

Experimental determination of the load-bearing and deformation characteristics of the Flöhatal Bridge at Hetzdorf

by Reinhardt Günther and Dieter Schulze

Deck slabs in reinforced and prestressed concrete as used for railway bridges are being examined within the framework of an international research project. The measurement object in this article is the Flöhatal Bridge at Hetzdorf in Germany which was constructed as part of the project to straighten the railway line between Chemnitz and Dresden. Strains in the concrete and on the transverse reinforcement were measured together with deformation in the box girder cross-section, wheel loads from locomotives and various temperatures. The article describes the complex on-line measurement system with 87 measuring points for static measurements and 46 parallel measurement channels for the acquisition of dynamic signals. The main feature of the results is the comparison between the computed and measured results.

Introductio

Situated on the Dresden-Chemnitz railway line between the railway stations of Öderan and Falkenau there is a bridge, the Hetzdorf Viaduct, which was built in the years from 1866 to 1868. The two-track 326 m (357 yd) long structure is located in a bend with a radius of 750 m (820 yd); it is 43 m (141 ft) high and consists of four large and 13 small arches. **Figure 1** shows an aerial photograph of part of the bridge which is constructed from granite, sandstone and gneiss. Owing to its poor state of preservation, it is not able to fulfill the demands of rail traffic. Consequently, after extensive investigation of a number of alternatives, a new route was selected which would straighten out the line in the vicinity of the viaduct.

As can be seen from the map in **Fig. 2**, two new valley bridges had to be built along the line of the new route,

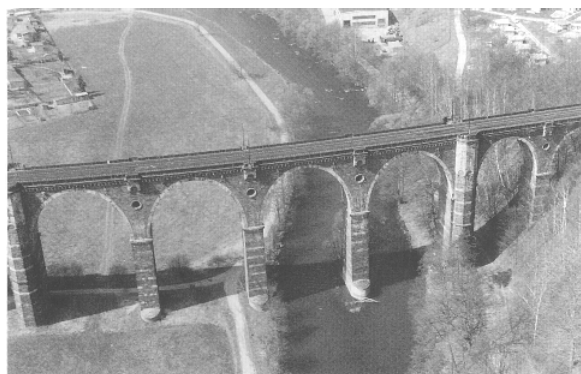


Fig. 1: View of part of the Hetzdorf Bridge which was built about 130 years ago.

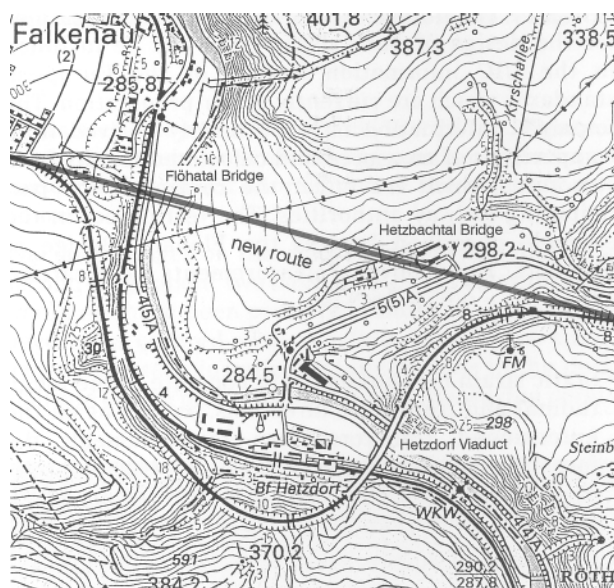


Fig. 2: Map showing the old and new sections of the railway line.

one over the Hetzbachtal and one over the Flöhatal. Designed before 1989, the two new bridges were the first railway bridges in the region of Germany now known as the "new federal states" to be built as prestressed continuous structures using the repeated push technique. The bridges were designed for a specified speed of 100 km/h (62 mph). A higher speed was not considered necessary due to the speeds in the sections before and after the new part of the route.

The bridges - **Fig. 3** shows the Flöhatal Bridge - each have a length of 344 m (376 yd). The bridge superstructures are each supported on seven piers with heights between 15 m and 36 m (50 - 118 ft).



Fig. 3: View of one of the two new bridges.

Test objective

As a member of the Union Internationale de Chemin de fer (UIC), the German Railway is also participating in tests conducted by the European Railway Research Institute (ERRI) to find the "stresses and strength of reinforced and prestressed concrete-deck railway bridges". The objective is to make recommendations for the design of deck slabs which will be included in the UIC information leaflets or the European standards which are currently under preparation. The imparted information is to be mainly derived from comparisons of measured and calculated results from structures which are under the control of the participating railway authorities. The test object in the example described here is the Flöhatal Bridge at Hetzdorf. The following measurements were carried out:

- Static strain measurements in concrete in the longitudinal and transverse directions, as well as on the untensioned transverse bar reinforcement; deformation measurements on the girder box under defined static loading with the aim of determining relevant static computational models.
- Strain measurements as above, but under defined dynamic loading over the full permissible speed range with the aim of establishing dynamic coefficients for the parts requiring verification.
- Measurement of axle loads and axle distances for the regular rail traffic in conjunction with strain measurements with the aim of defining load and stress combinations for the fatigue design in the compressive zone and for the transverse reinforcement.

Problem definition and test concept

From the test objective a measurement program formed which included strain measurements on the concrete and on the transverse reinforcement in the deck slab, deformation measurements on the cross-section of the bridge girder box, acquisition of the wheel loads

from a test locomotive and temperature measurements. Both static and dynamic measurements were carried out.

The measuring points were located in a column cross-section, in a span cross-section in the girder box and on the track. **Figure 4** shows a block diagram giving an overview of all the measuring points and equipment used for the signal processing. A total of 87 measuring points were arranged to measure static strain. Their signals were acquired by UPM 60 Multi-Point Measuring Units with UMH 3209 Selector Modules. The UPM 60 was completely controlled in all its functions by an IBM compatible 486 computer. Forty-one of the static strain-gage measuring points were located in the column cross-section and 46 in the span cross-section. The dynamic measurements were carried out using 46 parallel measuring channels with four DMC 9012A Digital Measuring Amplifiers controlled from two Macintosh computers. Twenty-two of the dynamic measuring points were arranged in the column cross-section and 24 in the span cross-section. Of course, static measurements could also be carried out with these parallel measuring channels. The recording of the wheel loads took up another four dynamic channels, two for each of the two tracks. For this, two further DMC 9012A amplifiers were used. The

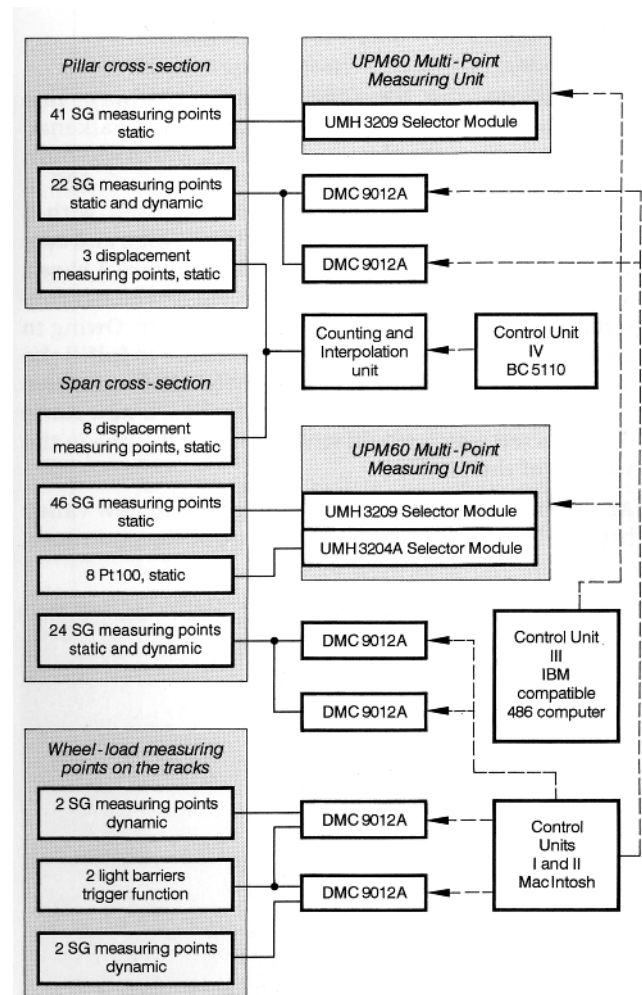


Fig. 4: Block diagram of the complete measurement system installed on the Flöhatal Bridge.



Fig. 5: View of the measurement system installed inside the bridge girder box.

measurements of the air and concrete temperatures were made using eight static channels via a UMH 9204A Selector Module in one of the two UPM 60 Multi-Point Measuring Units.

The synchronization required for the start of the DMC 9012A instruments during the dynamic measurements, i.e. for the locomotive and train runs with speeds from 10 to 80 km/h (6.3 - 50 mph) on both tracks was provided by triggering with the aid of reflecting light barriers which were fitted to both tracks at 5 cm (2 in) above the top of the rails. The signals from the light barriers were each wired to DMC 9012A channels which were controlled by the Macintosh computers and used as trigger channels.

A total of 11 incremental displacement transducers of the type IKF30 were located in the two measurement cross-sections for acquiring the deformation displacements under load. The signals from these transducers were processed in a counting and interpolation unit.

Figure 5 gives an impression of the measurement system accommodated in the bridge girder box. To the left can be seen the two stacked UPM 60 Multi-Point Measuring Units and the DMC 9012A Digital Measuring Amplifiers in the right half of the picture.

Transducer installation

The installation of the measuring points on the test object was undertaken in three stages. The strain gages had to be applied to the transverse reinforcement on the prestressed concrete bridge a year before the measurement deadline and before the concrete was poured. Here, special protective measures were needed with regard to the pouring of the concrete and to the forces later transferred to the stressing rods.

For the strain measurements the wire strain gages WG 30/10, which were at that time available from TPW in Thalheim, were used and configured to form full bridges. Special attention was given to the covering of the measuring points. The initial covering was a colophonium/wax mixture which had proved very successful in many measurements with the strain gages from Thalheim. A layer of AK22 Putty was then kneaded over this. Then a layer of ABM 75 Covering Tape, consisting of aluminum foil and putty, was applied. **Figure 6** illustrates diagrammatically how the strain gage was covered. The connecting cables for the measuring points were laid in conduit in the cavity in the girder box which was later available for the measurements

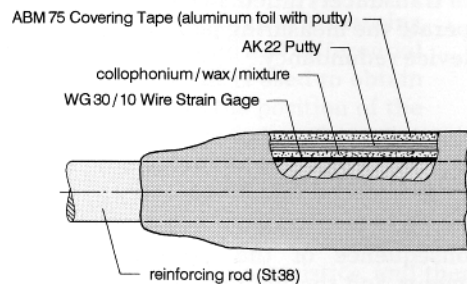


Fig. 6: Formation of the covering on the strain-gage measuring points fitted to the transverse reinforcement.

(cross-section approx. 4 m x 4 m [13 x 13 ft]). **Figure 7** shows two strain-gage measuring points on the transverse reinforcement shortly before the concrete was poured.

The strain gages on the deck slab were installed in a second stage about two months later. Installation later would not have been possible because the area would have been covered with a ballast bed. These strain gages were each installed in indentations in the deck slab and cast in place. All strain-gage measuring points

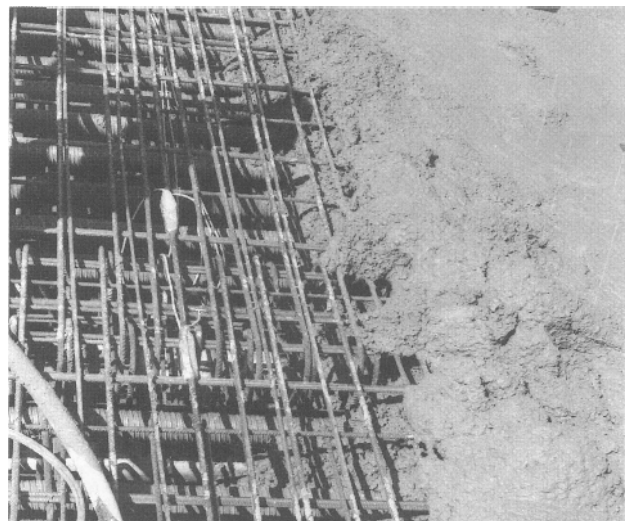


Fig. 7: View of the strain-gage measuring points on the transverse reinforcement shortly before the concrete was poured.

on the deck slab and on the transverse reinforcement were applied double so that if one failed at a measuring point, the other one could be used.

The fitting of the remaining strain gages to the concrete surface was carried out in a third stage shortly before the start of measurements. A mobile elevated platform with a maximum operating height of 42 m (138 ft) was used as a variable working platform.

Once the installation of all the transducers was finished together with their cabling, test measurements could be carried out based on regular train-traffic crossings. Despite the extreme care taken, particularly in installing the transducer circuits inside the bridge structure about one year prior to the measurements, a number of transducers failed. In most cases it was possible to operate the measuring point due to the built-in double-device redundancy.

Carrying out the tests

As a consequence of the extensive program of measurements and the limited time available during the closed periods, the measurements were carried out over three days, or rather nights. The following static loads were tested:

- Load 1: → two coupled rail vehicles
- Load 2: → one rail vehicle on each track

Each of these loads was measured three times in previously specified load positions longitudinally along the axis of the bridge.

Weighed test locomotives of the type 155 with a total weight per unit of about 120 t were available as loads for the dynamic measurements which were monitored at measuring points connected to the DMC 9012A Digital Measuring Amplifiers. These locomotives crossed the measurement cross-section on the bridge starting with a crawling speed which was incremented in steps of 10 km/h up to 80 km/h.

The program BEAM version 2.1 for the DMC 9012A was used as the control and operating software together with a UPM 60 program developed by the authors. The crossings were recorded three times in each direction. Subsequently, 100 trains of normal rail traffic were recorded dynamically with the number of measurement channels reduced to 10 transducers to find the load and stress combinations needed as a basis for verification of fatigue characteristics.

Test results

The strains and deformations were computed with an FEM model for selected load positions and compared with the measurement results. The agreement between the computed values and the measurements is very good when the measurement spread is taken into account. An example highlighting the comparison is

shown in Fig. 8. The measuring points 1.7.2xd, 1.7.16x and 1.7.14xd are taken here as being representative of the many statically measured values.

From the results of the measurements under static load it could be concluded for the tested structure that the specifications stated in the national and international design regulations for the verification of the traffic load cover the actual load-bearing characteristics with an adequate safety margin. At selected measuring points the strains measured over the test speed range with the load of both locomotives were compared with the corresponding measurements under a static load. In the longitudinal direction of the

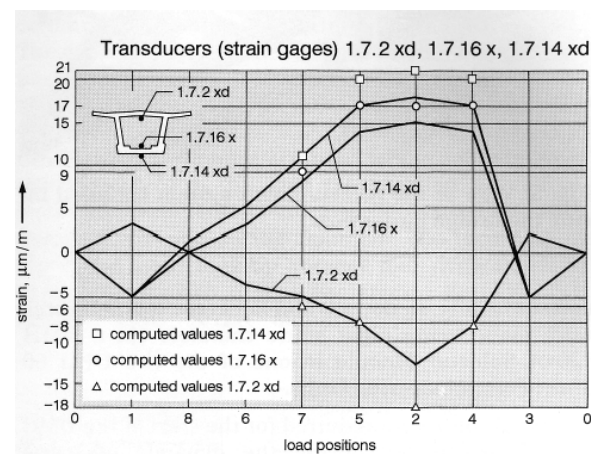


Fig. 8: Example of the comparison between the measured and calculated values based on strains measured with various load positions.

structure no significantly higher dynamic factors could be found than specified in Eurocode 1, Part 3 (ENV 1991-3: 1994) for local stresses. In the transverse direction this also applies to the measuring points in the concrete. The values were up to 10% higher on the transverse reinforcement.

The measurements of wheel loads and distances, the speeds of the service trains passing over the structure and the resulting strains at selected points were compared with the figures in the regulations. The tonnage from the measured trains in operation, extrapolated over a time period of one year, gave about 45% of the value for the EC standard traffic combinations as specified in the above mentioned Eurocode.

From the lines of influence for the strains and stresses together with the parameters of the measured operating trains (axle loads and axle distances), operational load factors for the verification of the fatigue characteristics were determined using a deterioration hypothesis. They are about 75 % of the values quoted in the Eurocode.

Dipl.-Ing. Reinhardt Günther is with the Deutsche Bahn AG, Magdeburg Network and was the measurement engineer during the tests on the bridge. **Dipl.-Ing. Dieter Schulze** is with the same establishment and is responsible for solid railway bridges.