CETRA^{2014}

3rd International Conference on Road and Rail Infrastructure
28–30 April 2014, Split, Croatia

Road and Rail Infrastructure III

Stjepan Lakušić – EDITOR

Organizer
University of Zagreb
Faculty of Civil Engineering
Department of Transportation

CETRA^{2014}
3rd International Conference on Road and Rail Infrastructure
28–30 April 2014, Split, Croatia

TITLE
Road and Rail Infrastructure III, Proceedings of the Conference CETRA 2014

EDITED BY
Stjepan Lakušić

ISSN
1848-9850

PUBLISHED BY
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Kačićeva 26, 10000 Zagreb, Croatia

DESIGN, LAYOUT & COVER PAGE
minimum d.o.o.
Marko Uremović · Matej Korlaet

PRINTED IN ZAGREB, CROATIA BY
“Tiskara Zelina”, April 2014

COPIES
400

Zagreb, April 2014.

Proceedings of the
3rd International Conference on Road and Rail Infrastructures – CETRA 2014
28–30 April 2014, Split, Croatia

Road and Rail Infrastructure III

EDITOR
Stjepan Lakušić
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Zagreb, Croatia

CETRA^{2014}
3rd International Conference on Road and Rail Infrastructure
28–30 April 2014, Split, Croatia

ORGANISATION

CHAIRMEN

Prof. **Stjepan Lakušić**, University of Zagreb, Faculty of Civil Engineering
Prof. **Željko Korlaet**, University of Zagreb, Faculty of Civil Engineering

ORGANIZING COMMITTEE

Prof. **Stjepan Lakušić**
Prof. **Željko Korlaet**
Prof. **Vesna Dragčević**
Prof. **Tatjana Rukavina**
Assist. Prof. **Ivica Stančerić**
dr. **Maja Ahac**
Ivo Haladin
dr. **Saša Ahac**
Josipa Domitrović
Tamara Džambas

All members of CETRA 2014 Conference Organizing Committee are professors and assistants of the Department of Transportation, Faculty of Civil Engineering at University of Zagreb.

INTERNATIONAL ACADEMIC SCIENTIFIC COMMITTEE

Prof. **Vesna Dragčević**, University of Zagreb
Prof. **Isfendiyar Egeli**, Izmir Institute of Technology
Prof. **Rudolf Eger**, RheinMain University
Prof. **Ešref Gačanin**, Univeristy of Sarajevo
Prof. **Nenad Gucunski**, Rutgers University
Prof. **Libor Izvolt**, University of Zilina
Prof. **Lajos Kisgyörgy**, Budapest University of Technology and Economics
Prof. **Željko Korlaet**, University of Zagreb
Prof. **Zoran Krakutovski**, University of Skopje
Prof. **Stjepan Lakušić**, University of Zagreb
Prof. **Dirk Lauwers**, Ghent University
Prof. **Zili Li**, Delft University of Technology
Prof. **Janusz Madejski**, Silesian University of Technology
Prof. **Goran Mladenović**, University of Belgrade
Prof. **Otto Plašek**, Brno University of Technology
Prof. **Vassilios A. Profillidis**, Democritus University of Thrace
Prof. **Carmen Racanel**, Technical University of Civil Engineering Bucharest
Prof. **Tatjana Rukavina**, University of Zagreb
Prof. **Andreas Schoebel**, Vienna University of Technology
Prof. **Mirjana Tomičić-Torlaković**, University of Belgrade
Prof. **Audrius Vaitkus**, Vilnius Gediminas Technical University
Prof. **Nencho Nenov**, University of Transport in Sofia
Prof. **Marijan Žura**, University of Ljubljana

CETRA^{2014} 28–30 April 2014, Split, Croatia
3rd International Conference on Road and Rail Infrastructure

BRIDGE EVALUATION METHOD USING METROLOGICAL METHODS IN SHORT AND LONG-TERM MEASUREMENTS

Gert Gommola[1], **Peter Krempels**[2]
1 Hottinger Baldwin Messtechnik GmbH, Darmstadt, Germany
2 DB route measurement – I.NPI 31(F) DB Netz AG

Abstract

Bridges are an essential component of the train and vehicle traffic network. Increasing traffic loads, the demand for faster transit speeds and the possible influences of weather effects drive the need to evaluate existing bridges that in some cases have been in use for decades. The existing construction documentation is not always sufficient to obtain reliable statements about e.g. the remaining useful life or changing utilization conditions. Suitable metrological methods combined with calculation models allow these tasks to be resolved.

Keywords: bridges evaluation, metrological methods, short–term measurements, long–term monitoring

1 Introduction

The Deutsche Bahn (DB) alone is responsible for approx. 28,000 railway bridges with diverse structural designs. Bridges age and fatigue differently depending on their construction. Even identically designed bridges evidence different behaviors as e.g. climatic conditions on site may vary. Deutsche Bahn generates calculation reviews at various levels, in compliance with Guideline 805 [1]. This frequently means a measured-value supported calculation review in the case of complex bridge structures [2]. The measured values, with which the calculation models are calibrated, are provided by short-term measurements with resulting loads from standard traffic or defined special loads. The real system behavior can be acquired easily by measurements on the object. Short-term measurements highlight weak points and safety deficits. Long-term measurements depict the behavior of the bridge under load collectives which include, e.g. in addition to traffic loads, wind forces, temperature fluctuations and other influences.

2 Short–term measurements for measuring system behavior on bridges

Static or dynamic short-term measurements as per Module 805.0104 (DB) are classified as follows:

- System measurements under defined operating loads for steel railway bridges;
- Experimental load-bearing evaluation (concrete constructions with high non-linear load-bearing behavior);
- Special measurements to clarify the behavior of e.g. moving bridges.

A bridge under investigation is experimentally evaluated with both general train traffic loads and traffic with some extent significantly higher loads. The necessity of increased loading is often justified by the aim of obtaining a measurable construction reaction (strains, curvature, shifts, inclinations, accelerations, etc.). The loads however are only located in the elastic deformation behavior of the construction and are specified by the bridge evaluator/structural engineer. He also defines the number and type of measurement points in the respective measurement cross-sections and the type of dynamic load by e.g. defined crossings of vehicles at different speeds. In this method, the number of measurement points can lie between double figure and several hundred applications. The duration of the measurement is frequently limited to just hours (closing sections; provision of load testing vehicles; special wagons). This defines the requirements for the measurement technology through the dynamic and simultaneous acquisition of measured values.

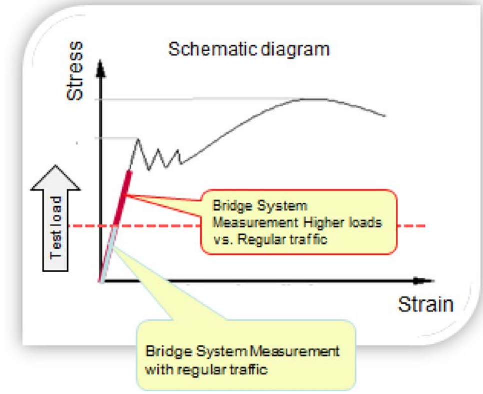


Figure 1 Schematic representation of the applied loads during a system measurement

3 Measuring the system behavior on the Fehmarnsund Bridge (Example Project)

3.1 Application and requirements

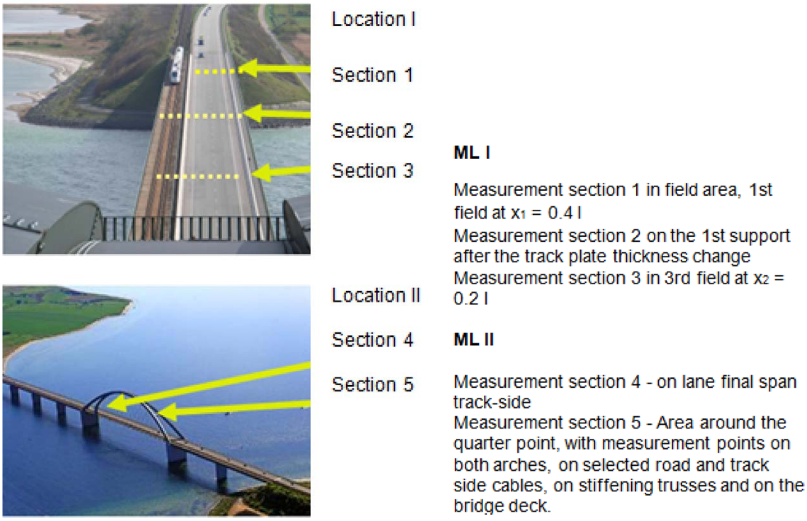
Arising from the discussion and the initial constructional proposals for the building of the Fehmarn Belt link (Fig. 2 – red arrow) from the Fehmarn Island (Germany) to Denmark, the Fehmarnsund Bridge (Fig. 3), which was built in 1963, was also subject to a new evaluation. This network arch bridge, located to the south of the planned Belt link (yellow arrow), will experience significantly greater use with a direct traffic connection, both in terms of traffic density and with regards to the forecast traffic load.

Figure 2 Geographical location

Figure 3 Network arch bridge (since 1962), Fehmarn Belt Bridge

The system behavior measurements between 11 and 14 June 2010 were intended to determine whether the structure could meet these requirements. The assessment of the resulting measurement results is not a part of this document. The basis of the assessment is the evaluation level 4 of the Guideline 805 and the evaluation guideline of the Federal Highway Research Institute. Numerous measurements with various loads were necessary on the road and on the rail tracks for calibrating the complex calculation models. The measurement program was agreed with the structural engineer group of the DB-Projektbau [3].

3.2 Measurement program



ML I

Measurement section 1 in field area, 1st field at x_1 = 0.4 l
Measurement section 2 on the 1st support after the track plate thickness change
Measurement section 3 in 3rd field at x_2 = 0.2 l

ML II

Measurement section 4 - on lane final span track-side
Measurement section 5 - Area around the quarter point, with measurement points on both arches, on selected road and track side cables, on stiffening trusses and on the bridge deck.

Figure 4 Measurement locations and corresponding measurement sections

It was agreed with the structural engineers that two measurement locations (ML I and ML II), with corresponding measurement sections, should be defined (Fig. 4). ML I comprises two field sections and a support section. ML II is located on the network arch bridge superstructure and has two measurement sections.

3.3 Type and installation of the transducers

Sensors were installed at 251 locations representative of the bridge statics to acquire diverse bridge construction deformation parameters under cyclical stresses. The specified measuring points were installed in the period from April to June 2010. The specific number of measuring points was based on the use of strain gauges (SGs) in an SG full-bridge circuit. The strain to be measured as reaction to the applied loads is acquired in a full-bridge branch (component expansion + temperature expansion, Fig. 5).

This quarter branch is connected with three passive SG to form the full bridge circuit. These passive SG do not experience any component expansion caused by applied loads like the SG in the quarter branch, but they acquire the resulting temperature expansions.

This circuit type significantly minimizes the acquisition of temperature-dependent strains so that only component strains in correlation to traversing events are acquired. The SG full bridge circuit type enables electrical connection to the downstream measurement electronics in a 6-wire circuit. Cable effects which could result in metrological errors, caused e.g. by temperature influences on long cables, are compensated for by the electronics here via two additional sense leads.

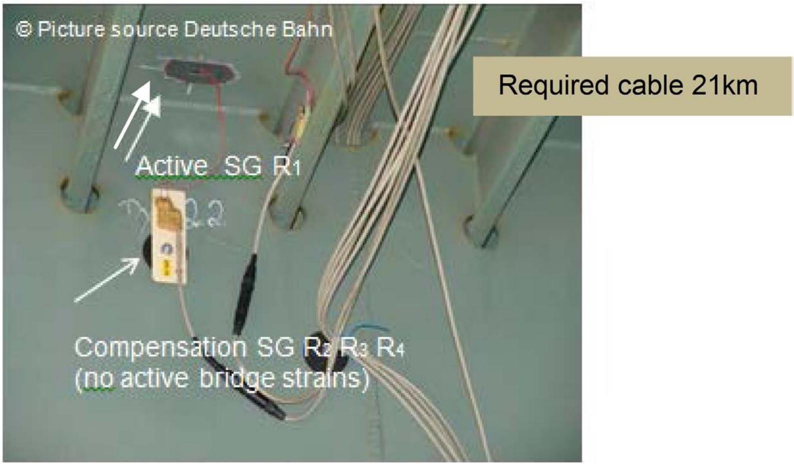


Figure 5 Strain gauge installation

3.4 Measurement data acquisition

Data acquisition systems were installed decentralized for measurement data acquisition, storage and transfer. Due to the dynamic acquisition of the measured values, the decentralized installed data acquisition systems (HBM QuantumX and MGCplus) and the main control room (Fig. 6) were connected with fibre-optic cables for NTP data synchronization and controlling the measurement system. The dimensions of the measurement layout itself and the complexity of the measurement task can also be indicated by noting that the use of fibre-optic cables replaced 60 km of electrical connection cables that would have otherwise been necessitated.

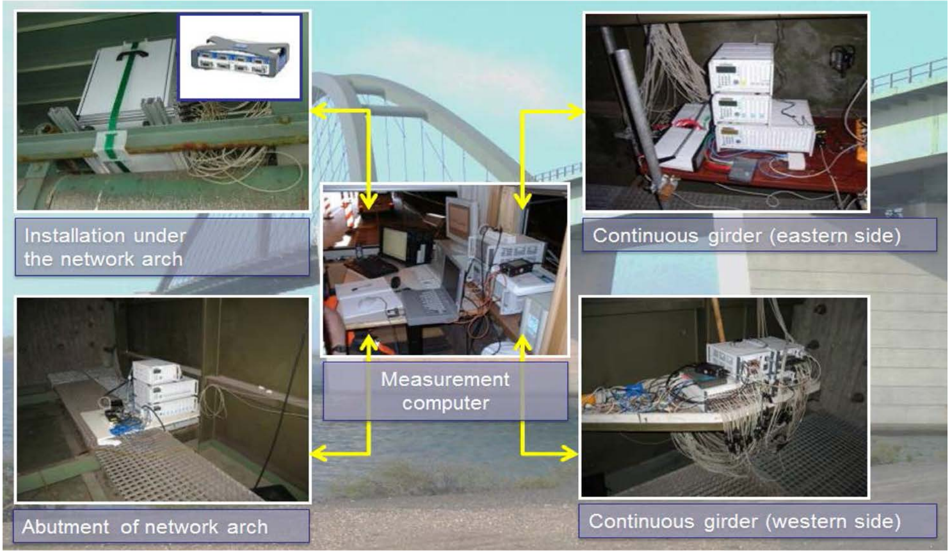


Figure 6 System architecture

3.5 Measurement implementation

Appropriate test loadings on the Fehmarnsund Bridge were implemented with locomotive units and additional heavy truck transports between 18:00 to 06:00 each night between 11.06. to 14.06.2010.

3.5.1 Quasi-static transits of heavy-load vehicles

Two heavy-load vehicles (Fig. 7) were used for transits in 4 different lanes (axis load 12t / 20t) at speeds v = 10 km/h and a vehicle distance of approx. 10 meters.

3.5.2 Locomotive train transits

The locomotive unit (Fig. 8) comprised a group of 2 x BR232 and 8 x BR155. The total mass was 123t with an average wheel set load of 22.5t for a BR 155 locomotive. The basic load position resulted in a vehicle mass of 6.276 t/m.


© Pictures Deutsch Bahn

Figure 7 Heavy transporter with 120t additional load

Figure 8 Load train comprising 10 locomotives

3.5.3 Combined transits

In this part of the measurement program, combined transits of locomotive units and heavy transporters on the routes were implemented with different travel directions and load patterns.

3.5.4 Dynamic measurements

Dynamic transits were implemented at maximum speeds for the locomotive units of approx. 120 km/h and approx. 80 km/h for the heavy transporters. The measurements were triggered by light barriers positioned at suitable points.

3.5.5 Measurement results (example)

Fig. 9 shows an example of the mechanical stresses acquired during parallel transits of locomotive units and heavy transporters during one of the implemented measurements.

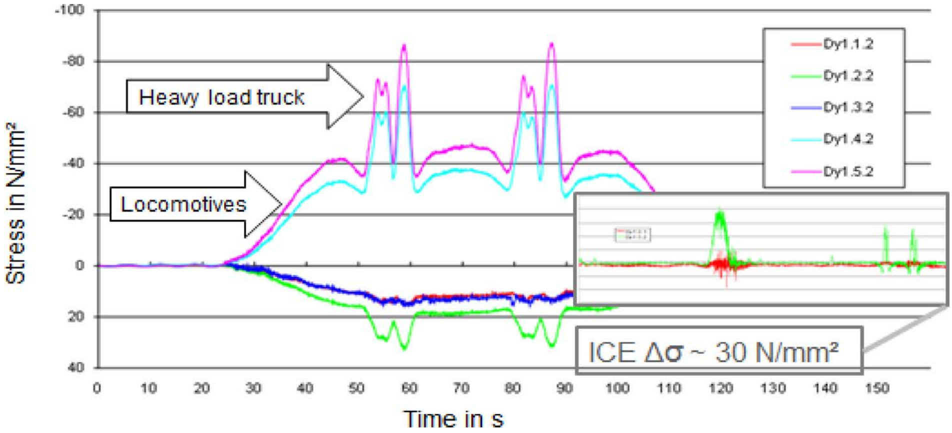


Figure 9 Stress ratios on five field continuous girder – Field center of first field transverse beam Section 2 (guide barrier) with parallel transit of locomotive unit and heavy transporter at measurement point 1 to scale copied comparison (ICE standard traffic)

4 Long–term monitoring on bridges

Long-term measurements provide statements about the resulting stress collectives of a structure under the influence of standard traffic, in combination with all other physical influencing factors on the structure that do not e.g. occur in short-term measurements. Structural health monitoring detects changes in time and helps to avoid accidents. The measurement data shows how structural components interact under real loads. The know-how thus obtained delivers important information for the maintenance of existing bridges and for the development of innovative construction methods. Monitoring is useful when the investment volume only permits a limited number of new structures per time unit, where historical structures need to be maintained and continue to be used, and where special constructions require permanent monitoring.

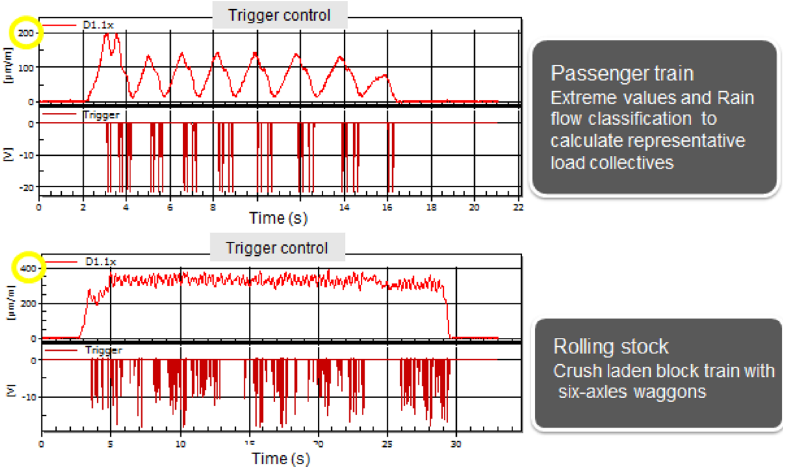


Figure 10 Permanent monitoring of resulting mechanical stresses on a DB auxiliary bridge, comparing stress of passenger and freigth trains

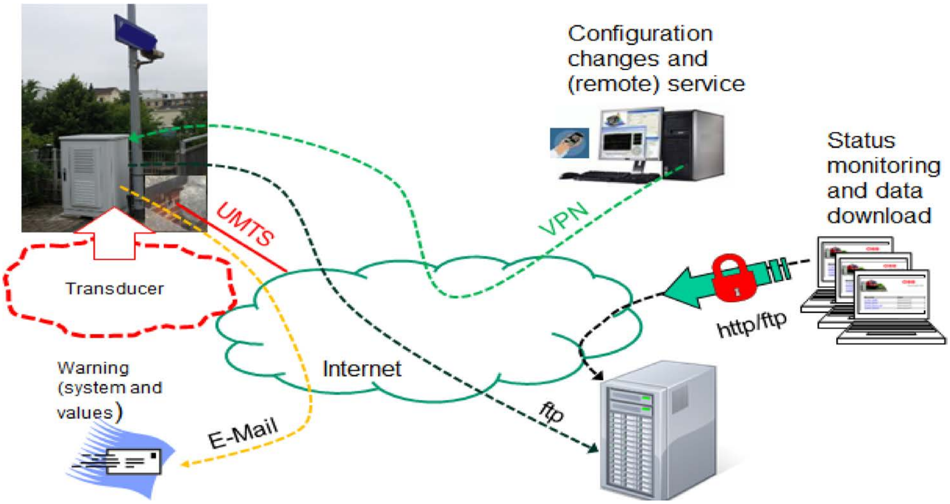


Figure 11 Typical design of a long-term monitoring system (data transfer) of the DB in cooperation with HBM

5 Long–term monitoring for remaining life statements – Status and prospects

The basic requirement for measurement technology-supported statements about the remaining service life of a construction (bridge) is the availability of reliable load data from the past. In part, these can be calculated on the basis of available documents about train loads and the number of trains or projected using information available about loading situations with reference to defined time periods. If such data is not available, it is not possible to make statements about the remaining useful life! Challenges are not only posed by changing climatic conditions, but also with regards to protection against vandalism and theft, if future solutions are to have a direct influence on standard traffic and the utilization analysis of railway bridges.

Aim of existing pilot projects:
- Long-term stability and durability of sensors and subsequent electronics;
- (e.g. endurance strength/protection of sensors against weather, overvoltage protection, etc.);
- Maintenance free overall system/secure remote data transfer;
- Remote configuration and analysis option;
- Redundancy at measuring points/if necessary, different measurement principles/prevention of false alarms;
- Automatic restart after failure;
- System power supply requirements in inaccessible areas (220V mains power supply; availability of data network, etc.);
- Data pre-processing / compression (no GBs or TBs of raw data);
- Protection against environmental influences vandalism (human and animal);
- Determination of fewer, but more meaningful measurement points per bridge;
- Safe data transmissions; possible data reduction;
- Specification of limit values for warning and alarm stages;
- Appropriate procedures when warning and alarm stages are reached.

There are series of approaches, particularly in the Asian region of installing long-term monitoring systems directly during construction (enormous mechanical stress) and/or as of the commissioning of a new bridge. Knowledge about the loads to be expected, etc. is necessary here in order to e.g. install sensors at load-relevant points. In particular, experiences gained from the system measurements are the basis for the first long-term measurements installed by DB in order to e.g. drastically reduce the number of measurement points and to determine the appropriate system architecture.

In contrast to short-term measurements (system measurements), long-term measurements also have increased requirements for e.g. the long-term stability of sensor components as well as secure data preprocessing and remote data transmission. The existing test projects very clearly show that there is still some need for expenditure in the sector of R&D as well as for further relevant long-term tests. There is also a need for further developments to be implemented by the measurement technology supplier, while the user (DB) also needs to set out appropriate specifications and standards. The standardization methods that currently exist and those which are in process of being created by the railway can also be guides in other sectors, e.g. in the sector of road bridges.

Acknowledgments

Particular thanks go to the personnel of the DB bridge measuring group (DB route measurement – I.NPI 31(F) DB Netz AG (Head office Maintenance Bridge measurement and evaluation) in Magdeburg, for their constantly constructive cooperation and the provision of documents and photos for this article!

References

[1] Guideline 805 Tragsicherheit bestehender Eisenbahnbrücken DB Netz AG, August 2008

[2] Geißler, K.: Bewertung und Ertüchtigung stählerner Eisenbahnbrücken. Der Prüfingenieur 38, Issue 04, Page 41 – 53. 2011

[3] Krempels, P., Gommola, G.: MESSTECHNISCHE bestehender Messtechnische Ermittlung Des Systemverhaltens Der Fehmarnsundbrücke Als Grundlage Für Eine Realitätsnahe Bewertung (Bewertungsprofil Nach Richtlinie 805) 6. Symposium “Experimentelle Untersuchungen von Baukonstruktionen” TU Dresden 09.09.2011

[4] Quoos, V.: Dehnungsmessungen unter Verkehrslasten (Straße, Bahn) sowie bei Temperaturgang am Netzwerkbogen und am 5-feldrigen Nebentragwerk der Fehmarnsundbrücke Report 10/38, DB Netz AG, I.NPT 2(F), Magdeburg, December 2010

[5] Gommola, G.: Bridge Evaluation Using Metrology Methods for Short- and Long-Term Measurements Civil Structural Health Monitoring Workshop (CSHM-4)

[6] Geißler, K., Knaack, H.-U., Bolle, G., Marx, S.: Messtechnische Konzepte In Den Regelwerken Von Infrastrukturbetriebern – New Module 805.104 In Guideline 805 7 5. Symposium “Experimentelle Untersuchungen Von Baukonstruktionen” Schriftenreihe Konstruktiver Ingenieurbau Dresden, Issue 18