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SIMULATION AND COMPUTER MODELING OF BRIDGE STRUCTURES DYNAMICS USING ANSYS

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Abstract. *This study focuses on utilizing computer modeling and simulation techniques, specifically the ANSYS software, to analyze the dynamics of bridge structures. The primary objective was to study the vibrations of a riverbed metal bridge structure and determine their characteristics. The research involved theoretical dynamic calculations considering the design features of the bridge components and the materials used in their construction. The obtained results enabled the determination of resonance frequencies for the vibration modes. By utilizing the ANSYS software, a three-dimensional virtual model of the bridge structure was created, allowing for a detailed analysis of its dynamic behavior. The first three vibration modes of the riverbed metal bridge structure were calculated, and numerical results were obtained for six modes. The findings of this research have practical significance as they provide informed decision-making support during the construction, maintenance, and modernization of bridge structures. The study of bridge dynamics using advanced technologies contributes to enhancing the safety, reliability, and longevity of these vital infrastructure assets.*

Keywords: ANSYS software package, computer modeling, bridge structures, dynamics, virtual model

SYMULACJA I MODELOWANIE KOMPUTEROWE DYNAMIKI KONSTRUKCJI MOSTÓW Z WYKORZYSTANIEM ANSYS

Streszczenie. *Niniejsze badanie koncentruje się na wykorzystaniu technik modelowania komputerowego i symulacji, w szczególności oprogramowania ANSYS, do analizy dynamiki konstrukcji mostowych. Głównym celem było zbadanie drgań metalowej konstrukcji mostu w korycie rzeki i określenie ich charakterystyki. Badania obejmowały teoretyczne obliczenia dynamiczne uwzględniające cechy konstrukcyjne elementów mostu oraz materiały użyte do ich budowy. Uzyskane wyniki umożliwiły wyznaczenie częstotliwości rezonansowych dla postaci drgań. Wykorzystując oprogramowanie ANSYS stworzono trójwymiarowy wirtualny model konstrukcji mostu, pozwalający na szczegółową analizę jego dynamicznego zachowania. Obliczono trzy pierwsze postacie drgań metalowej konstrukcji mostu koryta rzeki i uzyskano wyniki numeryczne dla sześciu postaci. Wyniki tych badań mają znaczenie praktyczne, ponieważ zapewniają świadome wsparcie w podejmowaniu decyzji podczas budowy, utrzymania i modernizacji obiektów mostowych. Badanie dynamiki mostów przy użyciu zaawansowanych technologii przyczynia się do poprawy bezpieczeństwa, niezawodności i trwałości tych kluczowych elementów infrastruktury.*

Slowa kluczowe: pakiet oprogramowania ANSYS, modelowanie komputerowe, konstrukcje mostowe, dynamika, model wirtualny

Introduction

Studying the dynamics of bridge structures is of great importance in evaluating their operational characteristics.

The investigation of the dynamics of bridge structures involves the study and analysis of various aspects. Firstly, an analysis of the loads and forces acting on the structure is conducted, such as road traffic, wind effects, train vibrations, or other dynamic factors [3, 4]. Subsequently, modelling and calculations are carried out to predict the dynamic behaviour of the structure, including the analysis of resonance phenomena and possible resonance frequencies [5, 7]. Furthermore, an assessment of the vibrational characteristics of the structure is performed, including the amplitude of oscillations, natural frequencies, and damping [8, 15].

Researching the dynamics of bridge structures requires the application of various methods and tools. Sensors, accelerometers, deformation sensors, and other instruments can be used for data collection and vibration monitoring [12]. Modern computer programs enable numerical modeling and calculations, which help predict the dynamic behaviour of the structure under different conditions and optimize its parameters [5].

Research on the dynamics of bridge structures using modern technologies and software tools, such as ANSYS, also enables virtual testing and optimization of bridge designs. This reduces costs associated with physical testing and allows engineers and designers to more efficiently utilize resources in the construction of new bridges or the upgrading of existing ones.

The results of studying the dynamics of bridge structures can have a wide range of applications. They can be used to optimize the design of new bridges and the reconstruction of existing bridge structures to enhance their durability, safety, and efficiency. The obtained data and analytical findings from the research can be utilized in developing engineering solutions for structural reinforcement, selecting optimal materials, determining parameters of damping systems, and formulating maintenance strategies and regular condition monitoring of bridges.

Furthermore, investigating the dynamics of bridge structures contributes to the development of more accurate models and predictions for determining allowable loads and forecasting the behaviour of structures under operational conditions.

Thus, research on the dynamics of bridge structures using modern methods and software is of great importance for infrastructure development and ensuring the safety of transportation networks. It enables obtaining more accurate data on the dynamic behavior of bridge structures, making informed decisions in design and maintenance, and reducing the risks of unforeseen circumstances.

1. Dynamic testing of bridge structures

During dynamic testing of bridge structures, various types of dynamic actions are employed, which can be categorized as follows: moving dynamic loads, impact dynamic loads, and continuous vibration loads. It should be noted that dynamic actions on bridges result in both vertical and horizontal displacements. However, the effects of these displacements on the load-carrying capacity of bridges vary depending on their purpose. In the case of road bridges, vertical oscillations are typically the focus of investigation. For certain types of bridges, such as suspension bridges with low horizontal stiffness, knowledge of both types of oscillations is crucial. For railway bridges, horizontal vibrations are of primary concern.

Two types of moving dynamic loads are distinguished: loads generated by the natural flow of vehicles [11, 15] and loads generated by specialized vehicles [10, 13]. Loads in regular traffic flow are uncontrolled, while those created by specialized vehicles (e.g., vehicles loaded with ballast) are controlled. The passage of vehicles occurs at a specified constant speed along different lanes to create maximum dynamic loads (figure 1). Impact loads are typically generated by mechanical and hydraulic hammers [6], loads dropped from a certain height [14], specialized machines for inducing impact vibrations [6], and other devices (figure 2). However, the most common type of dynamic load applied during dynamic testing of bridge structures involves the use of specialized vehicles moving at different speeds. Combinations of different types of vibration excitations are also employed.

Depending on the types and schemes of loading, different types of sensors are used to obtain information about the response of structures to the applied actions.

For moving dynamic actions such as natural traffic flow, movement of specialized vehicles, pedestrian movement, wind flow, and temperature, only electrical sensors are used. In fact, the same sensors used for static testing are employed, including strain gauges, inductive sensors, optical sensors, piezoceramic sensors, fiber optic sensors, and others [1, 2]. Instruments and systems such as MEGADAC 3108, Si425-500, STS, SHM, OPTIM MEGADAC, 3852A (HP), PSM-R, and others are utilized for processing signals from these types of sensors. Additionally, piezoceramic accelerometers and induction-type velocity sensors are widely used. In this case, vibrations are recorded in three directions – vertical, horizontal, and transverse.

a) 

b) 

Fig. 1. Dynamic loading of bridge structures using specialized sand-loaded vehicles: a) passage through the central roadway of a split reinforced concrete bridge, b) passage through the outer roadway lane of a split reinforced concrete bridge

For non-moving dynamic actions in the form of impact loads, accelerometric, strain gauge, fiber optic sensors, as well as displacement sensors, are used [6, 13]. However, in the latter case, the registered response of the structure is not typically a vibrational process but rather an impulsive response to the impact action. For non-moving continuous loads, accelerometers [6], optical lasers [2], and vibration velocity sensors [16] are used to measure the resulting vibrations. Acceleration and velocity sensors such as V401 CR, TCU102, Dytran 3100B, 5801A4, 353B03, 3031-100, WR-731A, PCB, CXL02, QA-700, CB, and SG, produced in Japan, the USA, Canada, Norway, Australia, Finland, Russia, are employed. The frequency range of acceleration sensors typically ranges from 0.5 Hz to 1000 Hz, with sensitivities ranging from 0.1 V/m/s² to 5.0 V/m/s². For velocity sensors, the frequency range is typically -5 Hz to 400 Hz, with sensitivities of -10 V/m/s to 20 V/m/s.

a) 

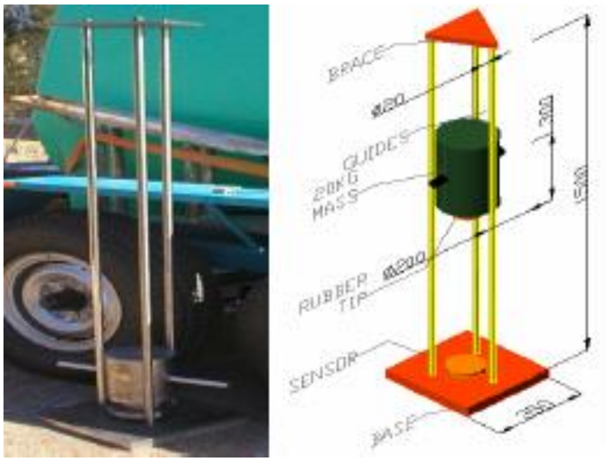
b) 

Fig. 2. Special devices for dynamic loading of bridge structures: a) machine for inducing impact loads, b) drop hammer with falling load

When processing signals obtained from strain gauges, optical sensors, and displacement transducers, the systems discussed above can be used. However, a wide range of devices and systems are employed for processing signals from accelerometers and velocity sensors, which are designed specifically for vibration signal analysis. Typically, these include multichannel systems such as TEACR-280 FM, SA-390, MCBS, VFC-05, USS8, Diamos, Jaguar, Cougar, SigLab, VX2842, HP3566A, and others. However, these systems are primarily intended for continuous vibration signals generated by operating equipment, such as machine tools, ventilation units, power generators, gas turbines, and so on. Consequently, they impose certain limitations on the amount of recorded information (1024, 2048, or 4096 data points), assuming the possibility of subsequent recording and processing of continuous signals. Similar conditions can be created when dealing with non-moving vibration loads, allowing for the full utilization of the mentioned systems.

However, the frequencies of vibrations in bridge structures are significantly lower compared to the frequencies generated by continuously operating equipment. In these cases, the limitation on the sample size, imposed by increasing the sampling interval to ensure the registration of information over a longer time span (the need to capture multiple periods of the resulting signal), leads not only to a restriction on the number of processed parameters but also to significant errors in the obtained results. Therefore, systems developed by researchers [1, 6, 9, 13] are widely used.

Standard mathematical packages that include data processing using fast Fourier transform are widely employed for information processing. Primary data acquisition devices are used as well. More complex systems are being developed, where stationary sets of primary transducers are employed on the structures, and information transmission is carried out through telephone communication lines or using GPS systems. However, in these systems, despite the use of modern technologies, standard information is recorded, and standard methods are applied for its processing.

2. Modeling of bridge structures dynamics

In addition to the aforementioned methods, there are other approaches to studying the dynamics of bridge structures that can provide information about their characteristics. Since analysis is often required for voluminous and complex models, solving such problems requires the use of modern software packages such as ANSYS. Analysis in this software package is performed using the finite element method.

Modern software tools allow for the creation of three-dimensional virtual models of structures and conducting various scenarios of loads and operating conditions. This enables researchers to analyze the dynamic behavior of the structure, identify potential issues, optimize the design, and make informed decisions regarding maintenance and bridge modernization.

By utilizing software packages like ANSYS, the complexity and size of bridge models can be effectively considered, providing more accurate and realistic results. This is particularly important when analyzing complex bridges, taking into account factors such as environmental changes, dynamic loads, and interactions with surrounding objects.

Therefore, the application of modern software tools, including ANSYS, is an efficient tool for studying the dynamics of bridge structures, enabling valuable insights into their behaviour and supporting informed engineering decisions.

The ANSYS software package consists of a large family of specialized programs that share common functions. However, the mathematical capabilities of each program are designed to solve specific classes of problems. One notable feature of the software is the file compatibility among all members of the ANSYS family across different platforms.

For the purpose of analysis within the ANSYS software package, a bridge structure was selected as the object of study. The bridge structure consisted of eight spans: seven approach spans and one main span (see figure 3). The bridge scheme employed a deck-girder configuration for the approach spans, with a truss system in the main span (3×16.76 + 53.30 + 4×16.76). The total length of the bridge was 171.64 meters.

By using the ANSYS software, engineers were able to conduct detailed analyses of the bridge structure, taking into account its geometry, material properties, and boundary conditions. The software allowed for the simulation of various loading scenarios, such as static loads, dynamic loads, and environmental conditions, to assess the structural behavior and performance of the bridge.

Fig. 3. Bridge with a metal truss

The river section of the bridge consists of a single span structure supported by 3-4 intermediate piers. The span structure includes upper and lower metal trusses (see Fig. 4) with a roadway at the bottom, metal connections, a beam grid with a monolithic reinforced concrete slab for the roadway section, and prefabricated sidewalks. The metal beam grid of the river section is composed of transverse and longitudinal beams with I-shaped cross-sections. The transverse beams are located at the lower nodes of the truss with a spacing of 7.5 m. Three longitudinal beams are installed at the level of the upper flange of the transverse beams with a spacing of 2.76 m. The cross-section of the upper and lower flanges of the trusses consists of two channel sections (No. 30) joined together by top and bottom welded cover plates (320×240×8.1 mm) with a spacing of 0.84–0.87 m along the axes. The trusses are connected by horizontal diagonal bracing members, whose cross-section consists of two angle sections (126×80 mm) joined by cover plates. The length of the metal river span is 53.50 m.

Fig. 4. The general view of the beam cage of channel span 3-4 s

The roadway section of the river span consists of a monolithic reinforced concrete slab with a thickness of approximately 0.17 m, which is placed on top of the beam grid along the transverse beams. The width of the roadway section is 7.0 m. The road surface is made of multi-layered asphalt concrete with a thickness of up to 0.3 m.

In the scope of this study, theoretical dynamic calculations of the main modes of vibration were conducted for the river-spanning superstructure. The calculations took into account the structural peculiarities of the spans and the materials they are made of. Graphical representations of the vibrations with corresponding numerical data were generated, which allowed for determining the resonance frequency of each identified mode of vibration. The obtained results were used for further calculations and comparison with the actual vibrations of the superstructure.

A three-dimensional virtual model of the bridge structure was built, taking into account its geometry, materials and connections. The dimensions, shape, and material properties of each structural element, such as channel girders, supports, and connectors, were specified.

The analysis of the forms and frequencies of natural vibrations in the ANSYS software involves following a specific sequence of actions. Calculations were performed for the first three vibration modes of the river-spanning metal superstructure using ANSYS (see Fig. 5). Table 1 presents the numerical results of the calculations for the first six vibration modes of the river-spanning metal superstructure.

Table 1. Calculations of vibrations for a metal deck truss bridge structure

No oscillation form	1	2	3	4	5
Resonance frequency, fp, Hz	2.51	3.24	3.57	3.96	4.74

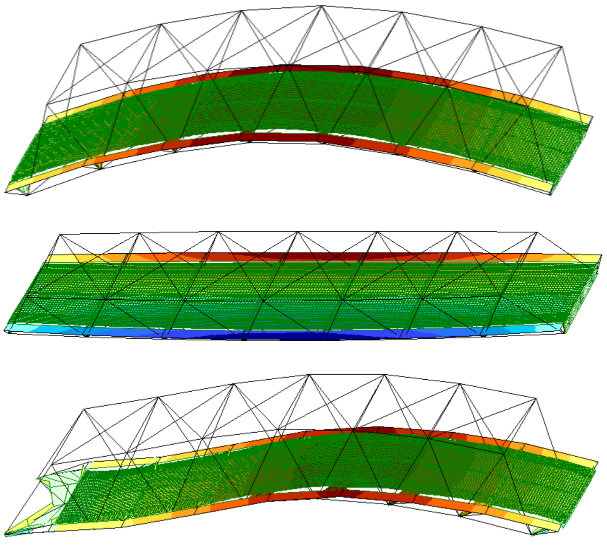


Fig. 5. Calculated forms of vibrations of a metal truss bridge structure

Thus, with the use of modern technologies and research methods, the study of the dynamics of bridge structures becomes more precise, detailed, and efficient. These methods allow for considering complex physical interactions and operational conditions, conducting virtual tests, and optimizing the design to ensure its safety and durability. Such research holds significant importance for engineers and designers, assisting them in making informed decisions during the construction, maintenance, and upgrade of bridge structures, thereby ensuring the reliability and stability of these vital infrastructure assets.

3. Conclusion

This study involved the investigation of the dynamics of bridge structures using modern methods and the ANSYS software package. The main objective was to study the vibrations of the riverbed metal bridge superstructure and determine their characteristics.

During the research, theoretical dynamic calculations of the main modes of vibration were conducted, taking into account the structural features of the superstructure and the materials from which it was constructed. The obtained results allowed for the determination of the resonance frequencies of the vibration modes.

The utilization of the ANSYS software package enabled the creation of a three-dimensional virtual model of the structure and a detailed analysis of its dynamic behaviour. The first three vibration modes were calculated for the riverbed metal bridge superstructure, and numerical results were obtained for six modes.

The research findings hold practical significance as they enable engineers and designers to make informed decisions during the construction, maintenance, and modernization of bridge structures. The study of bridge dynamics using modern technologies contributes to enhancing their safety, reliability, and durability.

Thus, this study provides valuable scientific and practical outcomes that can be utilized in the design and operation of bridge structures, contributing to the development of infrastructure and ensuring the safety of transportation systems. The integration of ANSYS software in the analysis process enhances the accuracy, comprehensiveness, and efficiency of the research, further emphasizing its relevance in the field of bridge engineering.

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