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ARCH BRIDGES UNDER TEST LOADINGS

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Abstract

According to the polish bridge design code road bridges with spans over 20m and all railway bridges, before they are given to public usage, all require the conduction of studies during a test loading. This paper is an illustration to the experience in arch bridge test loadings of the research team of Department of Structural Mechanics and Bridge Structures from the Gdansk University of Technology. It concerns the applied computational conceptions and researches on an example of three arch bridges, built between 2005 and 2007. The presented calculations' results consists the analysis of spatial construction schemes made using the finite elements method (FEM) and its comparison to the field studies. The goal of the studies is to check the correctness of the construction's work and of the design assumptions.

Arch bridges with the longest spans, visualisation of the computational model, the displacement – deflection graphs of the arch bridge construction, generating the extreme span's deflections, results of the calculations and field dynamic measurements of the some bridges, example of computation results and field dynamic measurements during the static tests are presented in the paper.

Keywords: *bridge, FEM, test loads, numerical modelling, arch bridges*

1. Introduction

In Poland, in recent years, an appreciable development of bridge building can be seen. Arch structures are more and more common, because of the original geometrical and aesthetical form, aside with an explicit structural system (Fig. 1). According to the polish bridge design code [6] road bridges with spans over 20 m and all railway bridges should be subjected to the test loading before giving them to the public usage.

The goal of these studies is to check the correctness of the construction's work and of the design assumptions. The test loading is preceded by a test loading's project, which consists of, among other things, an advanced theoretical analysis of the existing bridge. The goal of the formulation of the computational models is to make a clear image of the real work of the construction, with a great conformity of its elements [1, 2, 3, 4, 5] – the construction system's character, the assumed construction and material solutions, the bridge's construction elements relationships, and the sensitivity to external factors, which all are very essential in arch structures.

Puławy – 2008 (under construction)
$L_t = 212$ m

Kraków – 2001
$L_t = 166$ m

Wolin – 2003
$L_t = 165$ m

Fig. 1. Arch bridges with the longest spans in Poland

This paper is an illustration to the experience of the research team of Department of Structural Mechanics and Bridges from Gdansk University of Technology. It concerns the applied computational conceptions and researches on an example of three arch bridges, built between 2005 and 2007 (Fig. 2). The presented calculations' results consists the analysis of spatial construction schemes performed using the finite elements method (FEM) and its comparison to the field studies.

Poganice – 2006

Gorzów Wielkopolski – 2007

Nowy Dwór Gdański – 2007

Fig. 2. Pictorial view of the analyzed overpasses

2. Applied finite elements

In the presented calculations, the following finite elements, marked with symbols (R), (P) and (C), were used. These are available, among other programs, in SOFiSTiK [6].

(R). 1-dimensional, 2-nodal, spatial beam-type finite elements, Timoshenko type. These are the class C^0 elements, with linear shape function, considering the shear effect and eccentricity of the beam's axis.

(P). 2-dimensional, 4-nodal, quadrilateral shell-type finite elements, Timoshenko-Reissner type. These are the class C^0 elements, with bilinear functions of shape, with enriching of the deformation state of area, which causes the elimination of the block-effect. They also consider the shear effect and the diversity of the reference surface's location (its eccentricity).

(C). 1-dimensional, 2-nodal, spatial truss-type elements (class C^0 elements, with linear functions of shape), which do not withstand the compression (one-side constraint).

In all of the tasks, the adequate structure's computations were preceded by the analysis of the convergence of the finite elements division and by the evaluation whether the non-linear worklaw of the system should be taken into account. The kinematic and dynamic values derived from the computation, which are the characteristics of the construction, were compared with the results obtained during the test loadings of the analysed bridges.

3.The road bridge over Łupawa river, a part of the main road no 6, in Poganice

The load-bearing structure of the bridge is made of one-span steel arch with concrete skewbacks, not braced in the plane of connection of the arches, with a box cross section of the main girders (Fig. 3). The arch girders are deviated outside the vertical plane. The deck is made as a steel grid of stringers and traverses and a composite, prestressed reinforced concrete slab. It is overslung to the main girders by steel suspension members. The span of the bridge is $L_t = 80$ m, and the total width is $B_c = 15.03$ m.

Fig. 3. Construction of the bridge in Poganice

The FEM model of the viaduct was treated as a 3D beam – membrane system (Fig. 4). The reinforced concrete slab was modelled by the membrane elements (P), the suspension members – by the truss elements (C), the arch main girders, stringers and traverses were modelled by the beam elements (R), with taking into account of the axis' eccentrics. The model of the span construction consists of 1083 nodes, 1072 membrane elements and 676 beam elements.

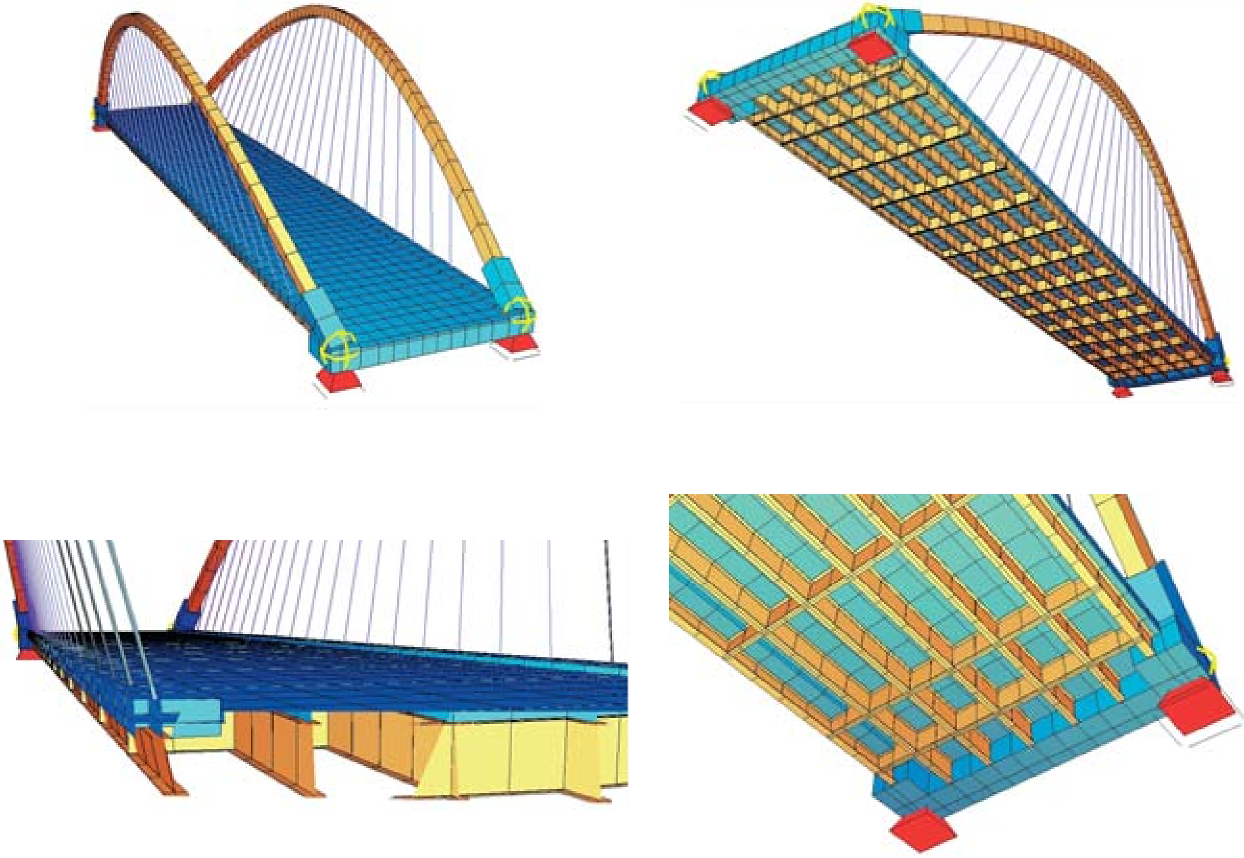


Fig. 4. Visualisation of the computational model – the bridge in Poganice

The analysis concerned the behaviour of the viaduct under a load of nine Tatra S-815 trucks, each one with a weight of 270 kN, for the verification of the construction in research „in situ". First, the deflections and displacements of the structure under static and dynamic loading were calculated in the most loaded points, and then, they were measured [5]. The example of a computation – measurement comparison graph is presented in Fig. 5.

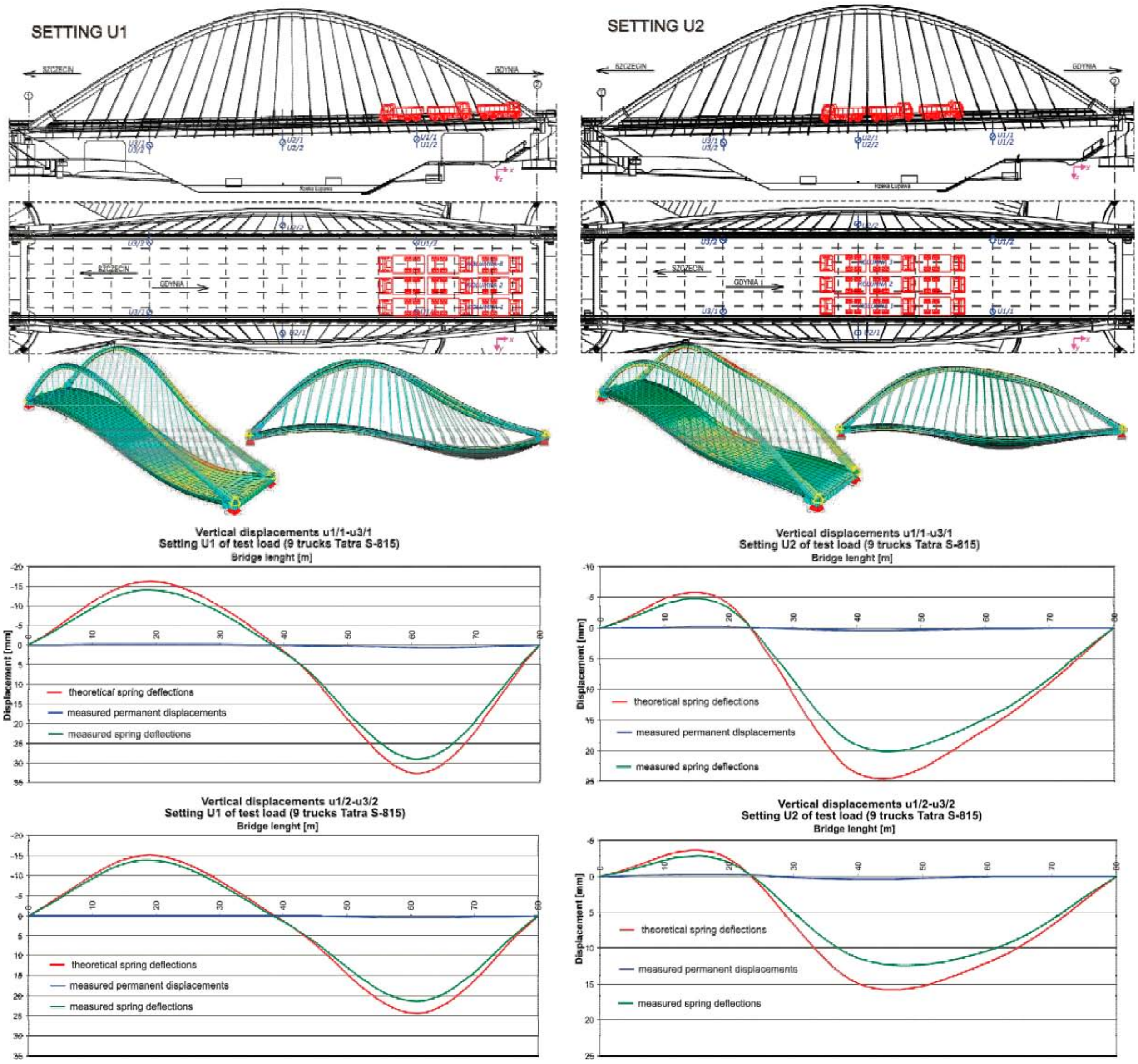
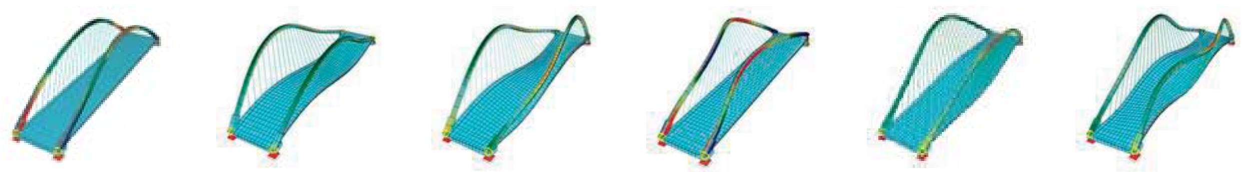


Fig. 5. The displacement – deflection graphs of the arch bridge construction from Poganice during the realisation of two settings of test loading, generating the extreme span's deflections

Measured values of the spring deflections – in the most loaded points – were about 89-90% of the values from calculations. Values of the measured permanent displacements were 0.3-3.0% of the spring deflections values. On the basis of the registered deflection and acceleration runs of the span construction, during the dynamic drive-throughs, the dynamic factors were estimated (φ_{max} = 1.60 during the trucks' drive-throughs over an artificial obstacle – a sill 10 cm high). The measured values of the bridge construction's deflections during the static and dynamic tests confirmed the theoretical assumptions, which were made in the calculations. The results of the research had shown a good correspondence between the proposed calculation model and the real behaviour of the bridge's construction.

From the registered deflection and acceleration runs of the span construction, with the use of a spectral analysis, the frequencies of eigenvibrations of the constructions were estimated. In the setting-up, in Fig. 6, the theoretical forms and theoretical and measured eigenvalues of vibrations of the span structure are shown.



$f_{1\ \mathrm{theor}} = 0.94$ Hz
$f_{1\ \mathrm{meas}} = 0.9$ Hz

$f_{3\ \mathrm{theor}} = 1.69$ Hz
$f_{3\ \mathrm{meas}} = 1.6$ Hz

$f_{4\ \mathrm{theor}} = 2.49$ Hz
$f_{4\ \mathrm{meas}} = 2.3$ Hz

$f_{5\ \mathrm{theor}} = 2.68$ Hz
$f_{5\ \mathrm{meas}} = 2.8$ Hz

$f_{8\ \mathrm{theor}} = 3.21$ Hz
$f_{8\ \mathrm{meas}} = 3.3$ Hz

$f_{10\ \mathrm{theo}} = 4.35$ Hz
$f_{10\ \mathrm{meas}} = 4.4$ Hz

Fig. 6. Results of the calculations and field dynamic measurements of the bridge in Poganice

4. The road bridge M1 over the Warta river on the Western Bypass of Gorzów Wielkopolski, a part of the main road no. 3 Szczecin – Zielona Góra

The bridge consists of two parts, separated by an expansion joint: section I – the midstream part and section II – the flooding part. The midstream section is a continuous, six-span composite construction, with a total length of 396.0 m (48.0+2×60.0+120.0+60.0+48.0). The span of 120 m is strenghtened by a steel tied arch (Fig. 7). The total width of the load-carrying structure is 14.40 m. The bridge spans consist of two steel box girders, connected with a reinforced concrete slab, braced by truss traverses in midspan and plate traverses over the supports.

Fig. 7. Construction of the arch stayed span of the bridge in Gorzów Wielkopolski

The FEM model of the bridge's section I was treated as a 3D beam – membrane system (Fig. 8). The model of the span structure consists of a 16 941 nodes grid, 15 642 QUAD elements (P), which are describing the deck slab, 9455 beam elements (R), modelling the main girders, suspension members and traverses, 12 278 kinematic constraints and 37 support constraints.

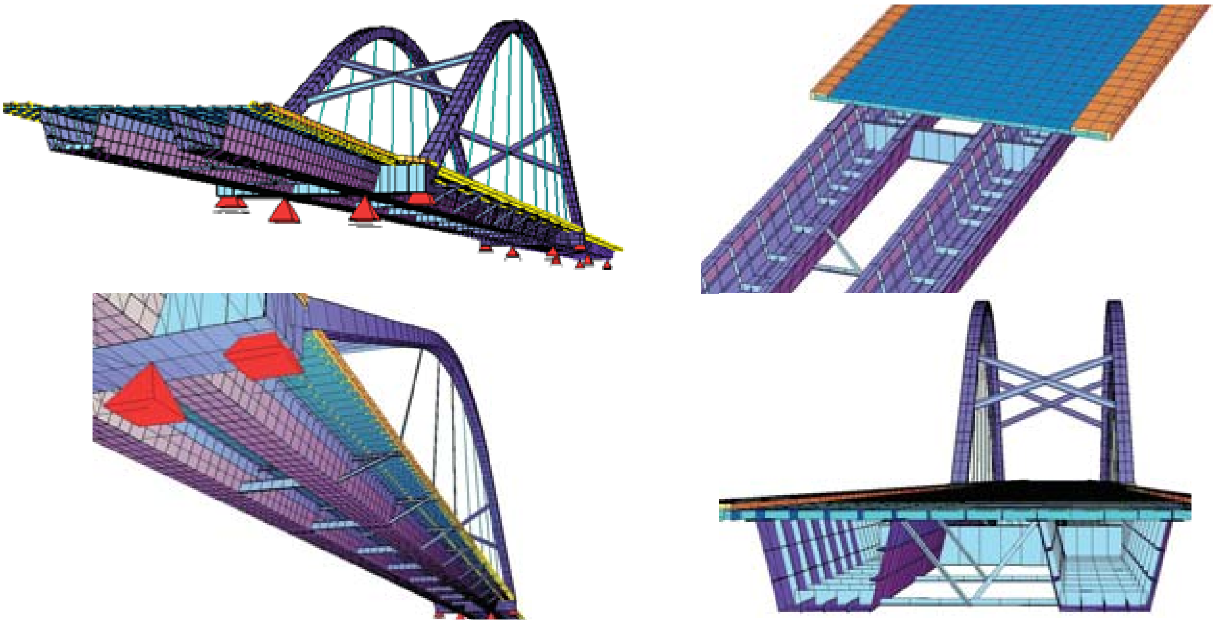


Fig. 8. Visualisation of the computational model – section I

The true behaviour of the construction under a road-derived load has been verified during the test load [5], which was carried out with use of a multi-combination setting of 12 Tatra S-81 trucks. During the test, the deflections and deformations of the span construction (the deck girders, arches) were measured, as well as the force increments in the suspension members and the accelerations of the load-carrying structure. Research for section I of the bridge was conducted during the static tests (4 settings = 20 schemes) and dynamic tests (72 tests). The results of static deflection tests had shown a very good correspondence between the theoretical and measured ones. Registered spring deflection results in the most loaded points of the arch span were about 87-94% of the theoretical ones, the permanent displacements were 0.5-4.2% of the spring deflections values. Representative static research results are shown on Fig. 9.

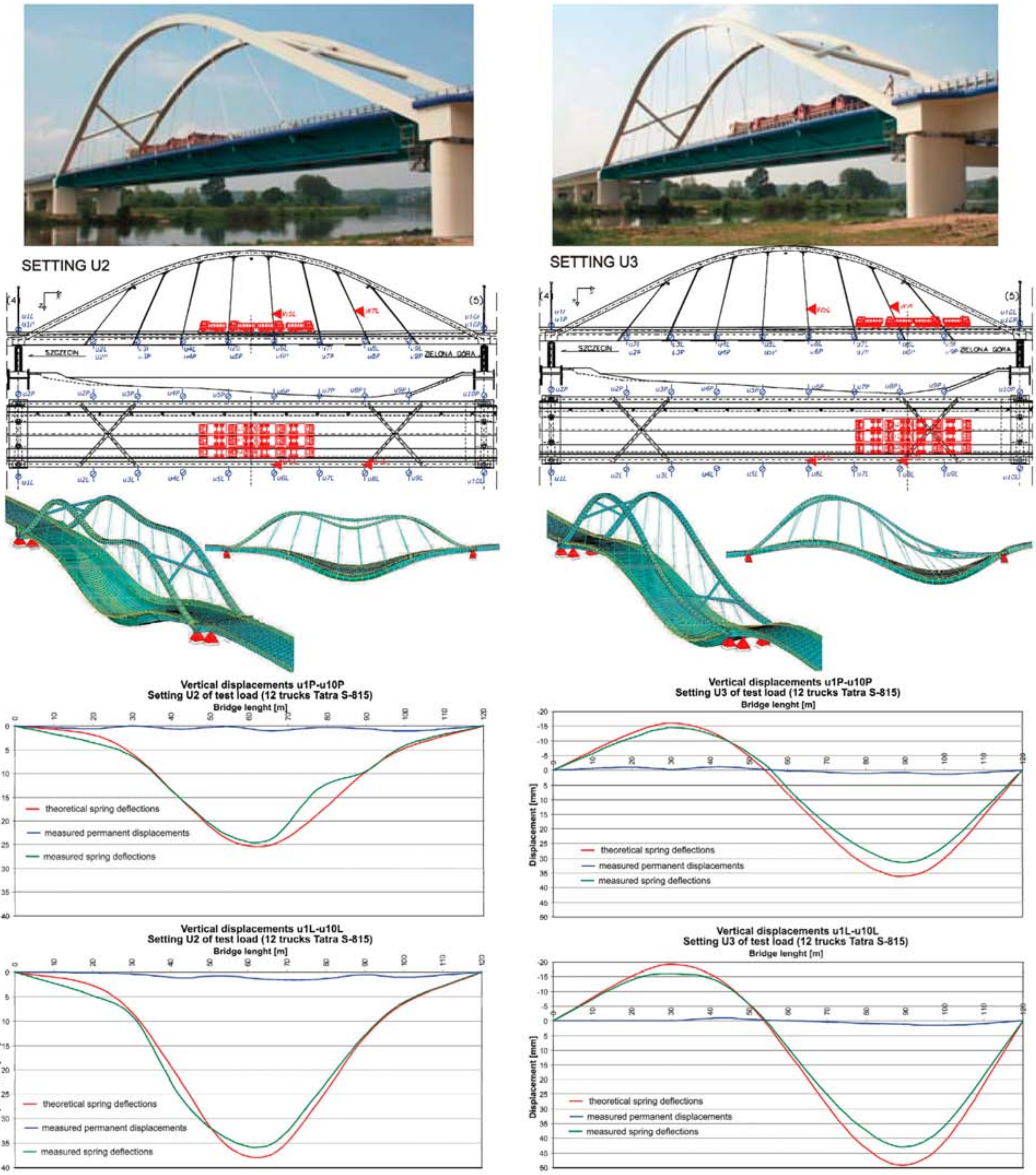
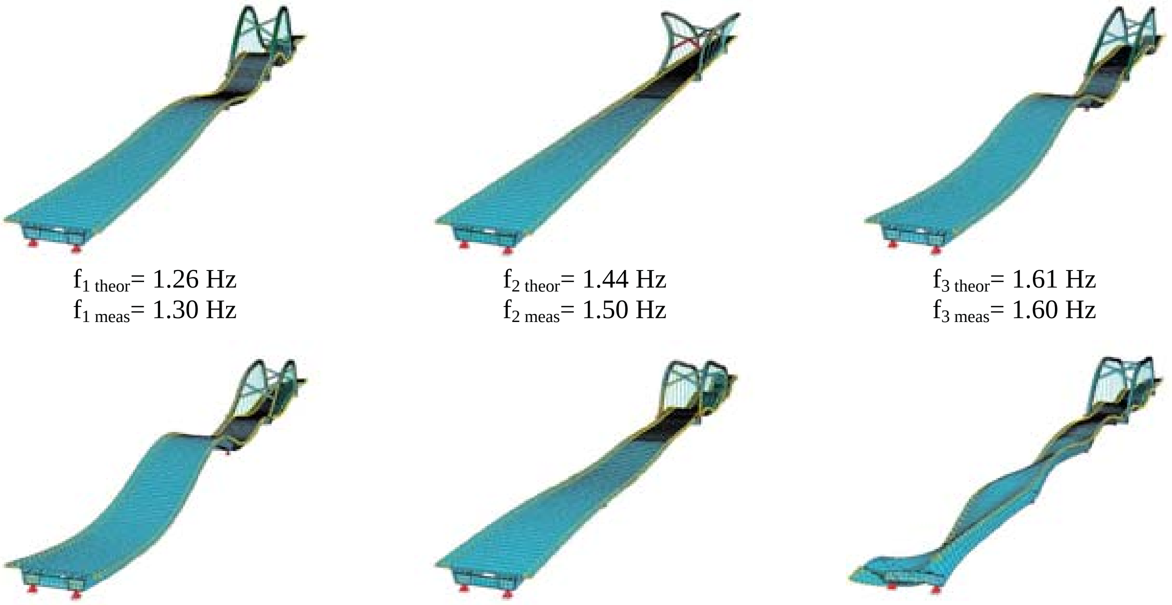


Fig. 9. The displacement – deflection graphs of the arch span construction of the section I of the bridge

The measured force increments in chosen suspension members were 94-113% of the theoretical values. Maximal value of the real dynamic factor, registered during the drive-throughs over an artificial obstacle – a sill 10 cm high, was $\varphi_{max} = 1.50$. The frequencies of eigenvibrations of section I, which were separated from the registered deflection and acceleration runs in the setting-up, are shown in Fig. 10.



$f_{1\ theor}$= 1.26 Hz
$f_{1\ meas}$= 1.30 Hz

$f_{2\ theor}$= 1.44 Hz
$f_{2\ meas}$= 1.50 Hz

$f_{3\ theor}$= 1.61 Hz
$f_{3\ meas}$= 1.60 Hz

$f_{4\ theor}$= 1.81 Hz
$f_{4\ meas}$= 1.85 Hz

$f_{5\ theor}$= 2.01 Hz
$f_{5\ meas}$= 2.00 Hz

$f_{6\ theor}$= 2.66 Hz
$f_{6\ meas}$= 2.70 Hz

Fig. 10. Results of the calculations and field dynamic measurements of section I of the bridge in Gorzów Wielkopolski

5. The road viaduct B9, a part of the road junction in Nowy Dwór Gdański, over the main road no 7

The viaduct is a one-span arch construction (Fig. 11) with a span of L = 54 m and the total width of 11.94 m. The load-carrying structure of the span is made of two steel arch girders, with a tubular cross section, while the arch girders are deviated to the inside of the vertical plane. The construction of the deck is made as a prestressed, longitudinal reinforced concrete slab, connected monolithically with transversally prestressed monolithical transverse beams. The skewbacks of arch girders are designed in the terminal traverses. The deck construction is overslung to the girders by steel oblique suspension members.

Fig. 11. Construction of the arch span of the viaduct in Nowy Dwor Gdański

The 3D viaduct model [5] was circumscribed on a grid of 1748 nodes (Fig. 12). The bridge span was simulated as a membrane – beam – truss system (the deck's slab – 1878 QUAD elements, the arches – 82 beam elements, suspension members – 32 truss elements, 120 kinematic constraints).

For implementation of settings, which caused the maximal internal forces and maximal deflections in construction, sets of test loadings were assumed. They consisted of six Tatra S-815 trucks. During the „in situ" studies, static and dynamic deflections of the span were controlled, in three measured cross sections, situated in ¼ L, ½ L, ¾ L as well as elongation of chosen suspension members. During the dynamic tests, the accelerations of the span were also controlled.

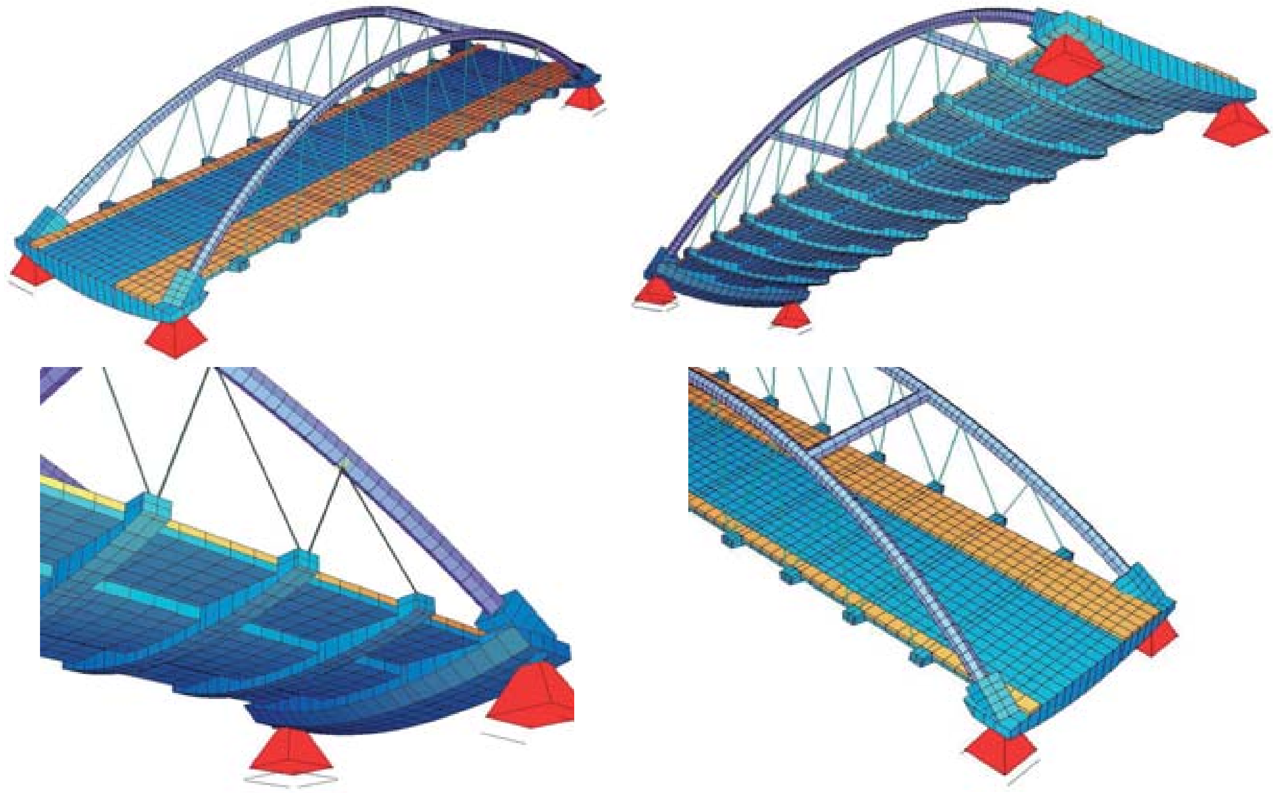


Fig. 12. Visualisation of the computational model – the B9 viaduct in Nowy Dwór Gdański

Measured values of the spring deflections – in the most loaded points – were 89-96% of the values from calculations. Values of the measured permanent displacements were 0.4-6.8% of the measured spring deflections values. The measured deflections values and their transverse distribution in the controlled cross sections confirmed the correctness of the theoretical assumptions, made in the computational model of the structure.

5. Conclusions

In the design practice, for the computation of the constructions mentioned in this paper, a beam grid scheme was mostly applied. However, results shown from the theoretical analysis and from the field research of arch bridges highlighted the need of applying more advanced computation models for getting a better image of the real behaviour of the structure. Using advanced methods of computation makes sense for the test loading of bridges, because these studies are the valuation of correctness of the bridge's work and on the basis of these results, the decision about how this type of construction will be used, is made.

The applied computation models should show the real work of the construction with a good compliance. They should consider the characteristics of the construction system, the assumed structure and material solutions, the bridge's construction elements relationships, and the sensitivity to external factors (the influence of the temperature, wind, other). The degree of the scheme's complexity depends on the significance of the problem and it has a direct influence on the valuation of the real work of the structure. Besides, it should be kept in mind, that when using

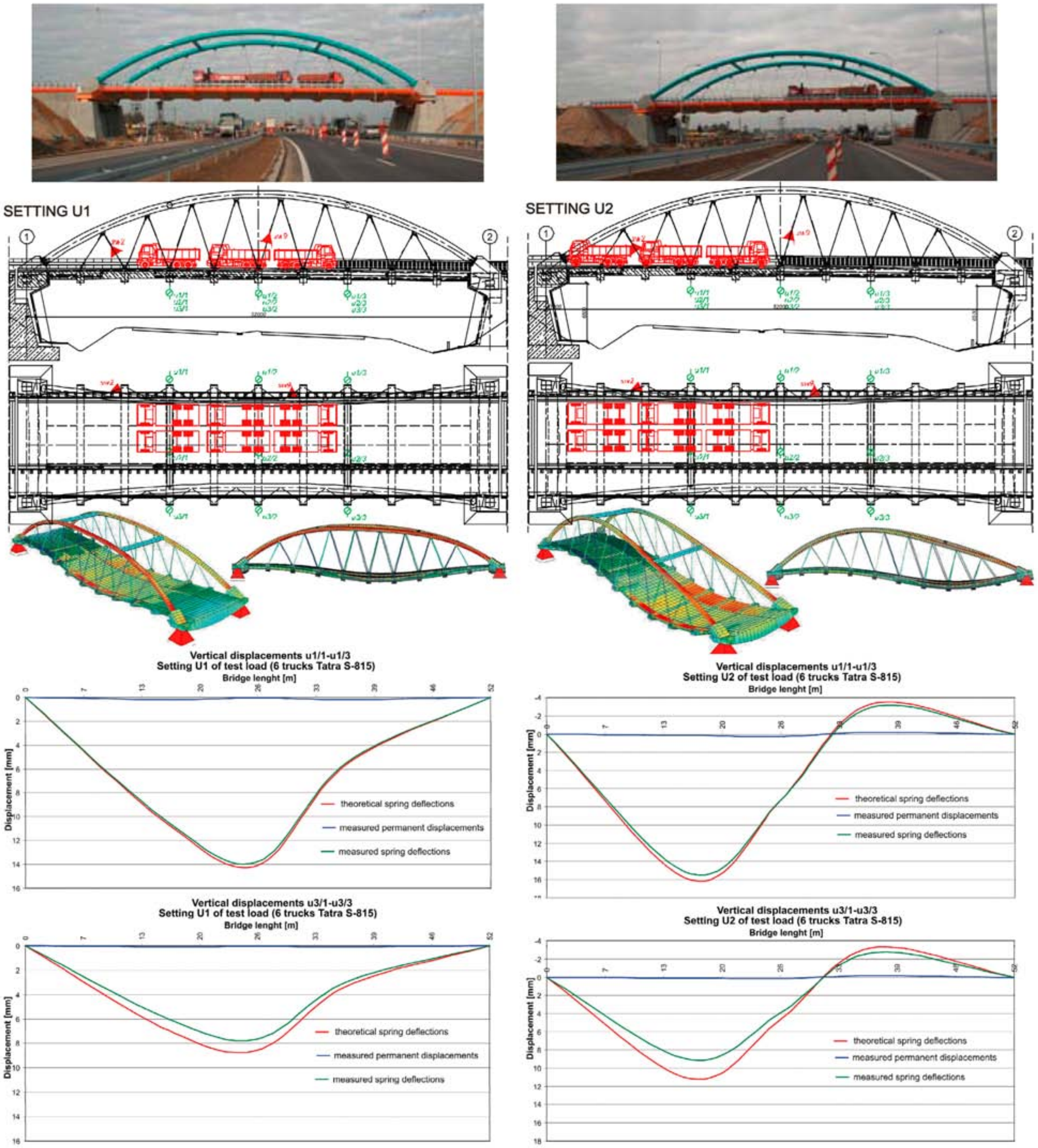


Fig. 13. The example of computation results and field dynamic measurements during the static tests

the QUAD or BRIC finite elements, because of the approximational character of FEM, the full analysis of convergence of the division must be done. It should also describe the influence of digitization on the result.

The research results are always burdened with some sort of error. Te main source of the differences between the theoretical results and those obtained from the field studies, aside from the geometrical representation, could be in the accuracy, with which the material parameters may be specified, their distribution in the construction or the realistic conditions of work of all the elements of the structure.

Examples shown above point out the fact, that the methodology of the theoretical analysis and field studies of the arch bridges, is correct.

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