3D COMPUTER MODELING MONOCELLULAR CLOSED CROSS-SECTION OF THE BRIDGE WITH THE ANALYSIS OF FREE OSCILLATIONS

Ilija M. Miličić[1],
Aleksandar Prokić[2],
Smilja Živković[3]
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Summary: *In this paper, computer simulation is controlled by the convergence solutions depending on the type and the number of adopted final element numerical methods (FEM) to application programs SAP2000 and Abaqus 6.13-1 for the purposes of dynamic analyses of the bridge structure. Computer modelling of the structure of the bridge is treated as a 3D design model with 2D finite element (Shell) and a large number of degrees of freedom of movement. To implement dynamic analysis of 3D models is recommended to use finer mesh finite element analysis in relation to the static analysis in order to more precisely describe the forms of oscillation.*

Key words*: Bridge, 3D model, dynamic analysis, natural frequency.*

1. INTRODUCTION

Structural systems of bridges in preliminary trials [1] to dynamic effects behave very differently. The different behaviour depends on a number of parameters, which is called the dynamic characteristics of the bridges in the service conditions. Therefore, it is very important to include computer modelling and simulation as a method for the preparation and drawing up a program testing the real object [2].
Experimental studies in this area have been modest, so that in this paper seek to verify the experiences of the author related to a specific type of road bridges. On the basis of precise knowledge of a particular parameter – specificity [3], it is often possible to use a simpler method or solution when interpreting the dynamic response of the tested bridge structures. In the area of the oscillation theory is known, that in the known arrangement the mass and stiffness of the structural system – the structure, can be determined (calculated) and natural forms of the appropriate oscillation frequency.
The natural frequency, dynamic factor and mode shapes can be directly determined:

- based on physics – mechanical properties of materials, and

[1] Ilija M. Miličić, PhD, CE, University of Novi Sad, Faculty of Civil Engineering Subotica, Kozaračka 2a, 24000 Subotica, Serbia, e – mail: milicic@gf.uns.ac.rs
[2] Professor emeritus Aleksandar Prokić, PhD, CE, University of Novi Sad, Faculty of Civil Engineering Subotica, Kozaračka 2a, 24000 Subotica, Serbia, e – mail: aprokic@eunet.rs
[3] Smilja Živković, MSc, BSc, University of Novi Sad, Faculty of Civil Engineering Subotica, Kozaračka 2a, 24000 Subotica, Serbia, e – mail: zivkovicsmilja@gmail.com

- static system structure.

Damping cannot be determined in such way because damping force can depend on:

- from the model (structural system) which oscillates,
- the elements of the second model (adjacent model – building),
- the environment in which the model is oscillating, etc., which the formation of the term of damping force becomes a remarkable problem and we do not investigate them in this paper.

On the other hand, the analysis of the results obtained in testing – the monitoring of certain sizes in the real structure and the results of computer simulation provides us:

- detect shortcomings and irregularities in the "work" of structure,
- the adoption of an appropriate assessment of the situation in the behavior of the bridge,
- prerequisites to development and design of modern bridge structures,
- the improvement of existing technical standards, rules, regulations and standards, etc.

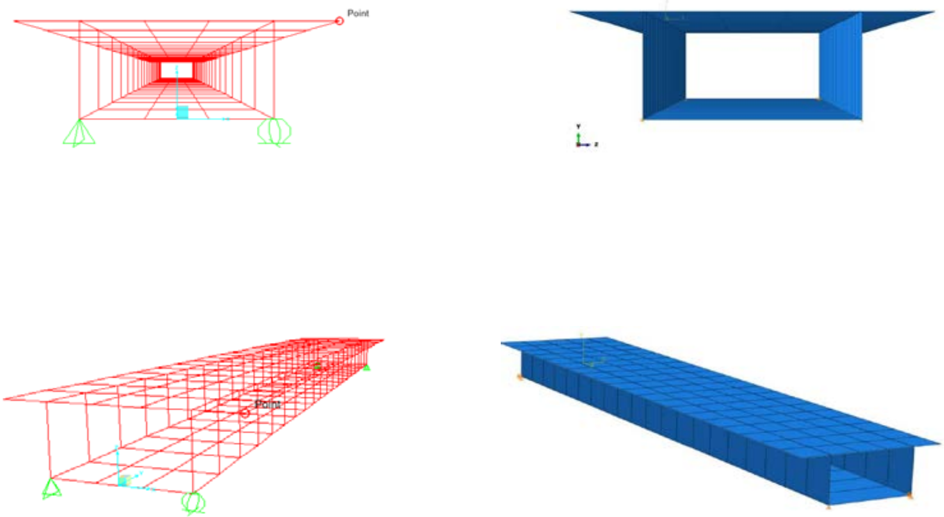
2. COMPUTER MODELING

Modelling is defined by a set of logical activities that build applications for the CAA computational model structures. This is essentially the most vulnerable and the hardest place in structural design. In general modelling represents experience and intuition professional who prepares the model structures. On the other hand, at modelling contractors required great creativity, judgment and perseverance with no small investment concrete work with your computer. Note that the results obtained by calculation of the numerical model by evaluating the behavior only of the built structure. The construction behaves according to the laws of physics and not by the regulations or guidelines for the use of computer application [5].

2.1. CHARACTERISTICS OF THE FINITE ELEMENT METHOD

The finite element method (FEM) is assigned to the discrete analysis methods and is based on physical discretization treated domain. Continuum with an infinite number of degrees of freedom is approximated by a discrete model of interconnected finite elements with a finite number of degrees of freedom. Approximation of the continuum to the FEM is carried out in such a way that:

- continuum is divided into sub – domains with the resulting dimensions (finite elements and configuring the network of finite elements),
- finite elements associated with a finite number of points (these points are located on the contour elements and are referred to as nodes)
- treated with variable fields, e.g. shifts every finite element describes the interpolation function,
- interpolation function are functions of a preset for the type of the finite element, and as a link between the values of the variable displacement fields at any point of the finite element and the value of the variable displacement fields at the nodes.



a) SAP2000 *b) Abaqus 6.13-1*

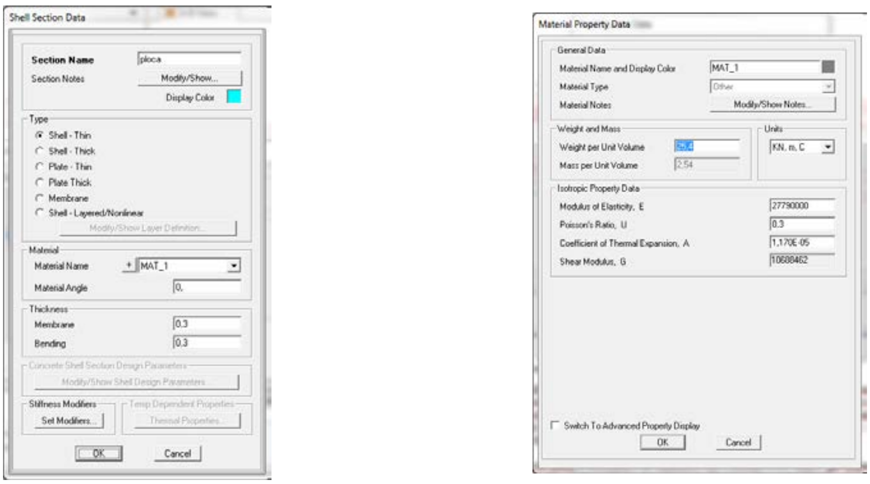


Figure 1 – Computational 3D bridge model

Accordingly, by using the interpolation function establishes a direct connection between the values of the function at any point of the basic element and the unknown parameters in the nodes. Method of continuous translation of the physical system in a discrete, that is, the way of forming the system of algebraic equations by means of which the contour is approximated a certain task, determines a variation of the FEM. We conclude that the variant of FEM method differs from other methods only in terms of formal approaches.

There are four basic types of FEM:

- Direct method
- Variational method,
- Method of residues, and
- Method of energy balance.

Many functions is an array of variables in one element, called interpolation function or approximate functions. The value of the function at a point is interpolated between its value in the nodes. With these features, there is provided only a qualitative change in the parameters of the element, which means that it is defined only by the shape and the intensity of the change determined by the values of the nodes. From choosing the interpolation function depends on the fulfillment of continuity between the individual elements. Whether they are or are not satisfied in terms of compatibility between the limits of the individual elements, the elements may be compatible and incompatible. The FEM is used as an interpolation function:

- Lagrange's polynomials,
- Hermite's polynomials,
- Serendipity functions, etc.

2.1.1 Free oscillations (bending – torsional oscillations)

Determination of natural frequencies is important information for dynamic analysis of structures. Real structures have "infinite" number of degrees of freedom, which is the number of natural frequencies of the structure is "infinite". For the experimental analysis of structures is not necessary to know the "infinitely" many natural frequencies. The most important frequencies are usually lowest, depending on the dynamic effects (load) that arises. According to [11], eigenvector analysis determines the undamped free – vibration mode shapes and frequencies of the system. These natural modes provide an excellent insight into the behavior of the structure. They can also be used as the basis for response – spectrum analyses, although Ritz vectors are recommended for this purpose. Eigenvector analysis involves the solution of the generalized eigenvalue problem:

$$\left| K - \Omega^2 \cdot M \right| \cdot \Phi = 0 \tag{1}$$

where

- ***K*** – is the stiffness matrix,
- ***M*** – is the diagonal mass matrix,
- Ω^2 – is the diagonal matrix of eigenvalues, and
- Φ – is the matrix of corresponding eigenvectors (mode shapes).

Each eigenvalue – eigenvector pair is called a natural oscillation mode of the structure. The modes are identified by numbers from „1“ to „n“ in the order in which the modes are found by the program. The eigenvalue is the square of the circular frequency „ω“ for that mode. The cyclic frequency „ *f* “ and period „*T*“, of the mode are related to „ω“ by:

$$T = \frac{1}{f} \tag{2}$$

and

$$f = \frac{\omega}{2\pi} \tag{3}$$

You may specify the number of modes „n“, to be found. The program will seek the „n“ lowest – frequency (longest – period) modes. The number of modes actually found „n“ is limited by:

- the number of modes requested, „n“
- the number of mass degrees of freedom in the model

A mass degree of freedom is any active degree of freedom that possesses translational mass or rotational mass moment of inertia. The mass may have been assigned directly to the joint or may come from connected elements. Only the modes that are actually found will be available for any subsequent response – spectrum analysis processing.

Table 1 – The results of computer simulations of free oscillations

Mode shapes	*Mode type*	*SAP 2000 (Hz)*	*Abaqus 6.13-1 (Hz)*	*Difference (%)*
I	*Torsion*	*2.9470*	*3.0504*	*-3.51*
II	*Vertical*	*3.5602*	*3.2007*	*10.10*
III	*Torsion*	*7.7966*	*7.6816*	*1.48*
IV	*Vertical*	*9.6847*	*8.9761*	*7.32*
V	*Torsion*	*9.8084*	*9.7193*	*0.91*
VI	*Torsion*	*12.7268*	*11.3460*	*10.85*

How would the results of the analysis of numerical methods to accept it is necessary to check the convergence of solutions depending on the number of finite elements.
From the literature [12], it is known that for oscillation analysis should be used more – a finer mesh size than the elements of the statistical analyses for describing the precise forms of oscillation.
However, the question is whether this is the case for understanding natural frequencies of oscillation model?
In this work, the analysis of free oscillations is contemplated the first half of natural frequencies and mode shapes of the structure theory in two applicative software (SAP2000 and Abaqus 6.13-1) by two independent modelers (Table 1). On the other hand, to check convergence solutions as a function of the shape and the number of finite elements discussed the first three frequency as other higher frequency equal to converge. Convergence solutions oscillation frequency is carried out only in the programming environment Abaqus 6.13–1., see Figure 2, 3 and 4.

Conclusion 1:
If the number of finite elements "<100" expressed the instability of solutions, while the number of finite elements "> 100", we have the stability of the value of natural frequencies.

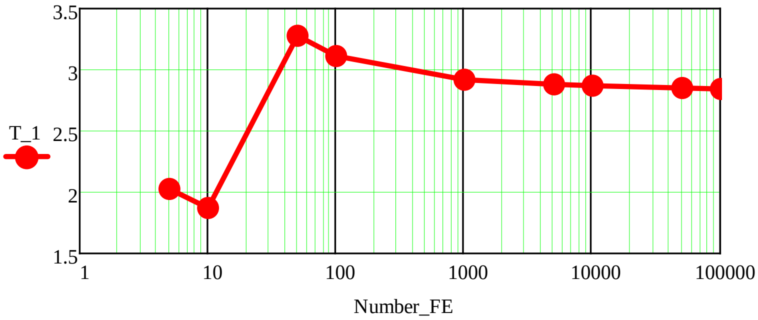


*Figure 2 – **I mode shapes** - a natural oscillation frequency as a function of the number of FE*

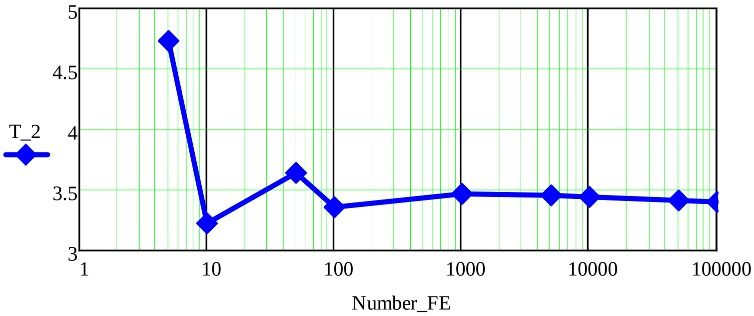


*Figure 3 – **II mode shapes** - a natural oscillation frequency as a function of the number of FE*

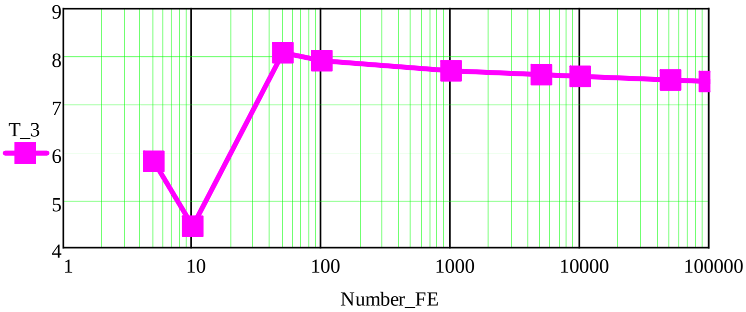


*Figure 4 – **III mode shapes** - a natural oscillation frequency as a function of the number of FE*

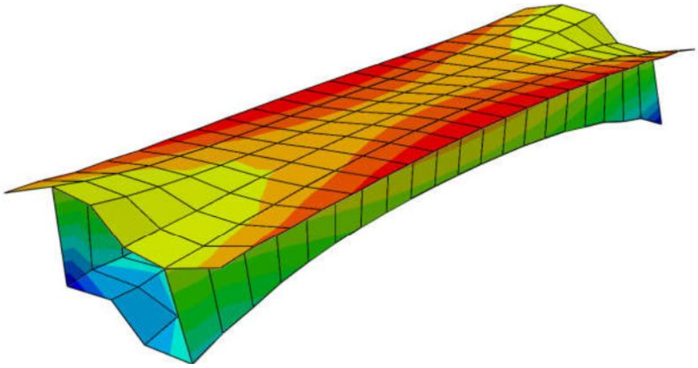


Figure 5 – Abaqus 6.13-1, The first mode shapes – coarse finite element mesh

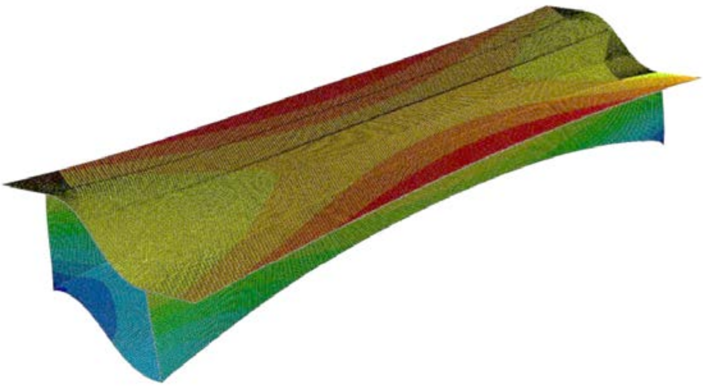


Figure 6 - Abaqus 6.13-1, The first mode shapes – fine finite element mesh

Conclusion 2
If the number of finite elements "<100" form of oscillation – change position FE is inaccurate (Fig. 5), or if the number of finite elements 100000, we geometrically precise form of oscillation 3d model (Fig. 6), which is an important the contribution of this research.

3. RESULTS OF COMPUTER SIMULATIONS

The research results of computer simulation of 3D model's response of free oscillations in the first six forms of oscillation are shown in figures 7, 8, 9, 10, 11 and 12. In order processing time was as short as possible and used computer memory as small as possible was not imposed on the finer network of final elements. Therefore, the results of oscillation forms of Abaqus software environments are somewhat lower quality, while in the program SAP2000 network pound the division within the 5x5 modelled finite elements, figure 1a. Common characteristic of all represented with these two computer programs that there are differences in describing oscillation forms 3D models.

SAP2000	***Abaqus 6.13-1***

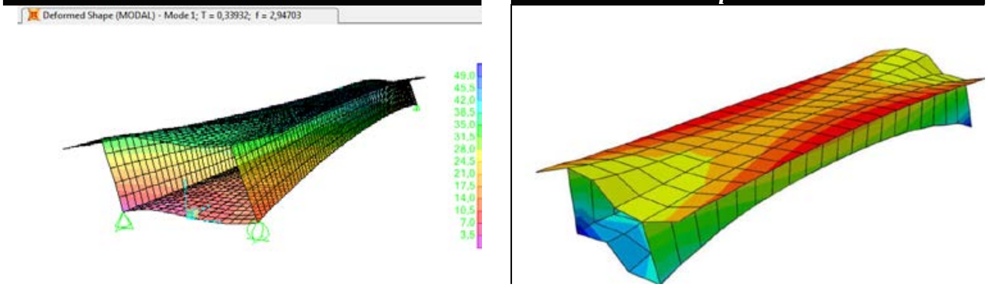


Figure 7 – The first mode shapes

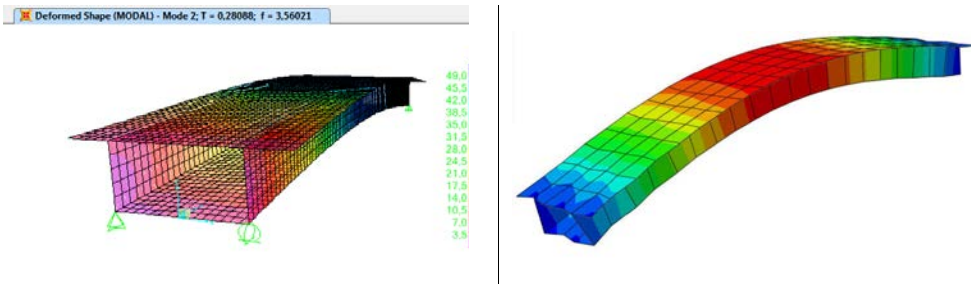


Figure 8 – The second mode shapes

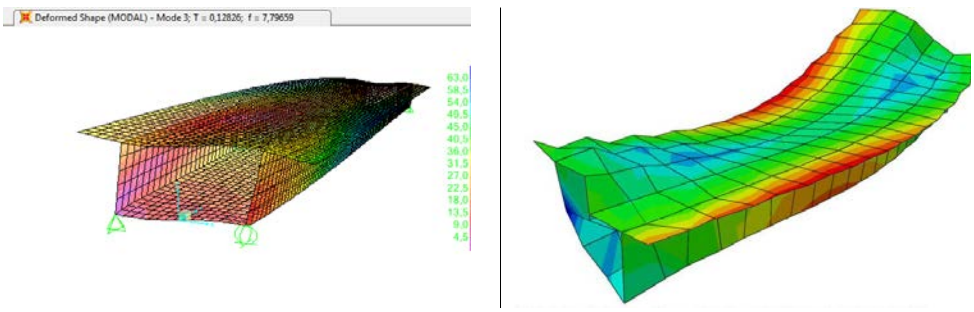


Figure 9 – The third mode shapes

SAP2000	***Abaqus 6.13-1***

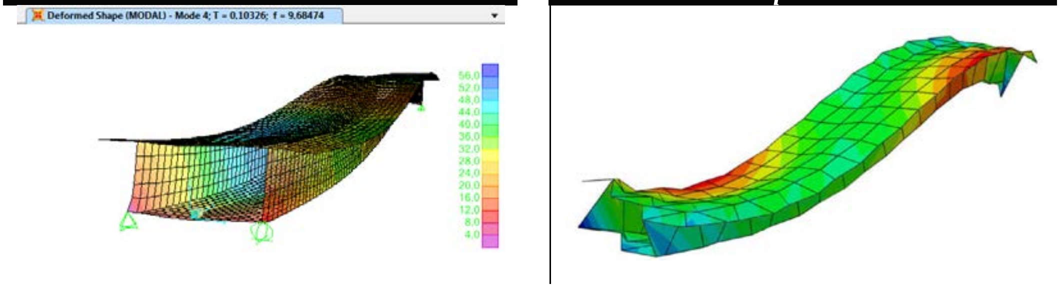


Figure 10 – The fourth mode shapes

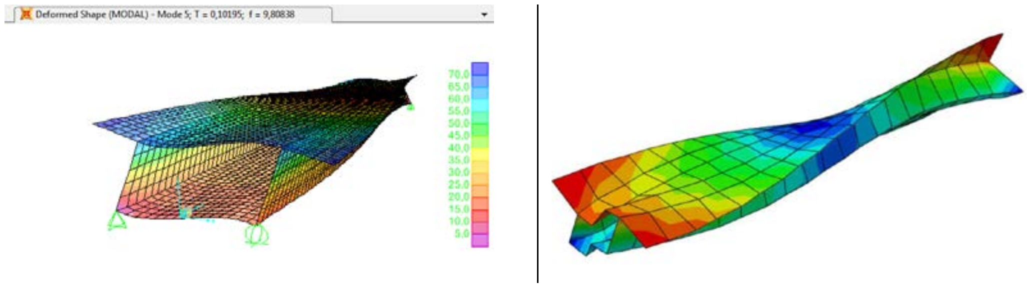


Figure 11 – The fifth mode shapes

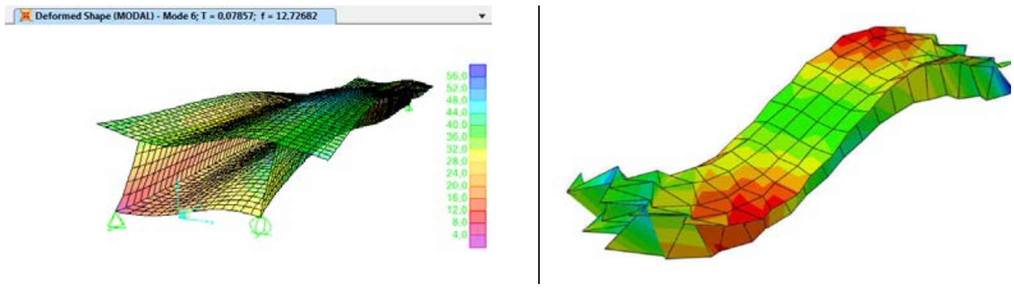


Figure 12 – The sixth mode shapes

4. CONCLUSION

Based on the presented theoretical analysis of free oscillations and simulation with 3D model of the bridge are given certain conclusions. "In situ" measurement of the treated dynamic size in this work are important in difficult to spot the "naked eye" detection and determination of the state of behaviour of the structural elements, and wherein the base for representing:

- a simple,
- quick and
- a non – destructive methods for testing structures.

By analysing the results of the dynamic parameters of a structural system between the two tests (for an interval of time) issues specific conclusions about substantial changes in the structures. On the other hand, the use of computers in the computer mechanics experimental methods have been given the speed and accuracy of reading measured values intended for:

- "online" monitoring parameters of the structural system,
- verification of analytical and numerical methods,
- validation of the results of computational simulation of 3D models of bridge structures.

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3Д РАЧУНАРСКО МОДЕЛИРАЊЕ ЈЕДНОЋЕЛИЈСКОГ ЗАТВОРЕНОГ ПОПРЕЧНОГ ПРЕСЕКА МОСТА СА АНАЛИЗОМ СЛОБОДНИХ ОСЦИЛАЦИЈА

Резиме: *У овом раду рачунарским симулацијама контролисана је конвергенција решења у зависности од типа и броја усвојеног коначног елемената нумеричке методе (МКЕ) са апликативним програмима SAP2000 и Abaqus 6.13-1, за потребе динамичке анализе конструкције моста. Рачунарским моделирањем конструкција моста третирана је као 3Д прорачунски модел са 2Д коначним елементима (Shell) и великим бројем степени слободе померања. За спровођење динамичке анализе 3Д моделом препоручује се коришћење ситније мреже коначних елемената у односу на анализу статичких утицаја у циљу прецизнијег описивања облика осциловања.*

Кључне речи: *Мост, 3Д модел, динамичка анализа, природна учестаност.*