The paper describes results of field testing and analysis of a short-span railway bridge carried out within static proof load testing. Scope of work, including experimental testing on site and additional investigations in laboratory, structural analysis by means of the finite Element Method (FEM) as well as comparison of the results, is presented. Special attention in paid to the problem of specific support of the RC slab girder by means of bitumen sheets. Deformations of such bearings significantly affect exceptionally small values of the structure displacements measured during the experimental tests of the short-span bridge.

Keywords: bridge, proof load testing, analysis, Finite Element Method.

INTRODUCTION

According to Polish Standards requirements after construction of a bridge and before its opening to the traffic the structure must undergo proof load testing to confirm its behaviour compatible with the design assumptions. It applies to road bridges with a span longer than 20 m or any extraordinary structures and to all railway bridges. Thus, a possible situation can be than carrying out a proof loading test of a-few-meter long railway bridge span which is the case presented below. Such an apparently simple task can bring some problems related to the scale of the structure deformations and displacements being at level of measurement accuracy.

DESCRIPTION OF THE STRUCTURE

The considered bridge is located along the railway line no. 272 in Poland. Its superstructure is a simply supported RC solid slab girder with the clear span equal 3.9 m (see Fig. 1a) The thickness of the slab is varying form 50 cm over supports to 60 cm in the mid-span. The slab is supported on the abutments by means of 8 mm thick bitumen sheets (Fig. 1b).
EXPERIMENTAL TESTS

According to Polish Standard PN-S-10040:1999 requirements after construction of the structure and before its opening to the traffic the bridge underwent proof load testing to confirm its behaviour compatible with the design assumptions. During the static test with application of a 115-tonne locomotive displacements of the superstructure in 6 points were measured: vertical displacements in 4 points (00-03) and horizontal displacements in 2 points (04-05) according to Fig. 2.

Position of the loading locomotive was chosen to generate the extreme deflection of the span. Taking into account dimensions of the locomotive only two first axles of a single boogie were located over the span while the third axle was outside of it (see Fig. 2a and Fig. 4).

Displacements of the structure were measured and recorded by means of LVDT gauges connected to Spider8 device produced by the company Hottinger Baldwin Messtechnik. Details of the gauges’ arrangement are presented in Fig. 3. Possible to reach accuracy of the system at measuring of displacements was equal to ca. 0.02 mm what was a sufficient characteristics for this test.

Fig. 2 - Location of measuring gauges and loading locomotive presented in: a) the side view, b) the cross-section (dimensions in mm)

Displacements of the structure were measured and recorded by means of LVDT gauges connected to Spider8 device produced by the company Hottinger Baldwin Messtechnik. Details of the gauges’ arrangement are presented in Fig. 3. Possible to reach accuracy of the system at measuring of displacements was equal to ca. 0.02 mm what was a sufficient characteristics for this test.

Fig. 3 - LVDT gauges used during the tests to measure: (a) vertical (in points 00-03) and (b) horizontal (in points 04,05) displacements
Another part of experiments was carried out in laboratory of the Wrocław University of Technology to check mechanical properties of the bitumen sheets supporting the span. A circular (of 160 mm diameter) two-layer specimen of a corresponding bitumen sheet underwent a uniform compression test in a loading press (Fig. 5a). During the test the applied force and the specimen’s deformation were controlled (the latter one by means of two independent clock gauges with measurement accuracy equal 0.01 mm). Results in a form of relationship between the average stress $\sigma$ and strain $\varepsilon$ received after a few preliminary compression of the specimen are presented in Fig 5b. On the basis of this diagram the average modulus of elasticity at the out-of-plane compression was found equal to 40 MPa.

![Fig. 4 - Position of the loading locomotive during the proof load test](image)

![Fig. 5 - Laboratory test of the bitumen specimen: a) arrangement of the test, b) obtained $\sigma$--$\varepsilon$ relationship](image)
NUMERICIAL ANALYSIS
For the purpose of verification of the experimental test results a numerical model based on FEM was applied. The bridge superstructure was represented by means of a grillage model (see Fig. 6) composed of orthogonal bar elements representing RC solid slab of the span. Each cross-section was modelled by 5 longitudinal elements connected in the transverse direction by means of bar elements located about every 50 cm. The variable thickness of the slab along the span was taken into account with application of tapered finite elements.

![Fig. 6 - Modified FE model of the bridge superstructure showing calculated deformation under the proof load](image)

In the first approach the boundary conditions were modelled as linear non-flexible supports (assumed in the original design of the bridge) located 10 cm away from the front surface of the abutments (see Fig. 2a and Fig. 7). However comparison of the displacements calculated by means of the initial model with the corresponding measured quantities did not provide satisfying compatibility (see Fig. 7).

Taking into account the level of the measured displacement magnitudes (not exceeding 0.2 mm) it was decided to consider more precisely the real support conditions of the span with bitumen sheets. The modified FE model, including spring supports representing the flexibility of bitumen sheets, is shown in Fig. 6. The coefficient of longitudinal elasticity $k_x$ of the spring supports, modelling the bitumen sheet out-of-plane stiffness (evaluated during the laboratory test described in the previous chapter), was calculated from the formula (1):

$$k_x = \frac{EA}{t}$$

where $E$ – modulus of elasticity of the bitumen sheet (assumed 40 MPa), $A$ – area of the part of the bitumen sheet represented by a single spring support, $t$ – thickness of the bitumen sheet.

The modified model provided more compatible results with the measured values. Comparison of the measured and calculated vertical displacements along its central line (indicated in Fig. 6) as well as in the mid-span cross-section is given in Fig. 7. It can be observed that for the modified model the zero vertical displacements took place 41 cm away from the front surfaces of the abutments what changed displacements of the whole span. Precise values of measured and calculated displacements of the span in measurement points nos. 00-03 is provided in Table 1. The table includes also relative differences given on percentage basis between the experimental and theoretical values.
Fig. 7 – Measured and calculated vertical displacements presented along the central line of the span and in the mid-span cross-section [mm]

Table 1 - Measured and calculated displacements of the span in measurement points nos. 00-03

<table>
<thead>
<tr>
<th>Measurement point</th>
<th>Measured displacements</th>
<th>Displacements calculated by means of initial model</th>
<th>Displacements calculated by means of modified model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$u_m$ [mm]</td>
<td>$u_{m1}$ [mm]</td>
<td>$u_{m2}$</td>
</tr>
<tr>
<td>00</td>
<td>0.177</td>
<td>0.149</td>
<td>-15.8</td>
</tr>
<tr>
<td>01</td>
<td>0.156</td>
<td>0.136</td>
<td>-12.8</td>
</tr>
<tr>
<td>02</td>
<td>0.100</td>
<td>0.084</td>
<td>-16.0</td>
</tr>
<tr>
<td>03</td>
<td>0.035</td>
<td>0.015</td>
<td>-57.1</td>
</tr>
</tbody>
</table>

Positive values indicated displacements downwards

CONCLUSIONS

The presented study shows that in case of testing and analysis of short-span RC bridges, where the controlled displacement magnitudes are very low (at the level of 0.1 mm), even the most detailed effects like deformations of bitumen sheet supports must be considered in theoretical analyses to get satisfying numerical representation of the structure behaviour. The commonly applied assumption of the theoretical span length of girders supported by a flat rigid surface equal to 1.05 of the clear span in some cases (like this one) can be not precise enough.

Besides, several additional remarks related to behaviour of the considered structural type can be formulated:

- Applied RC solid slab with the height-to-span ratio equal to 0.6/4.1 m = 0.146 provides relatively large stiffness of the span; the maximum deflection generated by the typical exploitation load do not exceed 0.19 mm which is less than 1/21000 of the span length,
- The mentioned high stiffness of the span is also a reason for low stresses within the main girder generated by the testing load,
- Internal forces generated by the testing load were relatively low comparing to values predicted by the UIC 71 code load (assumed in both Polish Standards, PN-S-
10030:1985 as well as in Eurocode 1, PN-EN 1991-2:2007 being taken into account in the design of the bridge) what was related to short length of the span where only some of the applied real vehicle’s axles could be entirely located on it,

- In spite of the live load location almost in the middle of the bridge width (see track axis in Fig. 2b) there is clearly unsymmetrical deflection of the span cross-section A-A presented in Fig. 7; the smaller deflection of the right-hand side part of the span is most probably related to presence of the slab girder edge beam (comprising a retaining wall for the track ballast) which stiffens this part of the span; thus it can be concluded that in case of very short spans even such small detail of the bridge cross-section (which could be regards as an element of bridge accessories) can influence its behaviour significantly,

- In case of short spans a precise model of the concentrated load (like a vehicle’s single wheel pressure) dispersion through the track pavement layers can be crucial for precise theoretical definition and representation of the structure’s response to the loads; in the presented analysis the assumed angle of the axle load dispersion through the pavement layers was equal to ca. 1:4.

REFERENCES


