company for optimization of production process of new type of prestressed railway sleepers. Thickness of thermal insulation of moulds required for acceleration of production in winter period was calculated.
- CarboChlorCon was used by Pontex and Eurovia companies for performance-based design of columns of motorway portals. Various material alternatives were compared and evaluated.
- 2D/3D model for simulation of interaction between tunnel excavation and overhead structures was prepared. Markov Chain Monte Carlo method together with Bayesian updating of parameters was used. The model will allow to estimate deflections of surface structures due to underground construction activities and to plan measures required for prevention of damage of surface structures.

CarboChlorCon software enables to predict corrosion of reinforcement more precisely than the most of current methods, which usually simplify the composition of concrete and don't consider the effect of cracks. Nevertheless, these effects are crucial for determining the service life of the structure. By more precise design of concrete cover layer, estimated 25 % of LCC of reinforced concrete structure can be saved.

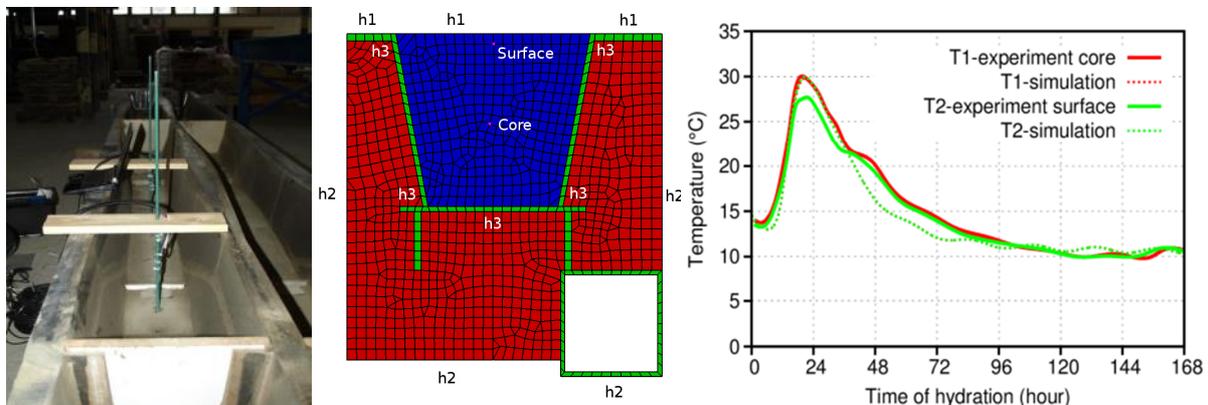


Fig. 14 Application of developed hydration model. Mould of railway sleeper (left), FEM model of railway sleeper in the mould (center), comparison of the model and experimental data (right).