Second Conference on Smart Monitoring,
Assessment and Rehabilitation of Civil Structures

SMAR 2013

Structural monitoring of the bridge in Szczercowska Wieś (Poland) under trial loading

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ABSTRACT: The subject of the paper is a loading test conducted on the bridge located on the provincial road nr 480 (km 40+578), over Pilsia river in Szczercowska Wieś, Poland. The aim of the test was to examine the stiffness of the bridge's structure consisting of five post-tensioned girders of 1.00m height and 18.40m total length. The test has been carried out with use of a truck with variable amount of sand ballast, introducing the load on the bridge. Results of the measurements of concrete strains and displacements of the girders during the test allowed designing a structural health monitoring system to be installed on the bridge for the evaluation of the effects of structural strengthening with prestressed CFRP laminates.

1 INTRODUCTION

Strengthening of bridge structures with use of composite materials has been very popular solution for improvement of constructions requiring retrofitting in recent years. Flexural and shear strengthening of RC beams has been proved very effective in terms of both ultimate and serviceability limit state (ULS, SLS).

The paper refers to a bridge in Szczercowska Wieś, Poland, built in 1965, which will be subject to the strengthening and retrofitting within the framework of the research project „Innovative Structural Health Monitoring in Civil Engineering Infrastructure Sustainability" TULCOEMPA, carried out by Lodz University of Technology in cooperation with EMPA Swiss Federal Laboratories for Materials Science and Technology. The aim of a loading test was to determine the bridge's behaviour under certain load levels and collecting data necessary for the design of a structural health monitoring system.

The structure of the bridge consists of 5 prefabricated post-tensioned girders of 18.4m length and 1.0m height. Prestressing force in each of I-shaped girders is introduced by 2 horizontal and 3 parabolic tendons. The lateral spacing between girders is 1.55m. The bridge deck is made of 16cm RC slab initially finished with levelling layers and 0.05m-thick layer of asphalt. Later in time, additional layer of asphalt has been applied on the bridge, which increased the overall asphalt thickness to 0.21m (Fig. 1). Three rectangular cross-beams are situated in the midspan and over the supports, connecting all the girders and the deck in transverse direction. The whole bridge is supported on two solid concrete abutments on both sides of Pilsia river.

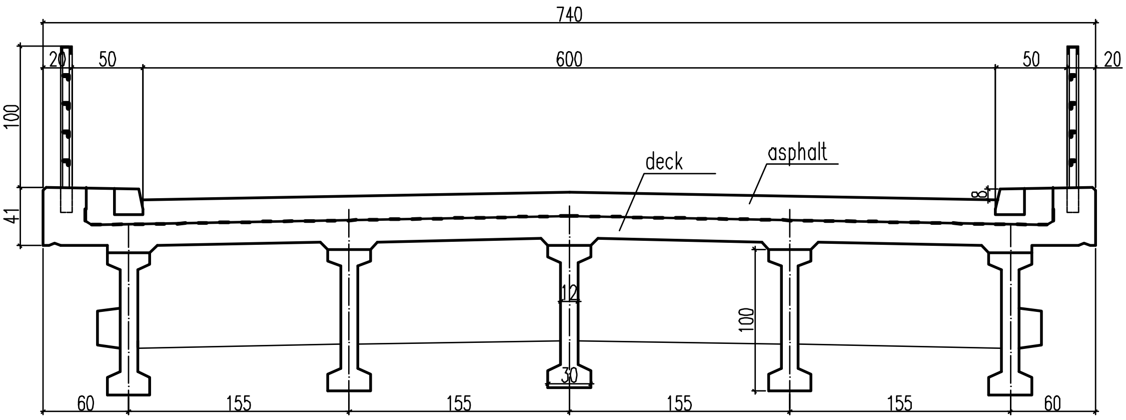

Figure 1. Bridge cross-section.

Due to rising demands in terms of load bearing capacity and planned upgrade of the road class, the bridge has to undergo retrofitting. Modernization of the bridge will consist of two parts. In the first phase the existing deck will be removed and two new post-tensioned girders will be installed on widened abutments. After that a new, 0.21m thick concrete deck will be casted on the girders and finished with levelling layers and asphalt. Overall width of the bridge and road width will increase from 7.4m and 6.0m to 9.7m and 8.4, respectively.

In the second phase of retrofitting, five existing girders will be strengthened for flexure and shear with CFRP laminates. Flexural strengthening of each girder will consist of two prestressed CFRP laminates of 1.20x100mm cross-section, applied on the bottom surface with use of unique gradient method developed at EMPA Swiss Federal Laboratories for Materials Science and Technology. Shear strengthening will be applied in form of CFRP sheets wrapping. Multi-layer, 75mm wide wraps will be installed over the whole girders length at 1.0m spacing. Currently extensive research is being carried out to prove efficiency of this type of strengthening and develop methodology of its application on the existing structure.

2 PURPOSE OF THE TRIAL LOADING

The main goal of the trial loading conducted on the bridge was to determine its behaviour in terms of concrete strains and vertical displacements occurring in the structure under certain external loads. Knowledge of expected deformations and strains was necessary to design a structural health monitoring system and choose appropriate measuring devices, strain gauges and LVDT gauges to be installed on the bridge. Launching of the monitoring system is planned for the beginning of year 2013 and will operate both before and after the structural strengthening with composite materials.

The second reason for conducting the loading test was the need to create a 3-dimensional finite elements model which would allow calculating accurately the deflections of the bridge under external loads. A number of various types of FEM models have been built in the aim of comparing the calculations output with the results of trial loading. More detailed information about the modelling along with the comparison with test results are given in the 5th chapter of this paper.

Finally, the gathered results of the trial loading will create a reference level for the future loading tests, scheduled after the structural strengthening of the bridge. Comparison of the structural behaviour before and after bridge's retrofitting will allow evaluating its efficiency in terms of increase of load capacity and improvement of serviceability conditions. The influence of the strengthening on the stiffness of post-tensioned girders still requires a lot of research and investigation.

3 LOADING TEST

The loading test was conducted in January 2012. The measuring devices have been installed on the girders of the bridge and one lane of the road passing over the bridge has been closed for traffic to allow the truck with load to enter the bridge. The load was applied to the bridge by means of a 4-axle Renault Kerax truck with variable amount of sand ballast.

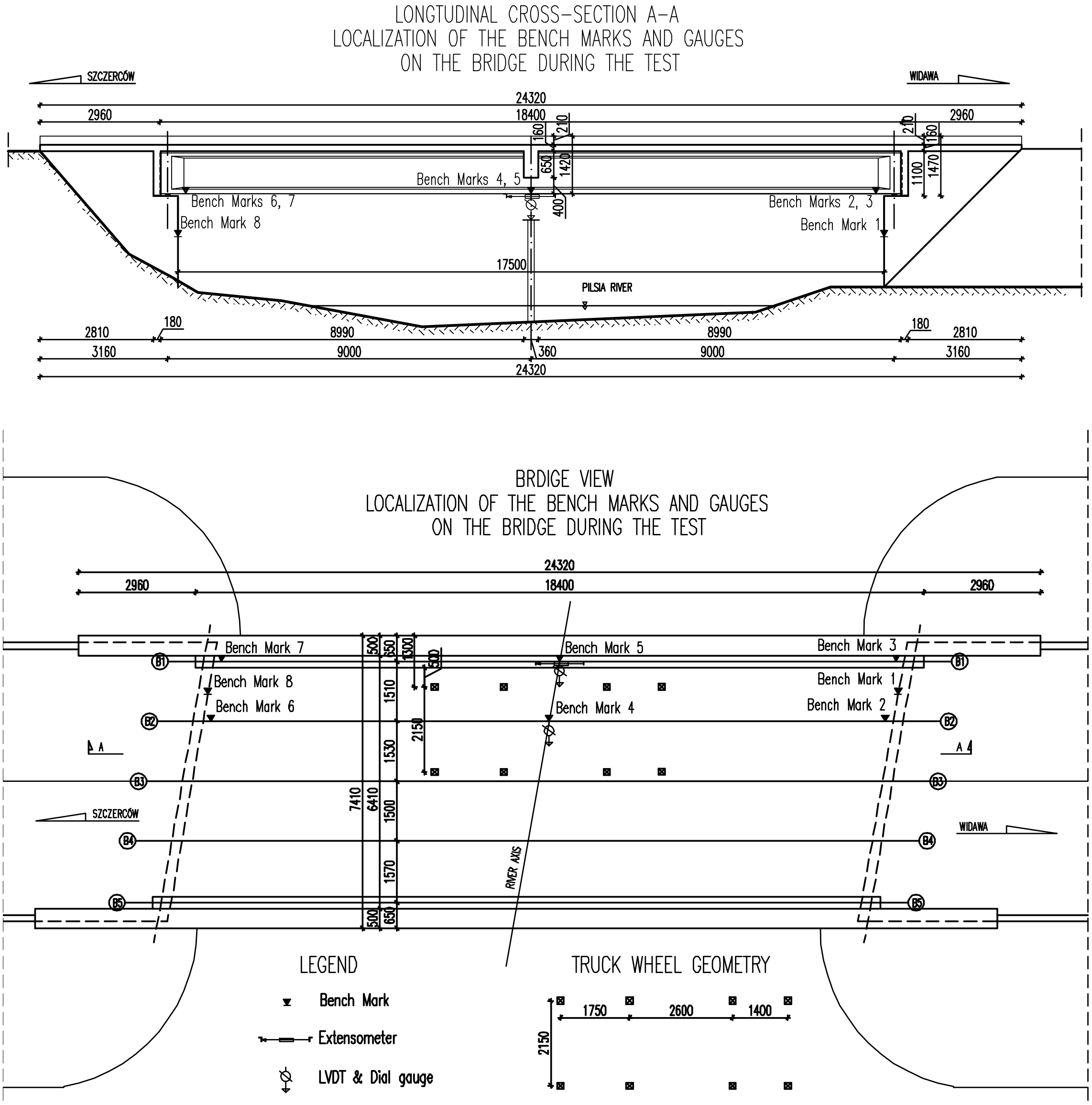

Figure 2. Location of the measuring instruments and the truck on the bridge during the test.

During the trial loading the displacements of the bridge's structure and concrete strains have been registered by 4 independent systems:

- dial gauges for the measurement of deflections situated on the bottom surface of the outermost and second outermost girders, in the middle of the span;
- LVDT gauges for the monitoring of girders' deflections, mounted in the same spots as above;
- digital extensometer with base length of 1200mm installed at the bottom surface of the lower flange of the outermost girder to register concrete strains;
- precise optical levelling performed by geodetic surveyors on a set of 8 bench marks for the measurements of vertical displacements of the structure.

Exact location of the measuring points for each system along the girders with the position of the truck introducing the load are given in the Figure 2.

The loading test has been divided into several steps, to analyse structure's response to two levels of load:

1) the bridge loaded by an empty truck (14 500kg weight)
2) the bridge loaded by a truck with a sand ballast (20 000kg total weight)

In the initial stage of the loading test the reference measurements on the empty bridge have been registered, including readings of vertical displacements of the girders and the supports (registered with dial gauges, LVDTs and optical levelling) and concrete strains at the bottom surface of the girder. All measurements were registered at each loading level by the computer system. Before the load application the bridge was visually checked for presence of concrete cracks or any other damage.

All loading steps were conducted according to the same procedure. At the beginning, the truck entered the bridge at constant speed of 0,5m/s. 15 minutes after the truck stopped in the middle of the bridge span, while there were no other cars on the bridge, first series of measurements has been registered. Series consisted of several measurements, repeated every 15 minutes till all the readings from the instruments stabilized, at least 3 measurements had to be done. Readings were confirmed as stabilized when the difference between two consecutive ones was smaller than 2% of the first reading.

Loading phase was repeated twice, with two different loads (14.5t and 20.0t) with a series of intermediate readings in between, while the truck was being loaded with sand ballast and its weight was being controlled in the Bełchatów Lignite mine. The intermediate readings started 15 minutes after the truck left the bridge. The series of measurements were registered according to the same manner.

4 RESULTS

The results of the measurements are summarized in Table 1. Despite the considerable load introduced on the bridge, their displacements were relatively small. Measured deflections of the girders varied from 1.10 to 2.10mm under different load levels, with the biggest value measured in the midspan of the outermost girder. The highest concrete strain measured at the bottom flange of the girder did not exceed 0.045‰.

Table 1. Summary of the measurements.

Measured value	Midspan deflection (mm)						Concrete strain (‰)	
Gauge type	Dial gauges		LVDTs		Optical levelling		Extensometer	
Load level	14.5t	20.0t	14.5t	20.0t	14.5t	20.0t	14.5t	20.0t
Outermost girder (B1)	1.34	2.05	1.31	1.98	1.30	2.10	0.032	0.046
Second outermost girder (B2)	1.24	1.92	1.24	1.86	1.10	2.05	-	-

The results of the measurements of the vertical displacements of the outermost girder (B1) and second outermost girder (B2) are presented on the graphs of the displacements in function of time (fig. 3).

Contrary to initial schedule, the periods of loading were shortened due to faster stabilization of the readings and traffic limitations. Therefore, the first step, when the bridge was subjected to the load of 14.5t lasted 20 minutes, which can be seen on the curves. Vertical displacements registered during that step did not exceed 1.34mm. In the next stage the bridge was unloaded for ca. 40 minutes and afterwards the load of 20.0t was applied to the bridge. The second loading step lasted more than 70 minutes and vertical displacements of 1.86 - 2.10mm were registered. Continuous measurements of the displacements registered with LVDT gauges were influenced by other cars passing the bridge (apart from the truck) during the test, which resulted in some pikes in readings visible on the Figure 3.

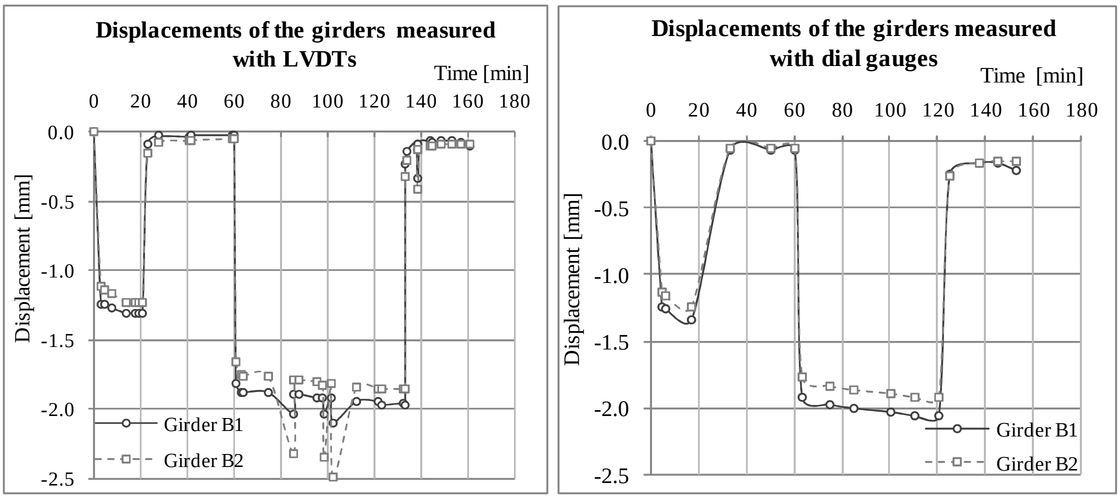

Figure 3. Vertical displacements of the girders' midspan.

Figure 4 shows the results of deflections registered with use of optical levelling, along with corresponding concrete strains measured several times during each step of the trial loading. Relatively low concrete strains, not exceeding 0.032‰ and 0.046‰ in the first and second step, respectively, proved high stiffness of the bridge structure.

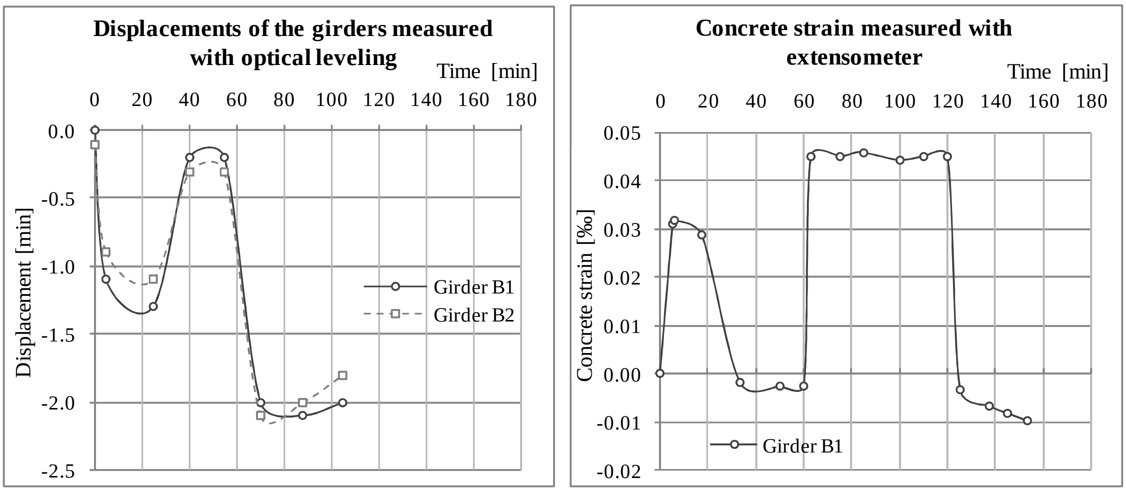

Figure 4. Vertical displacements and concrete strains at the girders' midspan.

The last set of graphs (Fig. 5) shows the vertical displacements of the bridge measured by the geodetic surveyors on set of 8 bench marks. Six of them were installed on the girders (one in the midspan and one in each support zone of both girders) and additional two on the concrete abutments. The results show that the supports and the abutments also experienced some vertical displacements under the load. Measured displacements reached 0.3mm under the highest loads, which means that the relative displacements of the girders’ midspan were equal to 1.80mm.

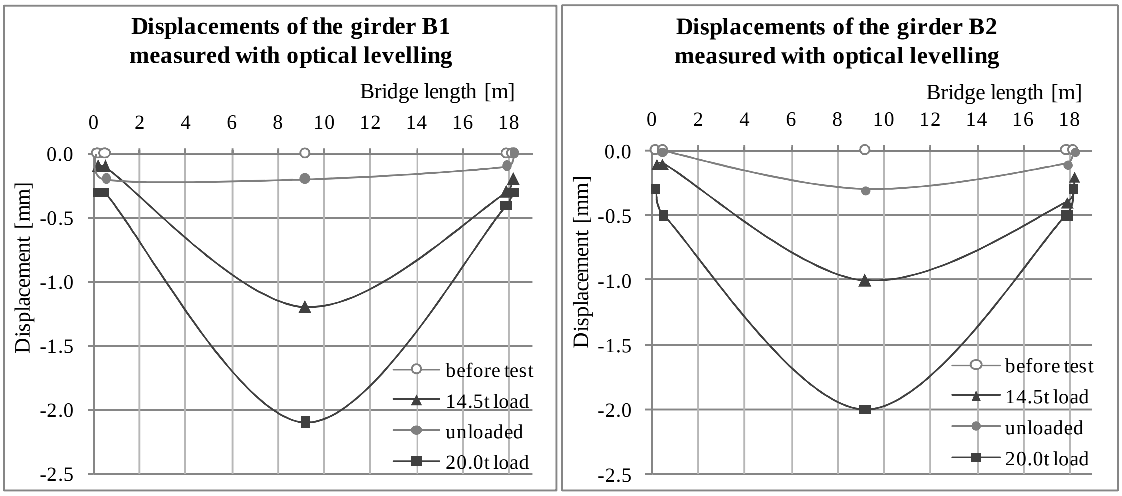

Figure 5. Vertical displacements of the girders at different phases of the test.

5 MODELLING

For the structural strengthening of the bridge it was necessary to perform theoretical analysis with 3D modelling of the bridge structure. For that purpose, numerous variable 3D FEM models have been created with use of Autodesk Robot Structural Analysis software. The loading test has been an opportunity to compare the numerical output from the modelling with the real behaviour of the bridge structure under certain load levels. The deflections of the girders in the midspan have been chosen as a point of reference between the modelling and trial loading results. Comparison of the calculated and measured deflections allowed choosing the most accurate bridge model.

Two models have been chosen for the final analysis. All of them consisted of five 18.4m long girders situated on the rectangular plan with uniform spacing of 1.55m. The girders have been connected by three cross-beams and concrete deck. The whole structure has been supported on two linear hinged supports. Cross-sections and material characteristics of the elements have been introduced according to the results of an assessment, which the bridge had been subjected to before the loading test. The load has been applied to the models exactly in the same way as to the real structure, through 8 point loads corresponding to 8 wheels of the 4-axle truck.

The main difference between the analysed models was the type of constituent elements. The first model has been built of 3-dimensional objects representing girders and cross-beams, while the slab has been modelled with use of 2-dimennsional panel. The second model has been entirely built of 2-dimensional panels, orientated in the directions adequate to their plane of loading.

FEM analysis of the bridge allowed selecting the 3-dimensional beam model as the most precise for estimation of the bridge deflections under the external load. The calculated deflections varied from 2.62 to 3.45mm under different load levels, which compared to the measurements results (1.34 - 2.10mm) showed sufficient reliability. The slight difference between the measurements and calculations' resulted from a different behaviour of the supports. 3D model assumed that the supports on both sides of the bridge are hinged and allowed for free rotation of the girders' ends in their plane. In the existing structure, however, the support bearing plates are deformed due to their age and do not rotate freely. Additionally, the cross-beams at both ends of the girders are situated too close to the abutments and disrupt the functionality of the simple supports. All this factors increase the stiffness of the whole bridge span and result in lower deflections than expected. An improved 3D FEM model is being prepared, where all the above mentioned issues are taken into consideration.

6 CONCLUSIONS

The loading test has been successfully conducted on the bridge in Szczercowska Wieś. The bridge behaviour was analysed under two load levels: 14.5t and 20.0t. Registered concrete strains and displacements of the structure were relatively small, deflection of the outermost girders in the midspan slightly exceeded 2mm under the highest load. Such results led to a conclusion that the bridge structure characterized with high stiffness, which was mainly the effect of the bridge's spatial structure scheme. The horizontal view shows that five parallel girders were not situated on rectangular plane, but rather overlapping each other, which shorten the effective span of the bridge (see fig. 2). Other factors that affected the bridge stiffness were the presence of cross-beams connecting all the girders in transverse direction and stiff supports, which in fact did not allow free rotation of simple support, as it was assumed in the numerical analysis.

Nevertheless it was possible to select the most accurate 3D FEM model of the bridge to estimate its behaviour in terms of displacements under external load. The numerical analysis gave slightly higher values of deflection than the real measurements, this however justifies use of the selected model because taking higher values into consideration is safe for the design.

In order to evaluate the structural strengthening in terms of serviceability conditions, similar loading test will be carried out after the strengthening of the bridge girders with prestressed CFRP laminates.