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REBUILDING BAILEY BRIDGE TO BRIDGE WITH BASCULE SPAN – A CASE STUDY

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Abstract. The structural analysis of a road foldable prefabricated steel Bailey-type bridge located over the Tuga River in Żelichowo, Poland is performed in this paper. Interesting and untypical bridge redevelopment performed made it possible to lift the middle foldable bridge span by approximately 4.0 m concerning the existing state. The paper begins with a survey of literature carried out on the investigations of foldable Bailey-type bridge subject matter. A description of the numerical modelling of foldable prefabricated bridges is performed. The comparison of the proof load test results with the FEM numerical model results has shown very good compatibility. This paper can provide scientists, engineers, and designers the basis for structural analysis in the field of foldable Bailey-type bridge constructions and numerical simulations.

Keywords: Bailey bridge, bridge structure, foldable bridge, FEM, structural analysis.

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Introduction

The history of temporary foldable bridges is closely related to the history of wars and the need to ensure the mobility of warfare units (Figure 1). Donald Bailey – the inventor of the portable, pre-fabricated, steel truss bridge known by his name (Bailey et al., 1948) – was a civil engineer for the British War Office during World War II. The development of a technical and technological design for the Bailey folding bridge made it possible to launch industrial production of this type of structure in a short time. The Bailey system bridge was first used in Italy in 1943. The important features of this type of bridge are: ease and speed of assembly, the possibility of repairing damaged spans by adding girders, and assembly by sliding longitudinally from one edge. Appreciating the high usefulness of folding system bridges after the end of World War II, similar foldable steel bridges were developed in many countries, and so: in the former USSR, the RMM-49 bridge, in Germany the LZB bridge (Leichte Zerlegbar Brücke), in England the ESTB bridge (Everall Sectional Train Bridge) and in Poland MS 22-80 (see Figure 2), MS-54 and DMS- 65 (see Figure 3) bridges.

Folding system bridges have a very wide range of applications also in civil construction. Foldable bridges, apart from military applications, are used to erect temporary bridges in crisis (e.g., during natural disasters) or are erected during repairs and reconstruction of existing bridges. They are mainly used as detour bridges in the reconstruction and renovation of existing bridge crossings, often along the main communication routes, where significant payloads are required. The longest folding bridge in Poland as a detour (bypass) bridge (DMS-65 type construction) was erected in Kiezmark near Gdańsk. The bridge with a total length of 1174 m was two-way with two independent roadways with a width of 4.2 m. In this situation, the erection of a DMS-65 temporary foldable bridge enabled the preservation of the flow of traffic in time of rebuilding the existing bridge.

As temporary bridges, they are often treated by designers as typical structures and are often calculated in a very simplified way with the assumptions of perfect cooperation of all elements, without taking into account any damage and imperfections resulting from many years of operation and material wear. Used in severe conditions of very heavy traffic, with very often violated restrictions on the maximum weight and permissible speed of moving heavy vehicles, they show – as the experience of the authors of this work demonstrates – significant overloads and uneven distribution of internal forces and stresses in structural elements. Folding system bridges are also used in the construction of permanent bridges.

Figure 1. Application of Bailey bridges during WW II (70th Infantry Division Association, n.d.)

a) viaduct along DK 51 in Stary Dwór, Poland **b)** bridge over DK 7 over the Piaskowy Canal, Poland

Figure 2. Diversion road with MS 22-80 bridge

Figure 3. DMS-65 detour bridge, Chełmno, Poland

The present research aims at the road foldable prefabricated steel Bailey-type bridge located over the Tuga River in Żelichowo, Poland. Interesting and untypical bridge redevelopment is performed making it possible to lift the middle foldable bridge span by 4.0 m compared to the existing state. The presented investigations can be treated as part of an expert bearing capacity assessment of the bridge with possibilities of carrying loads and extended working life under new requirements enabling the middle bridge span movable. The paper begins with a survey of literature carried out on the investigations of foldable Bailey-type bridge. Next, numerical modelling of foldable prefabricated bridges through 2D models and 3D models is described. The description of the bridge redevelopment with basic details and results of structural analysis is also provided. Further sections describe proof loads static and dynamic tests, which were utilized for the validation of the bridge FEM model. The paper also describes how the proof load test was conducted. In the end, the conclusions are made. The paper provides scientists, engineers, and designers with assessments and numerical simulation methods of prefabricated steel Bailey-type bridges.

1. Literature review

The literature concerning the subject of foldable prefabricated steel Bailey-type bridge investigations is extensive and has a commitment not only to the engineering community but also to the scientific community. The chosen papers are discussed in the chonological order. Mitchell et al. (1978) described the traffic situation before and after its completion of the construction, the design and construction of the temporary Bailey Bridge over the Derwent River at Hobart, Tasmania. Gopalakrishnan (1999) described the temporary and permanent restoration of the 116 m long Bailey suspension bridge across the River Diana in the foothills of the Himalayas in Bhutan. King & Duan (2003) presented experimental investigations on seven one-sixth scale models of the Bailey bridge trussed-steel frame. They concluded that the lateral bracing system of a planar frame was very important for preventing an early collapse and allowd the ultimate strength to be reached. Jarzyna (2004) described structure, technical and operational conditions, technology, and organization of construction during assembling and disassembling of railway-road bridge structure KD-66-C type for the construction of by-pass bridges over CMK tracks during the reconstruction of the Sochaczew–Mszczonów road in Poland. Parivallal et al. (2005) described the instrumentation details, loading arrangement, testing procedure, and measurement of one double-lane Bailey bridge response during the load test. Kałuziński & Mańko (2009) gave examples of the application of steel folding bridge type MS-54 as detour objects. Skorupka & Duchaczek (2010) presented an original method of the analysis of risk assessment of transport object exploitation in view of military steel foldable bridges, which might occur during the exploitation. Lee et al. (2011) presented the results of computational analysis for the stability and factor of safety of the Bailey panel bridge finite element method. Drozdowska (2011) described classical solutions to surfaces commonly used in folding road bridges such as DMS-65, MS-22-80, and MS-54 and presented the most common damages in bridge surfaces, as well as their causes. Joiner (2011) described the story of World War II design and development of the famous Bailey Bridge at the Experimental Bridging Establishment. Duchaczek & Mańko (2012) presented the strength analysis of a traverse in a DMS-65-type assembled bridge to identify the most strenuous places in the investigated traverse. Chróścielewski et al. (2012) showed calculation results and in-situ measurements of temporary MS 22-80 bridge and made conclusions of appliance sophisticated numerical modelling and necessity of in-situ measurements to check the correctness of structure work. King et al. (2013) described the experimental work of two full-scale Bailey bridge segment load tests where the midspan deflections of panel assemblies were measured and axial strains of several critical members during the loading. Marszałek & Piechota (2014) presented an evaluation of the load-carrying capacity of multi-span folding bridges based on floating supports. The authors showed that nomograms facilitated the simple and fast determination of the impact of changing fixed supports into floating supports with different bridge spans and its influence on the capacity. Mondel & Falkowski (2014) presented the specifications of Bailey bridge, MS 22-80, MS-54, and DMS-65 military road bridging systems, which were used for force training as well as for rebuilding civilian permanent bridges. Marszałek & Wrona (2015) presented the truss segment enabling the connection of MS-54 and DMS-65 bridge constructions. The computer calculations of the bridge proposed joint including the part of the designed fitting were also carried out. Biondini & Malerba (2016) studied the structural collapse of an existing Bailey bridge. The authors concluded that the bridge collapse occurred due to the secondary stresses originating from the out-of-plane distortions induced by improper lifting of the structure after the new location installation. Drozdowska (2016) provided an example of rebuilding a destroyed bridge by natural disasters using elements of a folding MS-54 military bridge. The construction drawings and numerical calculation were presented with the proposition of utilizing another folding type MS-22-80 bridge. Marszałek et al. (2016) attempted to assess the possibility of applying the DMS-65 structure for the temporary reconstruction, restoration, or repairing a transport infrastructure, damaged by natural disasters or other catastrophes. Chikahiro et al. (2017) showed reviews on fundamental numerical and experimental research results of the emergency bridge of Mobile Bridge. The concept of the bridge is based on the application of a scissor-type mechanism, which provides its rapid deployment. Chmielewski & Wolniewicz (2017) described procedures connected to the application of STANAG 2021 ENRG standardization agreement requirements to determine the load-bearing capacity of the DMS-65 folded bridge. Szelka (2018) investigated possible applications of foldable structures in bridge engineering and their development perspectives. The paper was supplemented with examples of foldable bridges (DMS-65, MS-54, MS 22-80, KD-66C) erected temporarily in Wrocław, Poland. Kamruzzaman & Haque (2020) studied 13 Bailey bridges within the Rajshahi Division of Northern Bangladesh. The results revealed that the investigated Bailey bridges deflected more than the safe limit. Ostrowska & Chmielewski (2022) presented two new technologies for the construction of single-span road bridges using the DMS-65 folding bridge structure. The proposed technologies were applied in practice and resulted in savings in cost and time of bridge foldable construction. Prokop et al. (2022) determined the applicability of the demountable Bailey bridge system to construction sites or other temporary conditions while meeting the regulations for the design and assessment of steel bridges. Papavasileiou et al. (2022) investigated the modal parameters of 30.48 m Triple-Single Bailey bridge based on traffic-induced vibrations and compared them with numerical results. Kusimba et al. (2022) assessed the Bailey Bridge's condition and investigated its adaptation as a permanent structure, targeting the Acrow Bailey Bridge in Japan. Szelka & Wysoczański (2023) described examples of the application of foldable structures DMS-65, MS-54, MS 22-80, and KD-66C for the construction of bypass bridges. Ostrowska & Chmielewski (2023) gave examples of the use of portable bridge structures in civil engineering with selected scientific principles of work organisation, influencing the maintenance of a high rate of their implementation. Many engineering and scientific investigations are taken into consideration in the subject of steel truss Bailey-type bridges used for more than 80 years. A proper assessment of Bailey-type bridges is taken to impact the range of required repair or structure reconstruction and guarantees the proper assessment of the load capacity investigated structure which in extended working life should assure the safe use of portable, pre-fabricated bridges.

2. Numerical modelling of foldable prefabricated bridges

The operation specificity of foldable prefabricated bridges should be taken into account in FEM modelling as the non-linear nature of their behaviour results from specific construction solutions. Factors significantly affecting the bridge behaviour, and thus the distribution of displacements and stresses, and the effort of the structure are backlash (lash) in pin connections between lattice segments of the main girders (Figure 4); backlash in vertical screw connections (Figure 5) between lattice segments (horizontal displacements of segments); backlash in screw connections of vertical transverse braces with lattice girders; foundation imperfections – vertical displacements on supports resulting from the uneven settlement of supports and bearings under the influence of loads or assembly imperfections; structural solutions

Figure 4. Detail of bolt and screw connections between lattice segments and 3D FEM visualization with GAP elements used to connect between segments in a Bailey-type panel

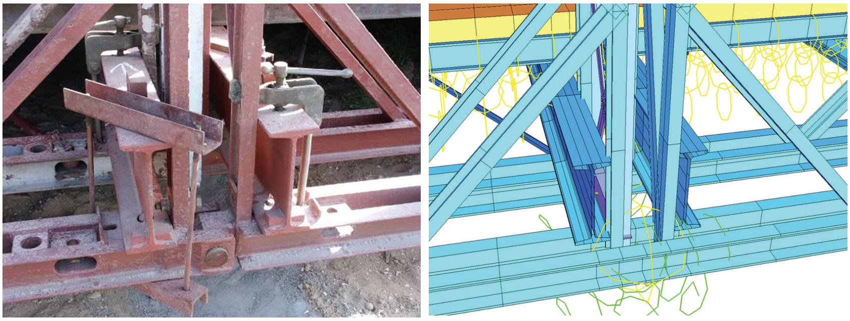


Figure 5. Support detail of the crossbars on the chords of the lower lattice girders and 3D FEM visualization with applied kinematic couplings to represent the method of cooperation of structural elements

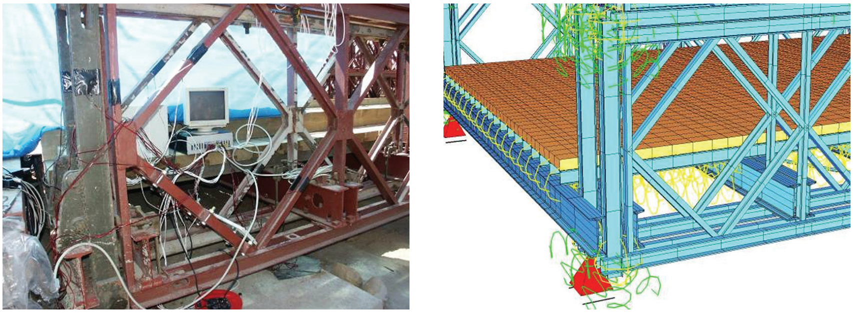


Figure 6. Support detail – Bailey girder segment with support post and 3D FEM visualization

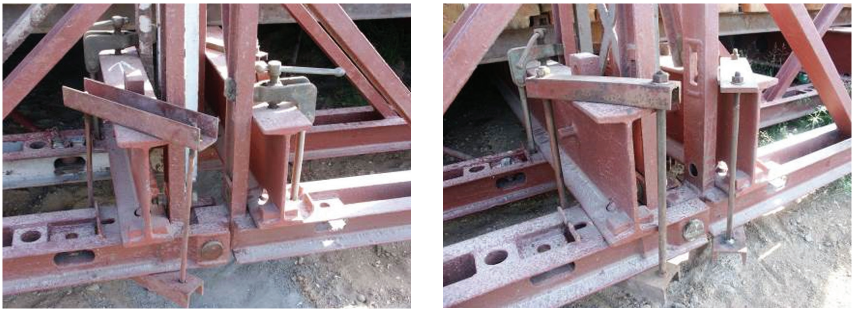


Figure 7. Bridge MS 22-80 type – different variants of fastening the crossbars to the bottom chords of panels

Figure 8. Bridge MS 22-80 type – deformations of panels examples on site

for supporting the crossbars on the bottom chords of lattice girders (Figures 6–8); a variety of lattice girder bars and braces (individual elements – reinforced or replaced) (Figure 7); displacements, and deformations of elements (Figure 8). In Figures 4–6 (on the right-hand side), the yellow and green curved lines visualize the GAP elements (the gap element transmits forces along its axis only after its deformation has exceeded the indicated gap) and the kinematic coupling elements (applied in specific degrees of freedom) applied in FEM analysis in screw and pins connections.

Under observations of the behaviour of foldable prefabricated steel Bailey-type bridges both during proof load tests and during their normal operation, it was found that various irregularities, damage, or changes resulting from the wear of individual elements occurred during their use: mechanical damage to the pins resulting from the incorrect assembly of the segments, increasing backlash in bolt connections of lattice segments as a result of changes in bolt diameters resulting from the wear of these elements and the fact of supplementing these elements with new ones, with dimensions different from the original solutions, increase in a backlash in screw connections between mesh segments as a result of wear of elements or replacement of screws with other ones with smaller diameters than the original ones, backlash in screw connections of vertical and horizontal bracings of lattice girders, loosening of connections – elements securing the crossbars to the bottom chords of lattice girders, permanent deformations and damage to lattice girder bars and bracing elements and the platform resulting from overloading during operation, negligence during assembly and disassembly, or storage, see Figures 7 and 8.

In engineering and diagnostic practice, when modelling foldable prefabricated structures, various descriptions of varying complexity are used, ranging from 2D beam diagrams with a simplified description of backlash in segment connections to 3D non-linear systems representing both the main girders, platform elements and braces, with the use of contact elements for mapping bolt and bolt connections of structural elements and clearances in them. The applied computational FEM models can be divided into five basic types:

1. A single, equivalent beam with bending stiffness corresponding to the stiffness of the lattice girder – a simplified way of taking into account the influence of backlash in bolt connections on the structure displacements – formulas calculated as for a single chain composed of pinned panels (Białobrzeski, 1978) – a system often used by engineers to estimate the structure’s effort from bending and for estimating extreme vertical displacements – deflections.

2. FEM 2D model of one substitute beam girder, which represents a lattice with rigid, non-flexible nodes, Figure 9 – a model most often used by designers of this type of bridge – a simplified way of taking into account the effect of backlash in bolt connections on the displacement of the structure.

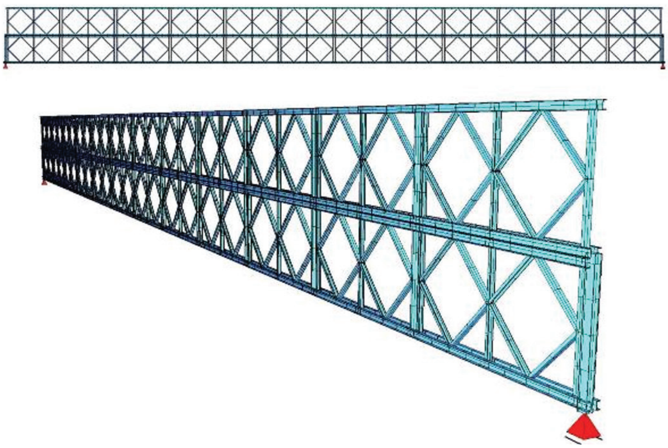


Figure 9. Visualization of the 2D model – a substitute lattice girder with rigid, non-flexible nodes

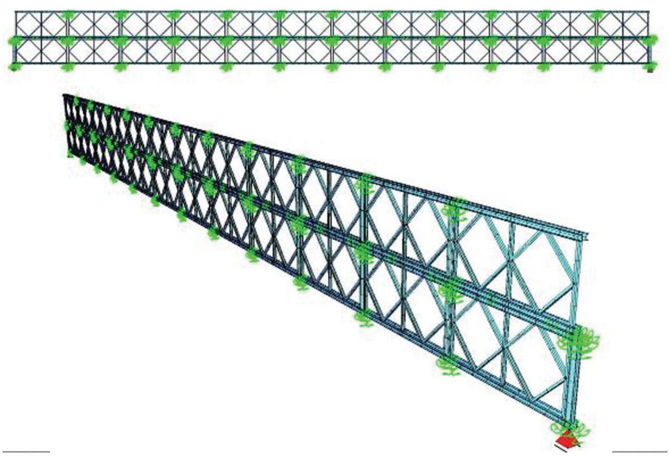


Figure 10. Visualization of the 2D model – a substitute lattice girder with rigid, non-flexible nodes with contact elements taking into account backlash (lash) in pin and bolt connections

3. FEM 2D model of one girder composed of lattice panels with rigid, non-flexible nodes, with contact elements including vertical bolt connections and pin connections between the segments, and taking into account backlash in pin connections, Figure 10.
4. FEM 3D model of truss panels with rigid nodes, platform elements and braces, Figure 11 – a simplified way of considering the effect of backlash in bolt connections on the displacement of the structure.
5. FEM 3D model of truss panels with rigid nodes, platform elements and braces, with contact elements taking into account connections between panels as above, Figure 12.

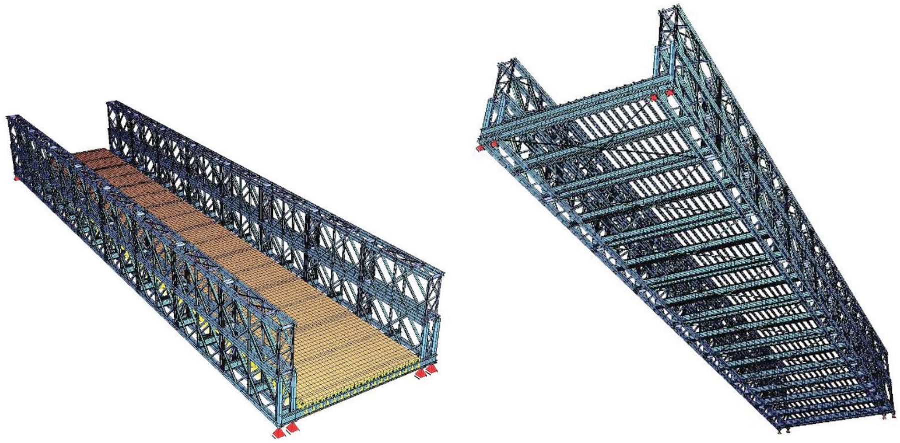


Figure 11. Visualization 3D model – lattice girders with rigid, non-flexible nodes, platform and bracing elements

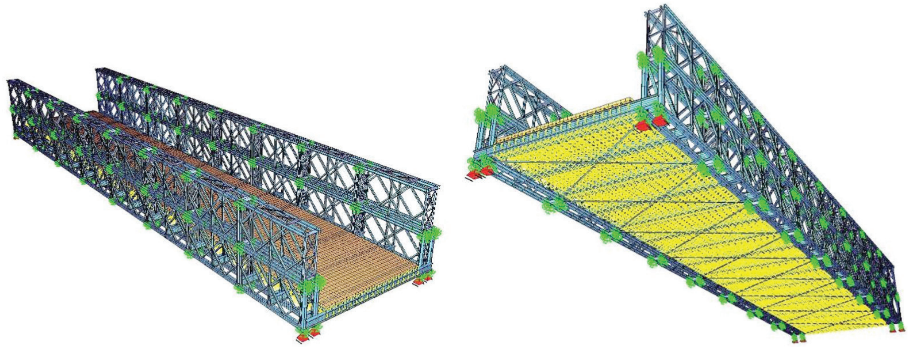


Figure 12. Visualization of the 3D model – lattice girders with rigid, non-flexible nodes, platform, bracing elements, and contact elements taking into account backlash in pin and bolt connections

3. Materials and methods

The subject of the present investigation is a reconstruction of an existing road bridge MS 22-80 Balyey-type over the Tuga River in Żelichowo, Poland, see Figure 13. The theoretical length of the span bridge is 57.90 m with the total length with gravel walls being 64.7 m. The total width of the bridge is 6.01 m with the width of the roadway equal to 4.2 m. The axial spacing of lattice girders (panels) is equal to 5.58 m and the construction height (panel height) is 1.55 m. The intersection angle of the bridge longitudinal axis with the river axis is ~80°. The bridge after the performed reconstruction has a possibility of lifting the middle span by 4.0 m concerning the existing state. In terms of geomorphology, the bridge location area is a fragment of the delta plain of the Vistula River within Żuławy Wiślane. This plain rises about 3.5 m above sea level.

As part of the rebuilding of Bailey Bridge to the bridge with a bascule span, the following works were designed and carried out: construction of the necessary structural elements; strengthening of the supporting structure; installation of balustrades; construction of 4 pylons; renovation and replacement of steel bridge structure elements; anti-corrosion protection; construction (replacement) of a new wooden surface on the bridge; repair and coating protection of the surfaces of concrete pillars, abutments, wings and gravel walls of the abutments; renovation and repair of existing shoreline reinforcements; profiling slopes along pedestrian routes on embankments and strengthening them; cleaning the river bed and the area around the bridge; installation of road barriers; installation of lanterns illuminating; installation of small architecture elements; installation of road and navigation

Figure 13. Views on the bridge over the Tuga River in Żelichowo, Poland: A road and sailing serviceability stage

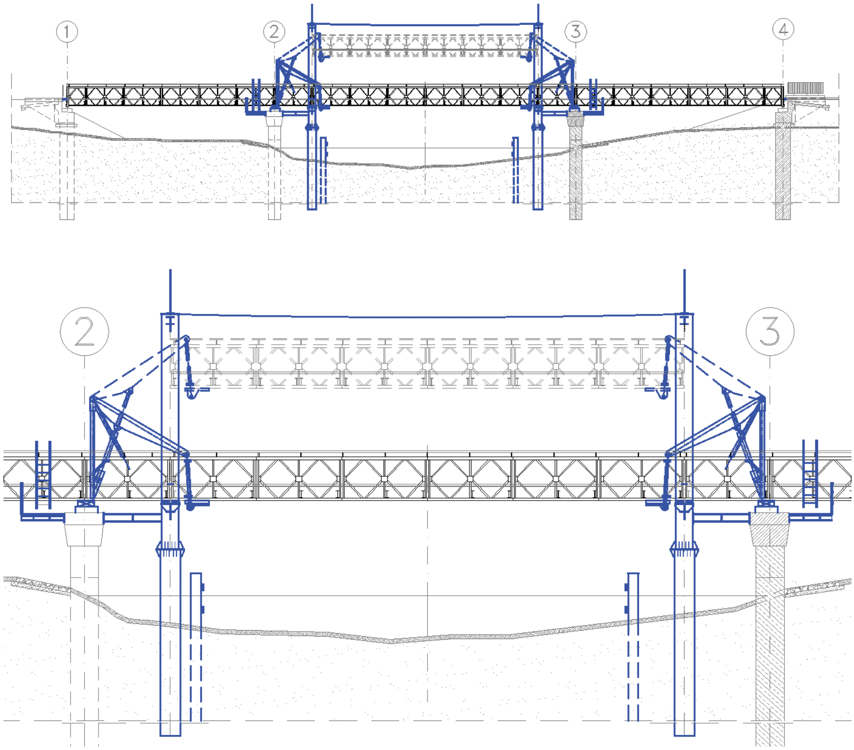


Figure 14. Side view (whole view and magnification of middle span) of the bridge over the Tuga River in Żelichowo, Poland

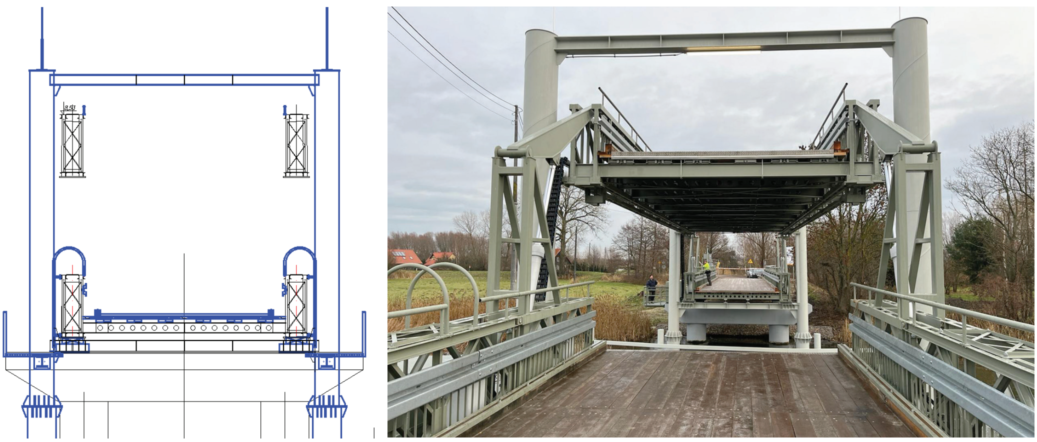


Figure 15. Cross-section and view of the bridge over the Tuga River in Żelichowo, Poland

markings on the bridge and a water gauge staff on the pillar. In Figures 14 and 15 by blue colours newly designed and constructed structural bridge elements are indicated. As guides for the drawbridge span, steel pylons (pipe 610/12) were designed, based on steel piles filled with concrete (pipe 711/11). The pylons at the level of the underside of the bridge structure are connected by a crossbeam on which the drawbridge and fixed span brackets are supported through elastomer bearings, thus creating an articulated connection of the end spans with the pylons. The abutment walls are reinforced concrete caps measuring 1.0×1.3 m and 9.0 m long with gravel walls, based on two piles that are 100 cm in diameter and 21 m long. The pillars are reinforced concrete piles 1.2×14 m and 8.9 m long, based on two columns constituting extensions of piles that are 100 cm in diameter with a total length of 24.0 m. Pavements on the bridge along the entire width between the internal girders of the bridge are made of new wooden logs, 6 cm thick, made of pine wood, laid on logs that are 5 cm thick and 15 cm wide, fastened to the steel structure bridge. The structural wooden surface of the roadway is protected with a fire retardant and a fungicidal impregnation.

4. Structural analysis

The three-dimensional (3D) finite element model (FEM) of the foldable prefabricated steel MS 22-80 Bailey-type bridge is built. In FEM numerical calculations, the SOFiSTiK structural engineering system is used (see, e.g., Malinowski et al., 2018). The 3D FEM model of lattice girders is analysed with rigid, non-flexible nodes, platform, bracing elements, and contact eleme-nts taking into account backlash in pin and bolt connections. The lattice girders and elements of the platform and bracings were modelled with 2-node beam elements of the Timoshenko type, C0 class with linear shape functions, taking into account eccentricities, while the wooden pavement – with 4-node shell finite elements. The model uses contact elements of the SPRI and GAP types, taking into account the flexibility of pin connections between the panels. Two cases are calculated, with the base position of the middle span (in the case of traffic road serviceability) and with the middle span raised (in the case of sailing serviceability), see Figures 16 and 17. Comparisons of real bridge details with numerical model views are performed in Figures 18–20. The validation of the bridge FEM model was performed utilising proof load tests, described in Section 5.

In Poland, new bridges are designed on actions of traffic load guidelines in the PN-EN 1991-2 standard (PKN, 2007). For rebuilding existing bridges, other loads can be allowed with the introduction of a ban on the movement of vehicles with a permissible total weight. The considered portable, pre-fabricated, steel bridge is able to withstand the appropriate traffic loadings without either overturning or being overstressed in any structure part. The bridge is designed for class D load according to the PN-S-10030 standard (PKN, 1985). The traffic load is composed of q and K types of loads, see Figure 21. The load values of q and K type are equal to 1.6 kPa and 320 kN (8×P = 8×40 kN = 320 kN), respectively. The distribution of q load (arbitrary distribution) and location of K load have to produce the largest responses in the analysed structural elements. Apart from this traffic load, dead-weight and bridge equipment loads (permanent loads) are also imposed.

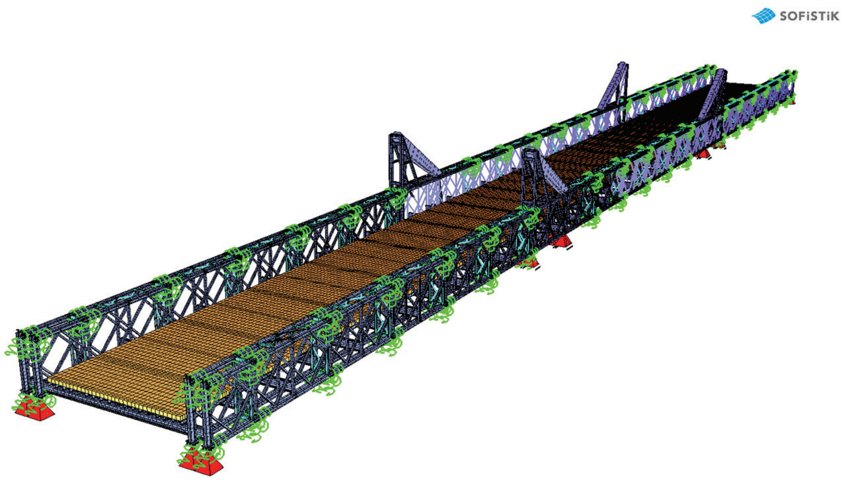


Figure 16. Visualization of the 3D FEM model – bridge in case of traffic road serviceability

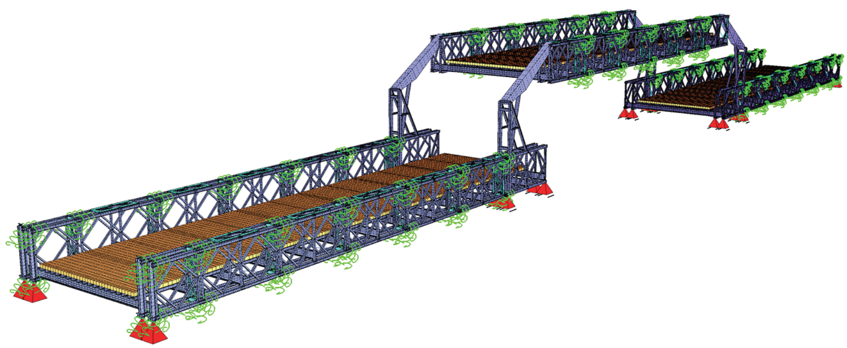


Figure 17. Visualization of the 3D FEM model – bridge in the case of sailing serviceability

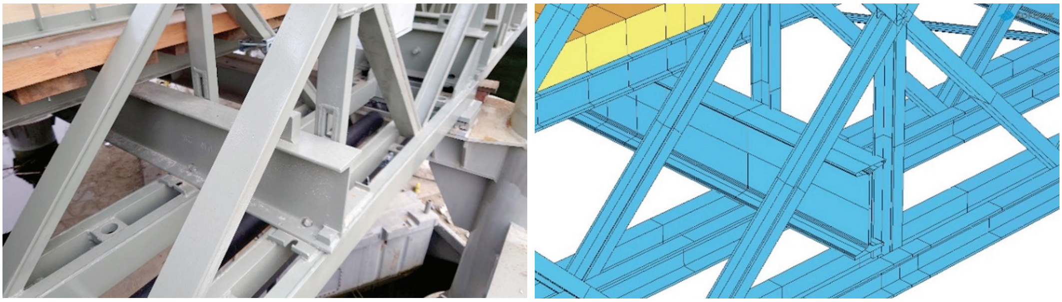


Figure 18. Bridge detail compared with the FEM model – support of transom on the double panel

Figure 19. Bridge detail compared with the FEM model – side view of the bridge

Figure 20. Bridge detail compared with the FEM model – bottom view on transoms, bracings, stringers, and platform deck

Based on numerical calculations, extremal values of internal forces and stresses in the superstructure are determined. In Figure 22, the maximal design stress HMH value envelope is shown for the combination of traffic load and permanent load. It should be noted that maximal stress HMH values in girder chords occur in pin connections – elements reinforced within the pin connections between segments. The characteristic and design values of forces used in dimensioning and verification of cross sections fulfil serviceable limit state (SLS) and ultimate limit state (ULS) conditions. The extremal values of internal forces in the bridge elements in all cross-sections fulfil bearing capacity conditions.

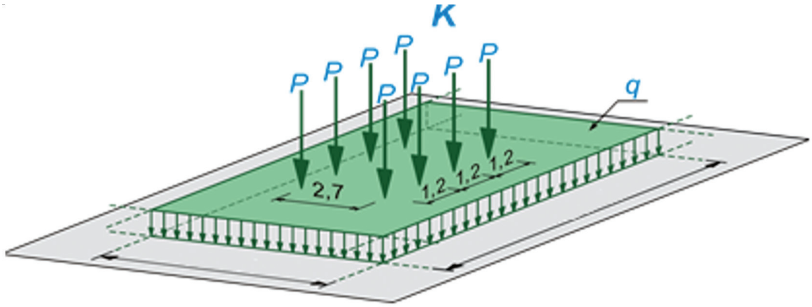


Figure 21. Traffic loads class C (q and K types)

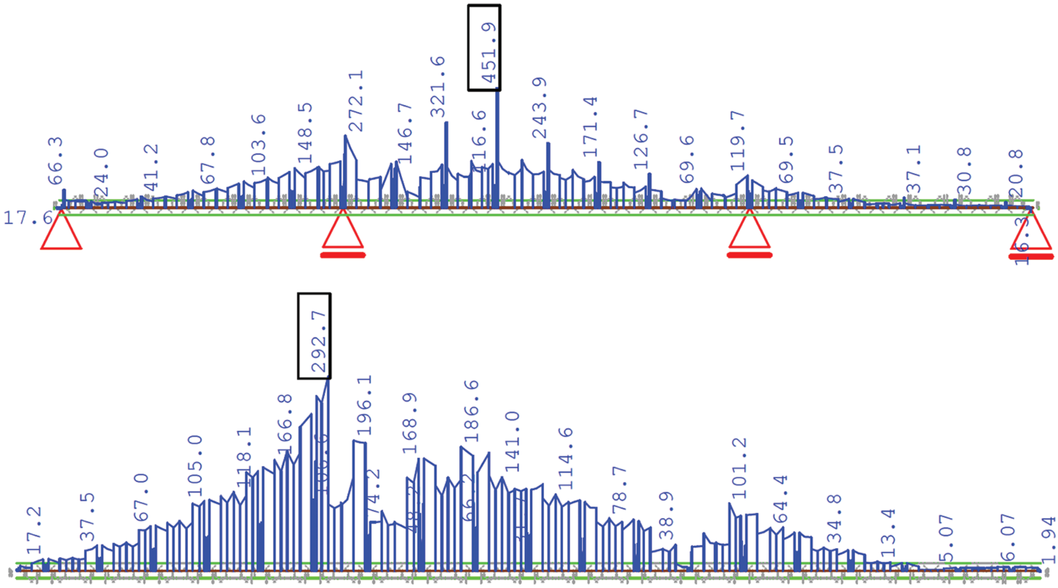


Figure 22. Chosen results of the FEM structural analysis: maximal stress HMH for external girder – lower and upper chords

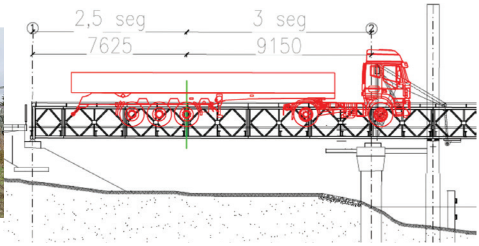
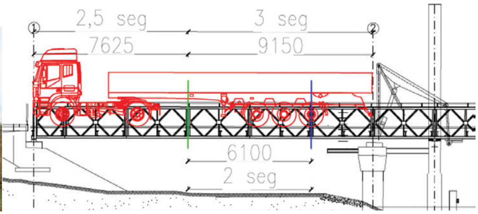
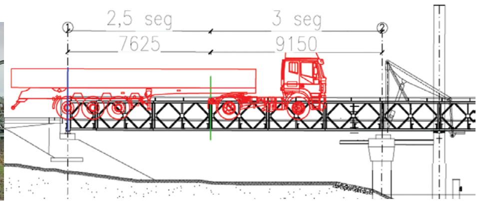
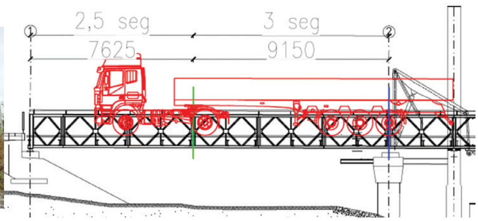
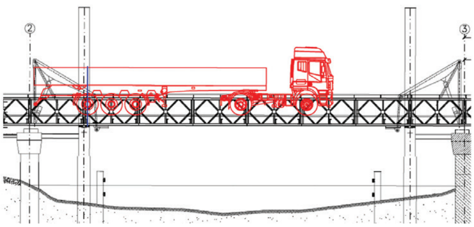
5. Proof load tests

The proof load test on bridges is one of the key issues before the bridge is operational in use (Chahud et al., 2018; Faber et al., 2000; Filar et al., 2017; Innocenzi et al., 2022). The static proof load test of the bridge included: measurements of vertical displacements – deflections of the span bridge structure, measurements of deformation/stress increments in the chords of lattice girders, and measurements of settlement of supports. In the proof tests, five different positions of the test load (one 5-axle car with a weight of 33 240 kg) were analysed, see Table 1. This load was selected to force the structure to generate internal forces and displacements at representative points at a level of at least 75% to 85% (guidelines by technical requirements of steel bridge proof loads, (Ziopaja, 2016)) of the internal forces and displacements that would arise from assumed standard traffic loads.

Vertical displacements of span deflections were measured and recorded using calibrated inductive sensors and specialized measuring equipment. The vertical displacements of support settlements were measured and recorded using the geodetic method using the calibrated precision levelling instrument. It should be noted that other equipment types are used also in measurements, e.g.: portable camera-based vibration monitoring systems (Bocian et al., 2023), terrestrial laser scanning technology (Gawronek & Makuch, 2019) or ground-based radar interferometry (Owerko et al., 2012). Strains/stresses in the steel structure were measured and recorded using the calibrated induction extensometers and specialized measuring equipment (Jasiński et al., 2023). A comparison of chosen measurement results from load tests with FEM numerical results is provided in Table 2. The localization of measurement points: p1, p2 and T1 is shown in Figure 23. The given in Table 2 uncertainty of measurement is defined as the standard uncertainty of measurement multiplied by the coverage factor k = 2, which for a normal distribution is equivalent to a confidence level of approximately 95%.

Measured deflections at points p1 ($f_{\mathrm{pl,p1}}$) and p2 ($f_{\mathrm{pl,p2}}$) during load tests show compatibility of 97–100% with FEM results ($f_{\mathrm{MES,p1}}$ and $f_{\mathrm{MES,p2}}$), see Table 2. Determined normal stresses ($\sigma_{\mathrm{pl,T1}}$, at the assumed value of the modulus of elasticity E = 210 GPa) based on measured strains ($\varepsilon_{\mathrm{pl,T1}}$) demonstrate compatibility of over 80% with FEM results ($\sigma_{\mathrm{MES,T1}}$), see Table 2. The measurements of the settlement of the supports carried out during the load tests (U3, U4 and U5 positions, see Table 1) did not show any vertical displacements. From the proof load test results, it was found that the static response determined by the numerical analysis

Table 1. Position of the lorry during the proof test and maximum effect on the bridge structure

U1			maximum span moment (max $M_{span\ 1\text{-}1}$) maximal span deflection (max $f_{span\ 1\text{-}1}$)
U2			maximum support moment (max $M_{support\ 2}$)
U3			maximum reaction (max $R_{support\ 1}$)
U4			maximum reaction (max $R_{support\ 2}$)
U5			maximum reaction (max $R_{support\ 2'}$)

satisfactorily corresponded to the real bridge response and could be used successfully for further detailed analyses and investigations.

Apart from the static proof load test, the dynamic test was performed. Dynamic tests of the bridge included: measurements of vertical displacements – deflections of the span structure; measurements of strain/stress increments in girders; and measurements of the structure accelerations. Measurements during dynamic tests were performed by calibrated inductive sensors and specialized measuring equipment. Dynamic measurements of vertical

Table 2. Position of the lorry during the proof test and maximum on the bridge structure

U1	at measuring point no. p1 at measuring point no. p2	$f_{pl,p1}$ = 15.78 mm ± 0.12 mm = 97% $f_{MES,p1}$ $f_{pl,p2}$ = 10.32 mm ± 0.12 mm = 100% $f_{MES,p2}$
U2	at measuring point no. p1 at measuring point no. p2	$f_{pl,p1}$ = 11.84 mm ± 0.12 mm = 99% $f_{MES,p1}$ $f_{pl,p2}$ = 7.56 mm ± 0.12 mm = 99% $f_{MES,p2}$
U1 U2	The maximum recorded values of normal deformations/stresses at the measurement points during the implementation of the static settings were	$\varepsilon_{pl,T1}$ = 227.4 μm/m ± 7.5 μm/m $\sigma_{pl,T1}$ = 95.5 MPa ± 3.1 MPa = 84% $\sigma_{MES,T1}$ $\varepsilon_{pl,T1}$= 58.8 μm/m ± 3.0 μm/m $\sigma_{pl,T1}$ = 24.7 MPa ± 1.2 MPa = 80% $\sigma_{MES,T1}$

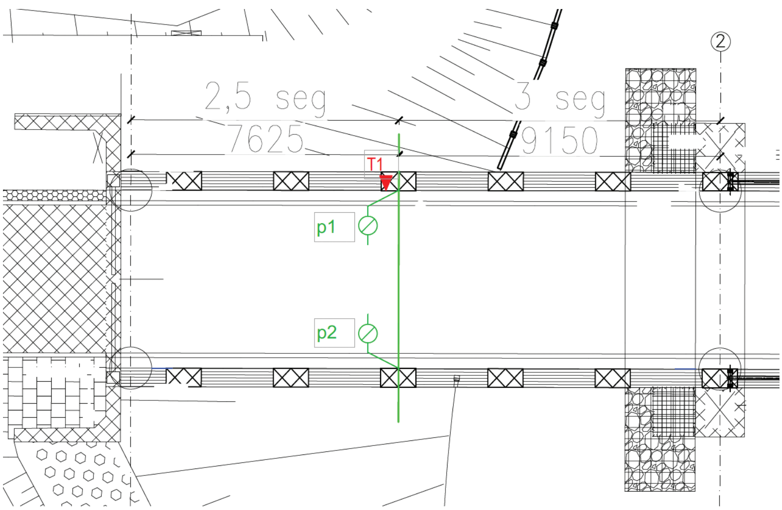


Figure 23. Localization of measurement points: p1, p2 and T1

displacements and accelerations of the span structure were carried out as follows: moving one 5-axle car (with a 33 240 kg weight) at speeds 10, 20, and 30 km/h at the curb on a smooth surface; moving one 5-axle car (with a 33 240 kg weight) at speeds 10, 20 and 30 km/h at the curb through an artificial obstacle in the form of a 10 cm high threshold. The graph of representative normal stresses in the function of time with results of the high-speed dynamic FFT for measuring point T1 during the proof test load (10 cm high threshold set in the measurement section 1-1 (span no. 1) at a speed of 20 km/h) is given in Figure 24. Dynamic tests allowed for the identification of frequencies of free vibrations and their comparison to the calculated values obtained in the FEM model.

Detailed inspection before and after the proof load test did not reveal any structural irregularities in the bridge. Measured values of vertical

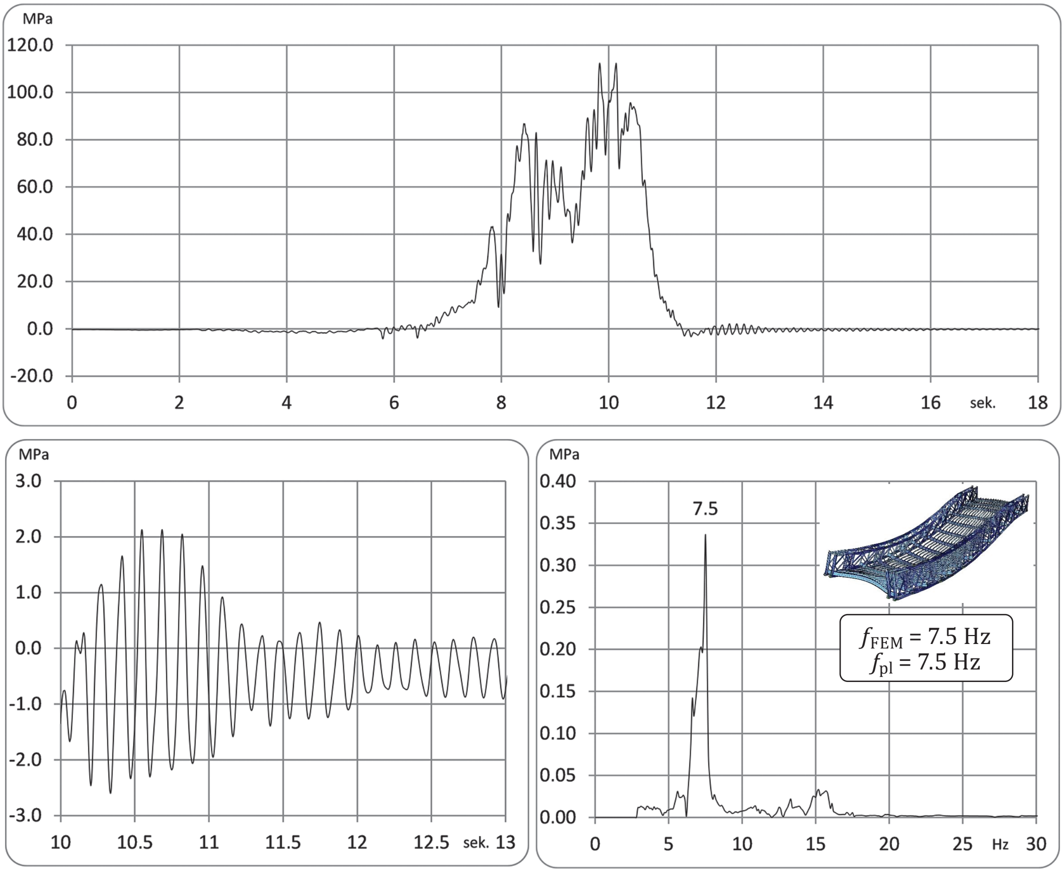


Figure 24. Normal stresses in the bottom chord of a truss girder and the high-speed dynamic FFT results

displacements – bridge deflections during static and dynamic tests confirmed the theoretical assumptions and validated the FEM model. Analysis of the results of static and dynamic proof tests of the bridge indicates correct construction and fulfils serviceability conditions.

Conclusions

Reconstruction or repair of bridges or viaducts along roads or railways highly loaded by traffic requires the construction of temporary bypass structures that are foldable prefabricated steel Bailey-type bridges. The literature review shows that the investigation subject of Bailey-type bridges is undertaken not only by the engineering community but also willingly by the scientific community. Due to the possibility of combining elements of Bailey-type bridges into a variety of complex spatial arrangements, they could be widely used not only in temporary but also in permanent bridges. The development of tools and calculation methods has made it possible to model these complex bridge structures and take into account many factors influencing load bearing-capacity.

The foldable steel MS 22-80 Bailey-type bridge was examined in this paper, from the structural analysis to proof load tests. Rebuilding the prefabricated MS 22-80 bridge with designed bascule span was an unordinary and interesting case in engineering aspects. It is the first Bailey-type bridge with a bascule span for the improvement of sailing serviceability. The bridge was originally installed only as a temporary bridge to provide the Tuga River crossing for pedestrians and vehicle traffic. Based on the performed investigation, the following conclusions can be drawn:

- The Bailey-type steel bridge is successfully rebuilt to a bridge equipped with a bascule span. The investigated bridge is in operation serviceable and fulfils imposed requirements for traffic road and sailing serviceability;
- The used FEM model of the portable, pre-fabricated, steel bridge was validated during the static and dynamic proof load tests. The proof load test results confirmed good compliance of numerical simulations within the adopted computational models (the 3D FEM model with contact elements of the SPRI and GAP types, taking into account the flexibility of pin connections between the panels) with the actual behaviour of the bridge structure;
- Based on the results of the structural analysis and proof load tests, the bridge after rebuilding is adapted for class D load according to the PN-S-10030 standard (PKN, 1985);

- The foldable prefabricated steel Bailey-type bridge can successfully be used as a permanent bridge with a designed bascule middle span;
- The bridge after redevelopment fulfils the conditions of bearing capacity and the possibilities of carrying designed traffic class D load according to PN-S-10030 (PKN, 1985) in extended working life;
- The structural analysis and proof load tests confirmed the validity of the adopted design solutions.

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