

METROLOGICAL DETERMINATION OF THE FEHMARN SUND BRIDGE SYSTEM BEHAVIOUR AS A BASIS FOR ASSESSMENTS ACQUIRED THROUGH MEASUREMENT (ASSESSMENT PROFILE ACCORDING TO GUIDELINE 805)

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1. Introduction

With the planned construction of the fixed link across the straits known as the Fehmarn Belt, which will connect the island of Fehmarn in Germany with the Danish island of Lolland, a heavy increase in traffic is predicted on the Fehmarnsund Bridge, built in 1963. For this reason, it became necessary to verify available or new mathematical load bearing calculations against assessments acquired through measurement. This paper describes only the execution of measurements and their evaluation or interpretation; however, it does not determine any results nor does it derive any conclusions with regard to utilisation.

2. Combining calculation and metrological assessment to determine the load bearing capacity and life of railway bridges

2.1 General preliminary considerations

Deutsche Bahn alone owns about 28,000 railway bridges in various kinds of designs. Many of these bridges have already been in use for decades. Construction plans that are available are not always sufficient [1] to make reliable statements, for example, about the remaining life or changing conditions of utilization, which is the case with the Fehmarnsund Bridge. Increasing traffic loads as well as demands for higher traversal speeds and the potential influences of environmental effects additionally urge the need for assessment of existing bridges. Adequate metrological methods combined with calculation models enable these tasks to be solved.

2.2 Measuring the system behaviour of bridges

This method involves an experimental investigation of the bridge under test considering both the loads during regular train traffic and partly substantially higher traffic loads. Increased loads are often required to obtain a measurable reaction of the structure. [2]. However, the loads

are always within the range of the structure's elastic deformation behaviour and are predefined by the bridge surveyor/structural engineer. He also defines the number and type of measurement points in the different measurement sections as well as the type of dynamic loading, for example, due to defined crossings of vehicles at different speeds. Typical measurement quantities include strain, acceleration, displacement and temperature. This method involves a number of measuring points ranging between several tens and several hundreds. The duration of the measurement is often limited to hours (route closure, provisioning of loading vehicles, special wagons). The requirements test equipment needs to meet are defined by the dynamic and simultaneous recording of measured values.

3. Measuring the system behaviour on Fehmarnsund Bridge

3.1 Task and requirements

Initiated by discussions and first structural suggestions for building the fixed link across the straits (Fig. 1) connecting the island of Fehmarn (Germany) with Denmark, the Fehmarnsund Bridge, built in 1963, has been reconsidered as well. Utilization of this network arch bridge south of the planned link across the straits will substantially increase when a direct transport connection has been established both in terms of traffic density and prognosticated traffic load. The aim of system behaviour measurement from June 11 to 14, 2010 was to provide information on whether the structure would be able to cope with these requirements. This paper does not provide any assessment of the measurement results obtained. Assessment is based on Assessment Level 2 of Guideline 805 (Deutsche Bahn) and on the assessment guideline for road transport. Extensive measurements involving different loadings of both road and railroad track were required for calibrating the complex calculations models. The measurement program was

coordinated with the DB-Projektbau group of structural engineers.



Fig. 1: Geographical location – Fehmarnsund Bridge (Source: Wikipedia)

3.2 Measuring program

Discussions with structural engineers resulted in the conclusion that it would be expedient to define two measurement locations with associated measurement sections. Measurement location I including 3 measurement sections is located in the bridge's span and girder sections; measurement location II including 2 measurement sections is located on the network arch superstructure.

3.3 Type and installation of the transducers

Sensors were installed at 251 locations representative of the bridge's statics; they were to



Fig. 2: Fehmarnsund network arch bridge

measure the deformation of the bridge structure resulting from variable cyclic loading. The predefined measuring points were fitted with sensors over the time period from April to June 2010. Most measuring points are based on the use of strain gauges (SG) in a full bridge circuit with one active bridge arm. This means that strain in response to applied load is measured in this strain gauge in the form of component expansion plus thermal expansion (Fig. 3). The other three SG

bridge completions will not experience any component expansion resulting from applied load, because they are installed in areas that are not subjected to strain resulting from applied load.

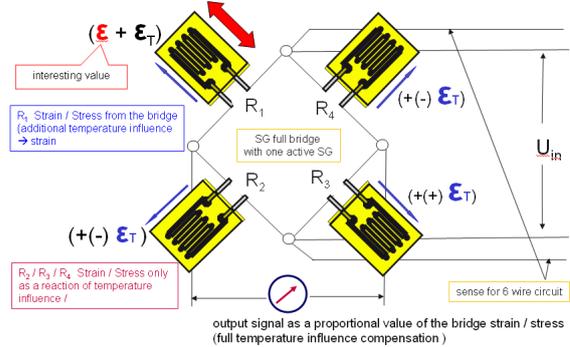


Fig. 3: Strain gauges in a full bridge configuration (6-wire circuit)

Full bridge completion and the simultaneous recording of material expansion resulting from temperature variations in all four strain gauges enable these unwanted temperature effects to be almost fully compensated for. The strain gauge full bridge configuration permits electrical connection to downstream measurement electronics using a 6-wire circuit. Two additional sense leads electrically compensate for line effects resulting, for example, from temperature effects on long cables that would cause measurement errors.

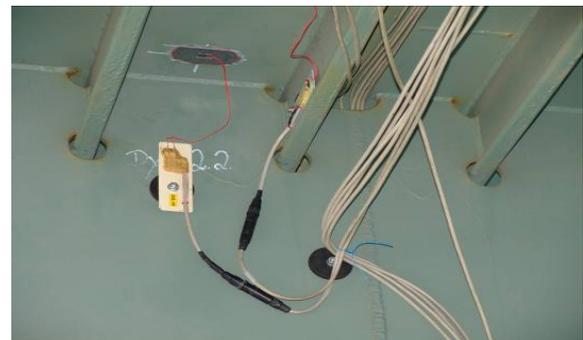


Fig. 4: Strain gauges installation

3.4 Measurement data acquisition

Distributed data acquisition systems were installed for data acquisition and storage as well as for data transmission. Optical fibre technology was used for synchronization of data from both the distributed systems and the main control station, which is a requirement resulting from the dynamic acquisition of measured values. Figure 5 describes the basic topology of the measurement setup.

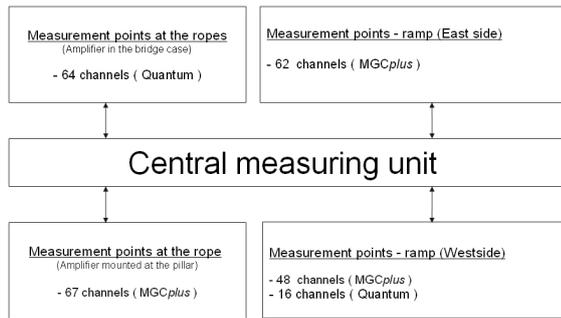


Fig. 5: Topology of the measurement installation

The distributed data acquisition systems were connected via fibre optic cable to enable data synchronization and control of the measuring system. The dimensions of the actual measurement setup as well as the complexity of the measurement task at hand become obvious by the fact that only through utilization of fibre optic cable could 60 km of usually required electrical connection cable be saved.



Fig. 6: QuantumX amplifier system (HBM) installed in a robust box in measurement section 5 below the bridge

4. Execution of the measurements

Test loads were applied to the Fehmarnsund Bridge involving different trains of locomotives and additional heavy-duty trucks on the road from June 11 to 14, 2010 between 6:00 pm and 6:00 am next morning.

4.1 Quasi-static crossings of heavy-duty vehicles

Two heavy-duty vehicles crossed the bridge (12t/20t axle load) in 4 different lanes at speeds of $v = 10$ km/h and a distance of approximately 10 meters between the vehicles.



Fig. 7: Heavy-duty truck with additional 120 t load

4.2 Crossings of a train of locomotives

This configuration involved a train of 2 x BR232 and 8 x BR155 locomotives. The total weight of a BR155 locomotive is 123 t with an average axle load of 22.5 t. The basic loading results in a vehicle weight of 6.276 t



Fig. 8: Loading train composed of 10 locomotives

4.3 Combined crossings

This part of the measuring program involved combined crossings of the train of locomotives together with the heavy-duty trucks with different directions of travel and load patterns of the tracks and roads.

4.4 Dynamic measurements

Dynamic crossings were implemented at maximum speeds of approximately 120 km/h for the train of locomotives and about 80 km/h for the heavy-duty trucks.

Measurement was activated by light barriers installed in adequate locations.

5. Test results (examples)

Figures 9 and 10 provide examples for parallel crossings of the train of locomotives and the heavy-duty truck.

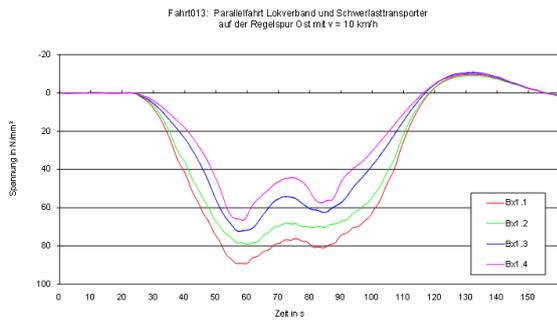


Fig. 9: Parallel crossing of train of locomotives and heavy-duty truck at measurement location I (5-span continuous girder; centre of first span) – Stress distribution at the floor panels

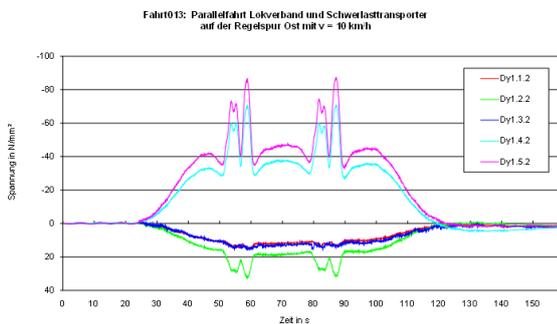


Fig. 10: Parallel crossing of train of locomotives and heavy-duty truck at measurement location I

(5-span continuous girder; centre of first span) – Stress conditions at cross girder, measurement section 2 (guide barrier)

Note

The current report is based on written or verbal information, explanations and images from the Department of Bridge Measurement of the Deutsche Bahn (German National Railways) in Magdeburg. Many thanks are due to Messrs. Volkmar Quoos, Peter Krempels and Uwe Friebe for their helpful assistance and support.

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