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ANALYSIS OF LOCAL INFLUENCES IN STRUCTURAL DETAILS OF THE BRIDGES

Summary. The article analyses the problems of local influences in structural details of bridges as the critical locations, whose damages or excessive force may directly affect the safety of users. These analyses are shown on selected examples. Presented is the example of local changes in the forms of proper vibrations in the node of the truss bridge that can be used in expert issues concerning the causes of damages. The second example are the changes in stresses in the stay cable anchorage element including the nonlinear material models. Models of this type can be successfully used by engineers as they allow for analysis of selected structural details without the need for detailed mapping of the entire structure, but only a selected section.

ANALIZA LOKALNYCH WPŁYWÓW W SZCZEGÓŁACH KONSTRUKCYJNYCH MOSTÓW

Streszczenie. W artykule podjęto problematykę analizy lokalnych wpływów w szczegółach konstrukcyjnych mostów, jako miejscach newralgicznych, których uszkodzenia lub nadmierne wytężenie może bezpośrednio wpłynąć na bezpieczeństwo użytkowania. Możliwość takich analiz pokazano na wybranych przykładach. Przedstawiono przykład lokalnych zmian postaci drgań własnych w wyniku uszkodzenia w węźle mostu kratownicowego, który może być wykorzystany w zagadnieniach eksperckich, dotyczących poszukiwań przyczyny powstałego uszkodzenia. Drugim przykładem są zmiany naprężeń w elemencie zakotwienia cięgna podwieszającego z uwzględnieniem nieliniowych modeli materiału. Modele tego typu mogą być z powodzeniem wykorzystywane przez projektantów, gdyż pozwalają na analizę wybranych detali konstrukcyjnych bez konieczności szczegółowego odwzorowania w modelu całego obiektu, a jedynie wybranego fragmentu.

1. INTRODUCTION

Monitoring the structural health of bridge structures may require analysis of local influences in structural details. Disclosure of such influences, in the elastic and beyond elastic range, is only possible with an exact mapping of detail in the calculation model. Until recently, the available tools allow for the numerical analysis of the structure only in the elastic range. Currently available numerical tools also allow conduction of advanced analyses on complex models in beyond elastic range. However, this often leads to a task that requires the use of computer with high computing power. The article presents two examples of local influences in the structural details of bridges with the use of a personal computer. The first example shows an engineering method of detailed modelling of the part of the structure that minimizes the size of the task. The second example uses the elastic-plastic material model, allowing for stress analysis in the "beyond elastic" range and their dependence on load history.

2. MODELLING AND ANALYSES OF STRUCTURAL DETAILS OF BRIDGES

2.1. Modelling of details and engineering modelling

Theoretical analysis of local influences in structural details of bridges are possible only with accurate modelling. Calculation models of such details are usually built based on the finite element method. This solution is effective for simple models, whose size and analysis does not lead to a large calculation task that exceeds the capabilities of personal computers; otherwise, it is necessary to use a computer with high computing power. The solution is to build a detailed model of the section of the structure and attach it to the spatial bar system. More information on this type of engineering modelling can be found in [1, 2].

For the analysis described in the article used the Sony Vaio personal computer with the following parameters: processor: Intel® Core™ i5 CPU; M460 2.53GHz 2 core; installed physical memory (RAM): 4.0 GB; available physical memory: 1.37 GB.

Modelling and analysis were performed with using the following software: Robot Structural Analysis Professional, Autodesk Simulation Mechanical.

2.2. Analysis of local changes of selected dynamic parameters

The subject of the problem is to show the ability of analysis of the work of the bridge's structural detail in the elastic range. The analysed element is the node of the truss railway bridge. The calculation model of the bridge was built as a frame spatial bar system. A detailed node consisting of over 3,100 coating elements (panels) was attached to one node of this system; these panels were given the appropriate thickness corresponding to the individual elements of the object (web, flanges, ribs, gusset plates). The analysis was based on the simulation of the node damage in the form of fracture of the bottom flange of the truss system and recording the form changes and frequency of the proper vibrations. A detailed description of the model, analysis of global changes of values of the vibration frequencies of the entire system and selected results of field tests are given in [3].

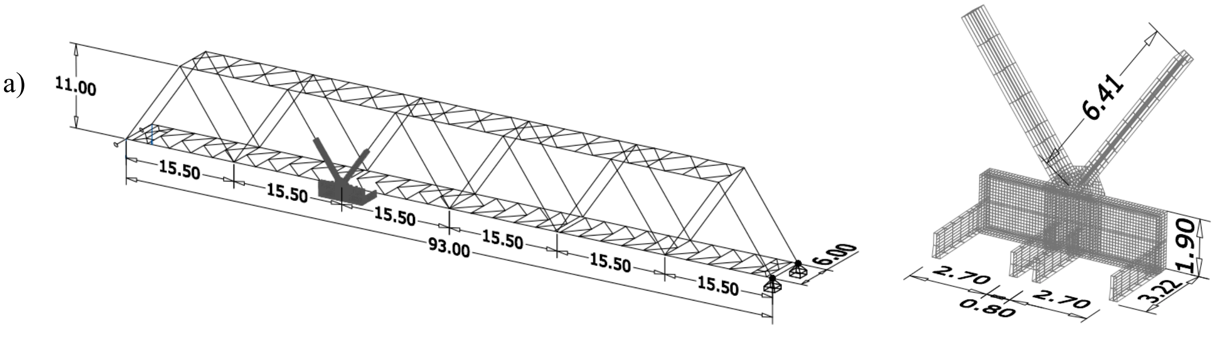

Fig. 1. The dimensions of model: a) whole bridge; b) detailed node
Rys. 1. Wymiary modelu: a) całego mostu; b) węzła szczegółowego

By analysing the local influences, it was shown that in the case of some forms of local vibrations, local disorders occurred. An example is shown in Fig. 2, where clear disorders of horizontal flexural form of vibrations in the node with the damage of the bottom flange can be seen.

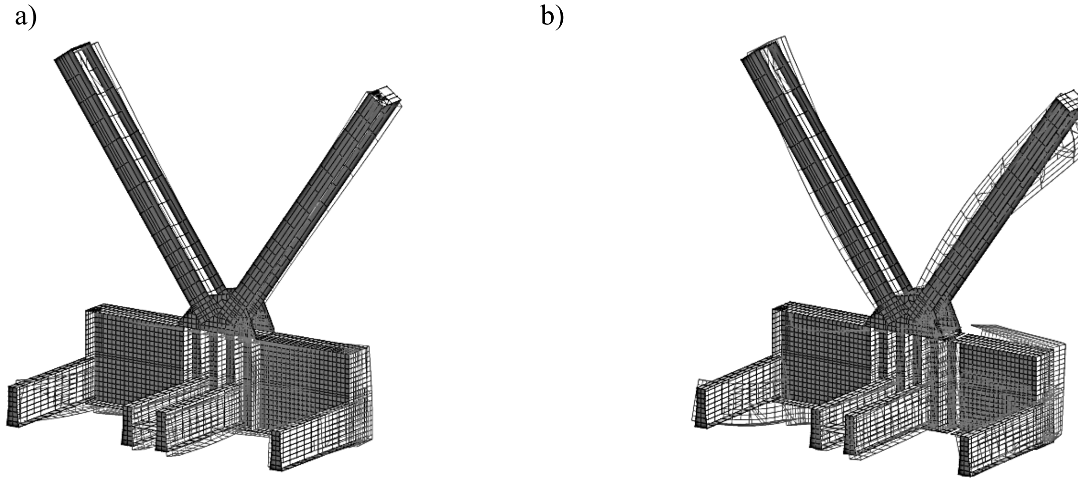

Fig. 2. View of the local disorder of vibration form (a horizontal flexural form, f=19.72Hz) resulting from damage: a) node with no damage; b) node with damage

Rys. 2. Widok lokalnego zaburzenia postaci drgań (postać pozioma giętna, f= 19,72Hz) wynikający z uszkodzenia: a) węzeł bez uszkodzenia; b) węzeł z uszkodzeniem

This character occurred in the model without damage at a frequency of 19.720 Hz while in the model with damage at a frequency of 19.700 Hz. The frequency difference of 0.02 Hz and a comparison of global vibration forms of the analysed models (Fig. 3) does not indicate any disorders. Thus, analysis of changes of global frequencies and forms of proper vibrations of the entire model would be insufficient in this case. The same would be in the case of the analysis of the bar model without a specific node.

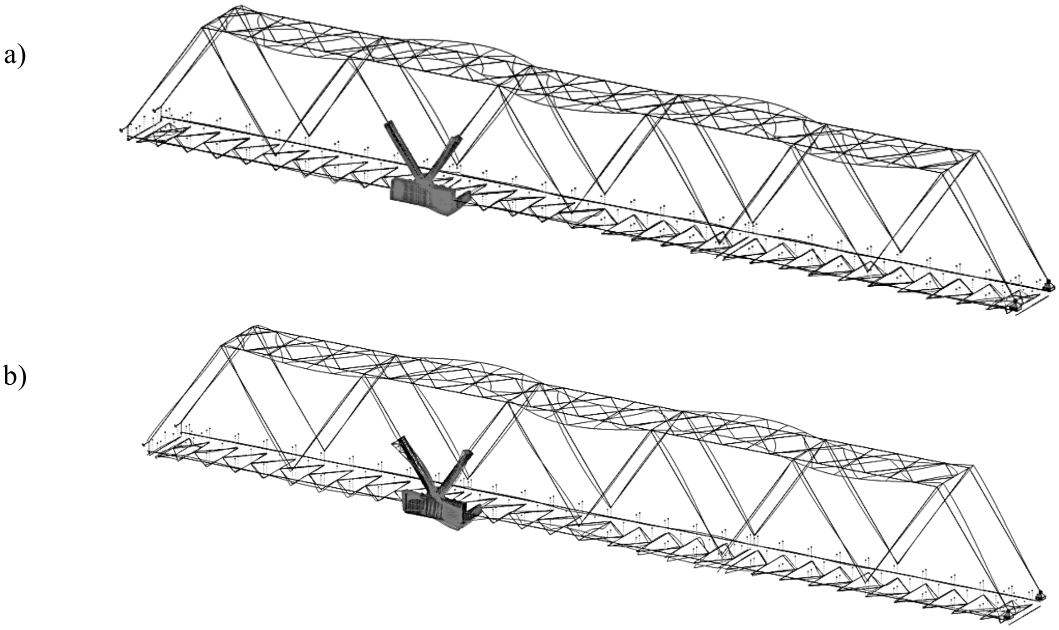

Fig. 3. Horizontal flexural vibration form: a) model without damage (f=19.720Hz); b) model with damage (f=19.700Hz).

Rys. 3. Pozioma giętna postać drgań: a) model bez uszkodzenia (f=19,720Hz); b) model z uszkodzeniem (f=19,700Hz)

2.3. Analysis of local changes of stresses and plastic deformations

This chapter describes the ability to analyse the changes in stress in the beyond elastic range. The considered structural detail is a stay cable anchorage element. Geometry, dimensions and general view of the model is shown in Fig. 4. The base plate has twelve holes with diameter of Ø30 mm; the peripheral of these holes was given a support in the form of restraint. The ring has a hole of a diameter of Ø50 for the bolt. The contact of the bolt with the ring was assumed as sliding with no friction, allowing movement of the bolt within the hole. All parts of the model were constructed with eight-node solid elements.

The analysis includes two models of material:

- linear-elastic model;
- elastic-plastic model with the plasticity condition of Huber-Mises with the isotropic reinforcement.

The load is the surface load distributed over the surface of the bolt, applied at an angle of 22° (parallel to the top edge of the ring). In the calculation model with the elastic plastic model of material, the load was applied in the form of two functions – including and not including the offload phases. The maximum (final) value of the load is 2MN. Functions of load are shown in Fig. 5.

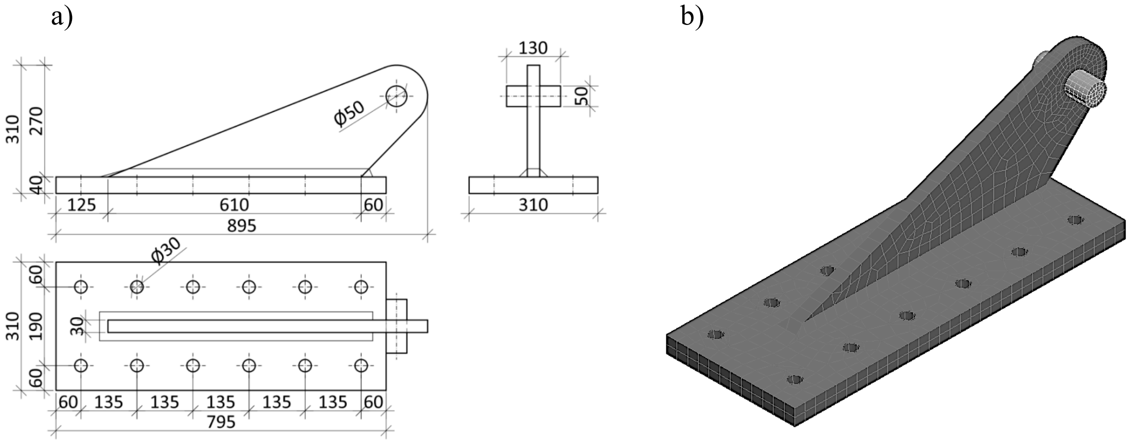

Fig. 4. The computational model of anchorage: a) geometry and dimensions; b) geometria i wymiary; b) widok ogólny

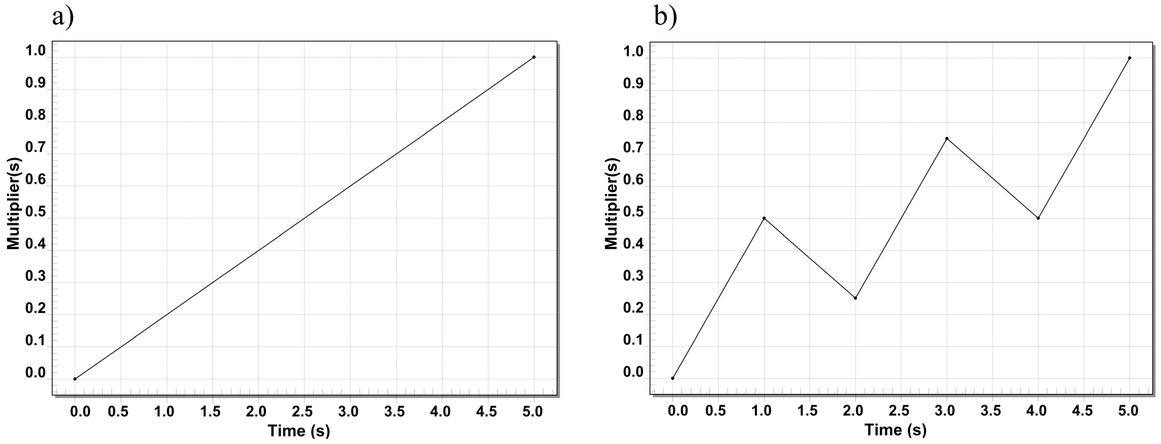

Fig. 5. The course of load function: a) without offload phases; b) with offload phases
Rys. 5. Przebieg funkcji obciążenia: a) bez faz odciążania; b) z fazami odciążania

Distribution of stresses within the hole was analysed. In total, three calculation models were analysed:

- model A - with elastic-plastic material and function of load without offload phases;
- model B - with elastic-plastic model with function of load with offload phases;
- model C - with linear-elastic material.

The maximum values of Huber-Mises (H-M) stresses were 1205 MPa in model A, 1223 MPa in model B and 2467 MPa in model C (almost two times the tensile strength of steel). When analysing the distribution of stresses exceeding the yield strength in the final phase of the load (Fig. 6), the difference between model A and B can be seen, which is an excellent example of the need to consider the history of the load (and fatigue effects in a later stage). Distribution in the case of linear-elastic material significantly differs from the models of elastic-plastic material, and recorded maximum stresses would not occur in reality, which excludes it from this type of analysis.

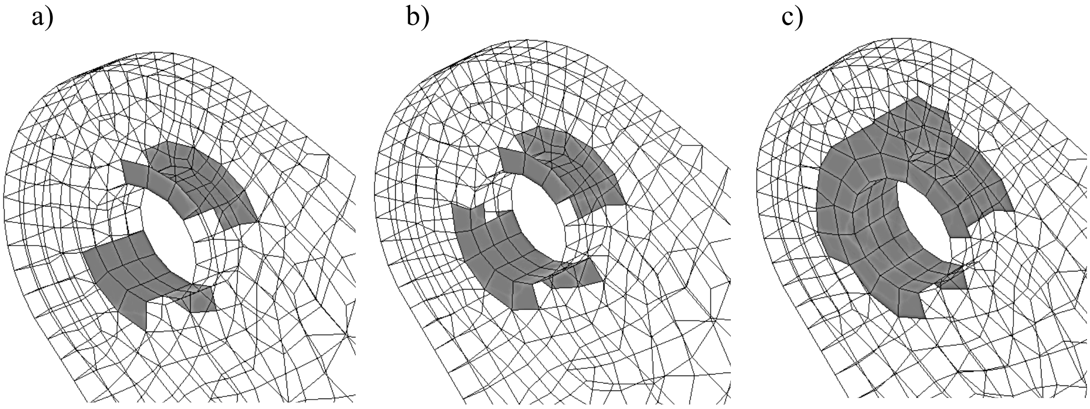

Fig. 6. The occurrence of stress above the yield stress (1172MPa): in a model with elastic-plastic material with function of load without offload phases; b) in a model with elastic-plastic material with function of load with offload phases; c) in a model with linear-elastic material

Rys. 6. Występowanie naprężeń powyżej granicy plastyczności (1172 MPa): a) w modelu z materiałem sprężysto-plastycznym z funkcją obciążenia bez faz odciążania; b) w modelu z materiałem sprężysto-plastycznym z funkcją z fazami odciążania; c) w modelu z materiałem liniowo-sprężystym

3. ANALYSIS OF LOCAL INFLUENCES VERSUS STRUCTURAL HEALTH MONITORING

One of the elements of transport safety is the safety and reliability of engineering structures, which are an integral part of the transport network. On the other hand, parameters of the structure's elements, both structural and non-structural, determine its safety and reliability. An important issue is therefore the structural health monitoring (SHM), which is the widely undertaken subject in the national and international literature [4-11].

Detection of local influences in the real structures through a built-in monitoring system should always be preceded by an advanced numerical simulations and possibly model tests [12]. This will allow the detection of local influences and their changes as well as it will be the basis for the selection of an appropriate measurement base, its parameters and the method of installation in a real structure.

4. SUMMARY AND CONCLUSIONS

The paper presents examples of the analysis of local influences in structural details of bridge structures. The example of the analysis in the elastic and beyond elastic range of the element is described. The given modelling capabilities can be used in matters of experts and designers.

The presented detail of the node of the truss bridge shows that, despite a slight change in the global frequency of proper vibrations of the entire structure induced by the damage, clear disorders of the form in the detail were observed. Obtaining such a result was achieved through appropriate modelling of the structural detail, while maintaining the size of the calculation task allowing the use of a personal computer.

In the case of analysis of the stay cable anchorage element, it was shown that the use of linear-elastic material in this type of analysis is insufficient and more complex models taking into account the plastic range and the strengthening material process should be used.

Both examples lead to the conclusion that the analysis of the structural details of bridges is an important element in the structural health monitoring and safety. An exact mapping of the detail's geometry and the way of cooperation of individual elements is important. More complex than used in engineering practice linear-elastic model should also be used, allowing for tracking the plastic zones and taking into account the history of the load. The presented modelling capabilities allow the use of personal computer for the advanced analyses.

References

1. Pradelok, S. & Bętkowski, P. & Rudzik, A. & Łaziński, P. Modelowanie inżynierskie szczegółów konstrukcyjnych mostu. *Budownictwo i Architektura.* 2013. Vol. 12(2). P. 55-62. [In Polish: Engineering modelling of structural details of a bridge].
2. Jankovski, V. & J. Atkočiūnas, J. Biparametric shakedown design of steel frame structures. *Mechanika*. 2011. Vol. 17. No. 1. P. 5-12.
3. Pradelok, S. & Rudzik, A. & Poprawa, G. Analiza teoretyczna wpływu postępującego pękania na zmianę częstotliwości drgań własnych kratowego mostu kolejowego. *XXVI Konferencja Naukowo-Techniczna Awarie Budowlane.* Szczecin-Międzyzdroje 2013. P. 275-282. [In Polish: Theoretical analysis progressive cracking impact on natural frequency of truss railway bridge].
4. Kuras, P. & Owerko, T. & Ortyl, Ł. & Kocierz, R. & Sukta, O. & Pradelok, S. Advantages of radar interferometry for assessment of dynamic deformation of bridge. *Proceedings of the Sixth International IABMAS Conference*. Stresa, Italy. 8-12 July 2012. P. 885-891.
5. Owerko, T. & Ortyl, Ł. & Kocierz, R. & Kuras, P. & Salamak M. Investigation of displacements of road bridges under test loads using radar interferometry – case study. *Proceedings of the Sixth International IABMAS Conference*. Stresa, Italy. 8-12 July 2012. P. 181-188.
6. Biliszczuk, J. & Barcik W. & Sieńko, R. System monitorowania mostu w Puławach. *Mosty.* 2009. Vol. 4. P. 12-17. [In Polish: The monitoring system of the bridge in Puławy].
7. Barcik, W. & Sieńko, R. & Biliszczuk, J. System monitorowania konstrukcji mostu Rędzińskiego we Wrocławiu. *Wrocławskie Dni Mostowe. Aktualne realizacje mostowe.* Wrocław 24-25 listopada 2011. [In Polish: Monitoring system of the Rędziński Bridge's structure in Wrocław].
8. Kowalewski, J. & Sulik, P. Wiarygodność i skuteczność monitoringu bezpieczeństwa konstrukcji budowlanych. *XI Konferencja Naukowo-Techniczna Problemy rzeczoznawstwa budowlanego.* Warszawa Miedzeszyn 2010. P. 263-271. [In Polish: Reliability and performance of the building structure safety monitoring].
9. Scianna, A. & Jiang, Z. & Christenson R. & DeWolf, J. Implementation of a Probabilistic Structural Health Monitoring Method on a Highway Bridge. *Advances in Civil Engineering.* 2012. Volume 2012. P. 40-48.
10. Oth, A. & Picozzi, M. Structural Health Monitoring Using Wireless Technologies: An Ambient Vibration Test on the Adolphe Bridge, Luxemburg City. *Advances in Civil Engineering.* 2012. Vol. 2012. P. 23-39.
11. Yu, L. & Momeni, S. & Godinez, V. & Giurgiutu, V. & Ziehl, P. & Yu, J. Dual Mode Sensing with Low-Profile Piezoelectric Thin Wafer Sensors for Steel Bridge Crack Detection and Diagnosis. *Advances in Civil Engineering.* 2012. Vol. 2012. P. 49-58.
12. Wróblewski, T. Badania doświadczalne modelu kolejowego mostu zespolonego. *Inżynieria i Budownictwo.* 2013. Vol. 5. P. 284-287. [In Polish: Experimental studies of model of composite railway bridge].

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