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FLOOD RISK CONTROL USING A NEW TYPE DAM GATE: VIBRATION ANALYSIS

Calin ITU, Sorin VLASE, Marin MARIN

Abstract: *Protecting some regions against flooding requires the construction of some dams, which are complex constructions, capable of withstanding various demands mainly due to the increase of the water level above certain limits. Dams with a gate are often used for this purpose and the paper aims to study the vibrations that occur at such a gate. The analysis is done on an innovative project of a dam with an oscillating central pivot. For the studied system, the frequencies and modes of vibration are determined. A study of forced vibrations is also carried out, determining the response of some sensitive points of the dam to a periodic excitation. The Finite Element Method is used to obtain the results.*

Key words: *Control Flood, Vibration, Finite Element Method, metallic dam, water flow*

1. INTRODUCTION

Floods lead to significant socio-economic damage and loss of human life. For this reason, even from the design stage, methods of building dams are sought to ensure the avoidance of floods and the increase of the water level above certain limits established by the project theme. This goal involves a wide range of subjects, starting from the actuation systems of the gates of a dam, to the mathematical models and software used in the design stage, as well as the analysis of possible socio-economic consequences. Extreme weather, which manifests itself more and more often in the recent period, in the context of climate change, as well as the rise of the sea level, caused by the same reasons, make the risk of floods present more and more, and with increasingly serious consequences, for the communities human. It is expected that more and more areas will be affected, in one way or another, by the increased risk of floods.

The mobile gates represent a well-known constructive solution, with a major role in maintaining a constant water level and, consequently, protecting the upstream areas from downstream water. In this study, the authors focused on the study of the behavior of the dam gate to its own vibrations. Some results regarding this problem and related problems are presented in the following.

The most devastating event related to this type of construction is the breaking of the dam. The effects of such an unwanted event can be devastating. The subject was analyzed by numerous researchers and the cases of breaking of existing dams were meticulously studied. Theoretical results and experimental determinations are presented in numerous works, among which we mention [1-5].

Another subject of study, determined by the practical importance of the phenomenon, is the breaking wave. As a result, the specialized literature presents a series of results, among which we mention [6-10]. The study of the vibrations of a dam gate is presented in [11-18]. Mathematical models have been developed to analyze different aspects of the mechanics of these systems [19-22]. Due to the complexity of the studied systems, numerous numerical models were analyzed. In this situation, the Finite Element Method (FEM) is the main study tool and analytical mechanics methods offer powerful tools for dynamic analysis [23-26].

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Floods permanently cause devastating damage to infrastructure, the economy, the natural environment and society. The size of these flood risks will determine the mitigation strategies that are required. Climate changes lead to the amplification of these risks and, as a consequence, to the increase of costs for human society. Especially in coastal regions, rising water levels can lead to major damage.

Physical, economic or political factors will impose the engineering solution that corresponds to the optimal compromise when designing a dam. In the work, the solution of a symmetrical dam is analyzed, consisting of two mobile parts that can rotate around a central tilting pivot and that are actuated by the water level. An analysis of the vibrations of the panels of the two gates is made on this constructive solution. The analysis method is FEM.

2. PRESENTATION OF THE DAM GATES SOLUTION

Depending on the constraints of a physical, economic, social and technological nature, numerous solutions were used to build the dams. The project studies a dam that blocks the passage of water through two symmetrical mobile gates. They can rotate around a central pivot and can thus close the passage of water in both directions. This whole structure is placed on the fixed concrete plate that ensures the fixing of the system and seals the bottom of the dam. For the construction of such a dam, numerous technical parameters must be taken into account, such as: water flow, the dimensions in which the dam must fit, the geographical configuration, the dimensions allowed for the construction site, the access possibilities, storage, etc. A sketch of the studied dam is presented in Fig. 1.

The dam is made up of a concrete structure to which the two mobile gates (Fig.2) are attached, by means of a pivot that can move in a spherical joint. A static analysis of the dam gates provided the acceptable technical solution for the gates. This solution consists of a structure, made up of bars and covered on the outside with a sheet metal covering [19]. In the work, three types of covers will be analyzed for which dynamic analysis will be done to identify the best solution (Fig.3).

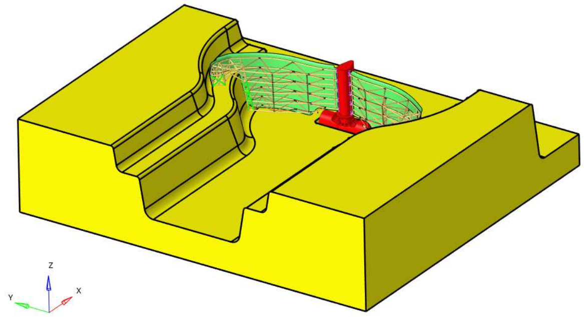

Fig. 1. The dam structure and mobile gates

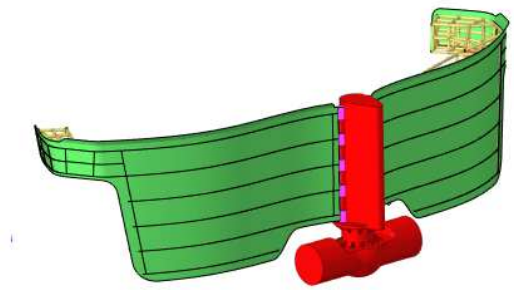

Fig. 2. The gates and the central pivot

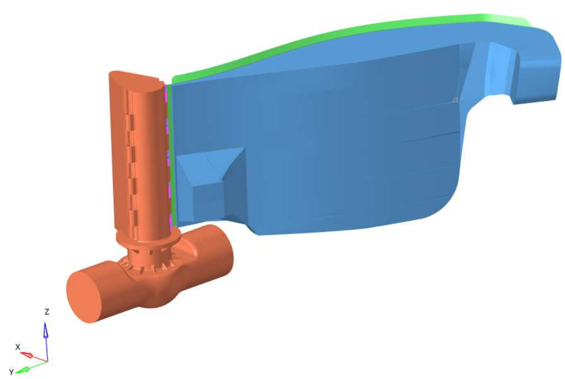

Fig. 3. The proposed solution

3. MODELS AND METHODS

FEM is used for the structural analysis of the system, a method familiar to researchers. Thus, the natural frequencies of the dam gates and the response of the structure to different excitation frequencies of the dam will be determined. The final project proposes a structure of bars covered, to ensure tightness, with an envelope. Two solutions are proposed for making the covering, one for which steel sheet is used and yours for which a composite material is used.

FEM is a method widely used by researchers for static and dynamic analysis of mechanical systems. The method offers many advantages for engineers who can study complex and different systems and various loading cases. In the present case, the metal skin that ensures the tightness of the gate covers a structure of bars, which ensures the static strength of the gate. This type of structure represents a simple constructive solution, which ensures, at a low price, the project requirements of the dam. For the researcher, the structure proves to be relatively simple to model. The finite elements used for model are SHELL type, and BEAM type elements are used for the bars that ensure the strength of the gates.

To perform the calculations, the authors used Altair Hyperworks software. For the studied system, it was considered that the materials used are homogeneous isotropic and the corresponding constitutive laws were used. SHELL finite elements are four-cornered, each node having six degrees of freedom per node. BEAM type finite elements are used for the analysis of the bar structure. The water develops a static pressure on the dam gates:

$$p = \rho g h$$

Here ρ is water density (1,000 kg/m^3), g is gravity acceleration (9.81 m/s^2) and h the variable height of the water level considered.

The water pressure values at the base of the dam upstream is $p = 0.039\, MPa$ and, for the two cases considered the water downstream are, $p_1 = 0.054\, MPa$, $p_2 = 0.069\, MPa$.

To perform the calculations, the dam gates, the internal structure made of bars and the central pivot are discretized, with the FEM. For modeling, finite elements from the library of the used software are used.

Boundary conditions are introduced, essentially represented by zero displacements, at the points where the gates rest on the concrete structure (Fig.7). The central pivot, around which the gates swing when the downstream water level increases, is modeled with tetrahedral finite elements. When the gate close the water acts both downstream and upstream.

For the gate structure shown in Fig.3, a calculation of the eigenfrequencies was made. Three types of material were considered for making the covering: steel plate, plate made of an alloy with aluminum and plate made of a composite material. The three variants can constitute feasible engineering solutions for the gate type analyzed. We are looking for a solution that best meets the conditions of the project, has a low price and easy maintenance. The results of this analysis can be found in Table 1.

Table 1

First ten frequencies calculates for the three cases

No. of frequency	**Solution 1 Steel**	**Solution 2 Aluminium alloy**	**Solution 3 Composite**
	Freq. [Hz]	Freq. [Hz]	Freq. [Hz]
1	10.53	9.79	6.58
2	16.14	15.19	7.24
3	16.98	15.62	7.79
4	20.65	20.12	8.33
5	23.01	24.68	8.99
6	24.29	26.36	10.81
7	25.34	27.18	10.85
8	26.55	28.65	12.04
9	27.97	29.22	12.56
10	29.07	30.52	14.58

A representation of the eigenfrequencies in the three cases is shown in Fig.4.

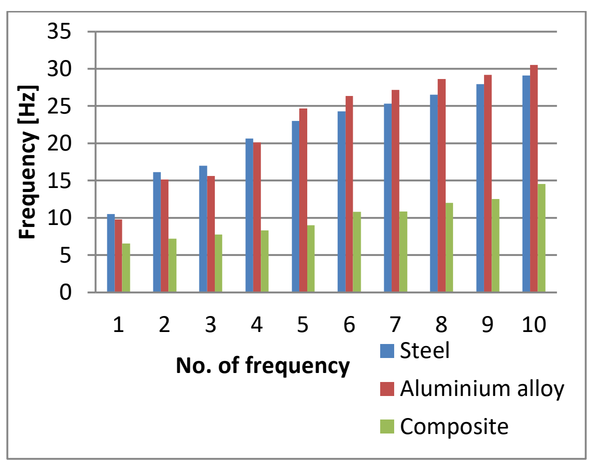

Fig.4. The eigenfrequencies for the three solutions

It can be observed that for the two solutions with metallic skin the natural frequencies are approximately the same, while for the composite skin the frequencies are almost halved. If the solution with the composite skin is adopted, additional analyzes are necessary to check if the dam gates withstand dynamic loading.

Following the analysis of the eigenmodes of vibrations, a number of 10 points of interest were identified where the vibration amplitudes are higher. These points of interest (or important points) are represented in Fig.4-6.

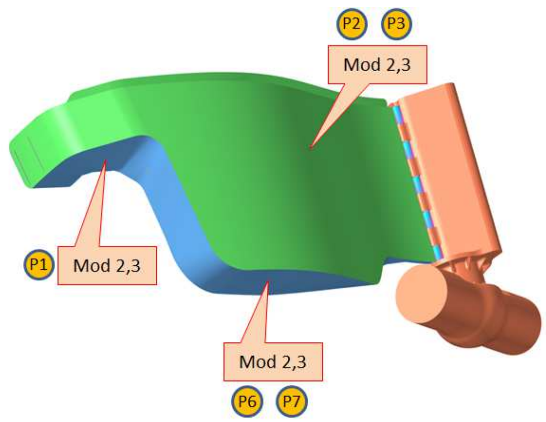

Fig. 5. The important points P1,P2, P3,P6,P7 located on the front side of the gate and in the lower part.

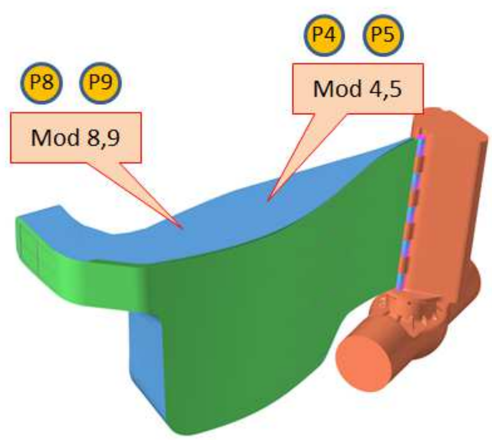

Fig. 6. The important points P4,P5, P8,P9 located in the upper part of the gate.

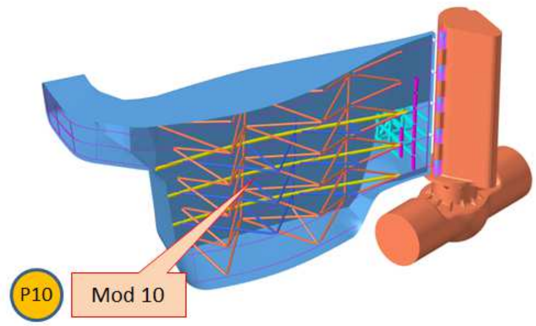

Fig. 7. The important point P10 located at the back sie of the gate.

4. RESULTS AND DISCUSSION

The response of the structure to an excitation of the support points of the gate assembly to a unitary excitation was determined. Fig. 8-17 shows the amplitude of the response of the points of interest to a harmonic excitation, with a variable frequency, between 0-40 Hz. At an excitation with an amplitude of 1 mm, the amplitude of the response of the points of interest is represented, in mm.

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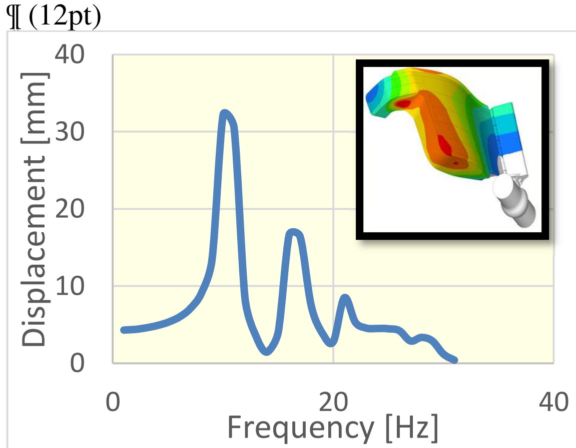

Fig. 8. Displacement of point P1

In the paper, the behavior of the structure of the gates of a dam to force vibrations and external excitations was studied. The symmetry of the structure (the two gates are identical) facilitates pre-processing, post-processing, modeling and calculation. An analysis of the dam gates at a variable frequency excitation shows us that there are points that can have a high intensity response. It is observed that the excitations to which the response can increase above certain limits are above the value of 5 Hz. influence the behavior of the dam gates. We identified 10 points that we called important points where the response of the structure can be significant. It is obvious that the maximum response occurs at frequencies close to the natural frequencies of the system.

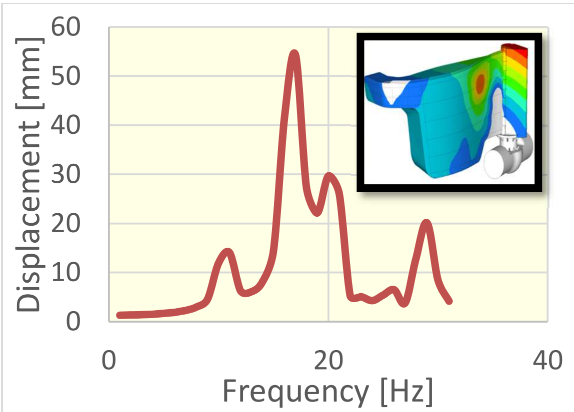

Fig. 9. Displacement of point P2

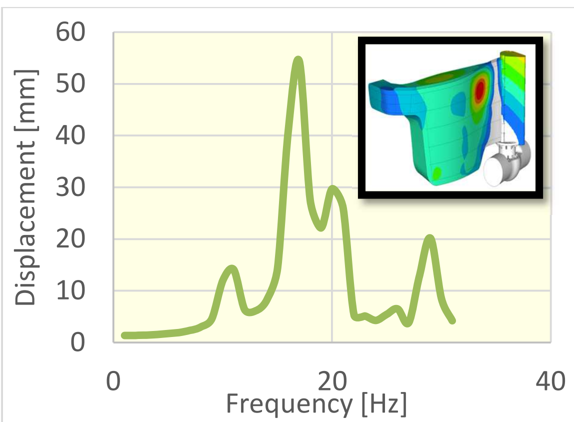

Fig. 10. Displacement of point P3

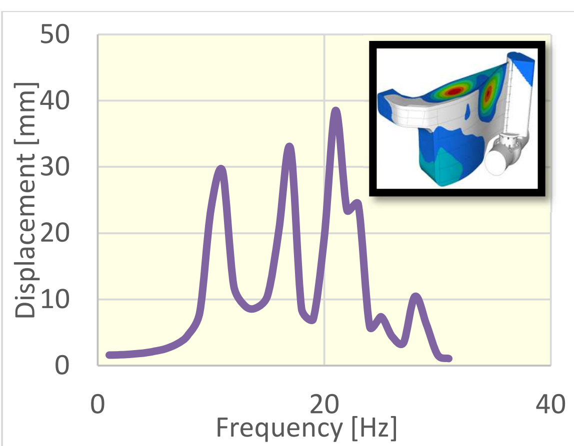

Fig. 11. Displacement of point P4

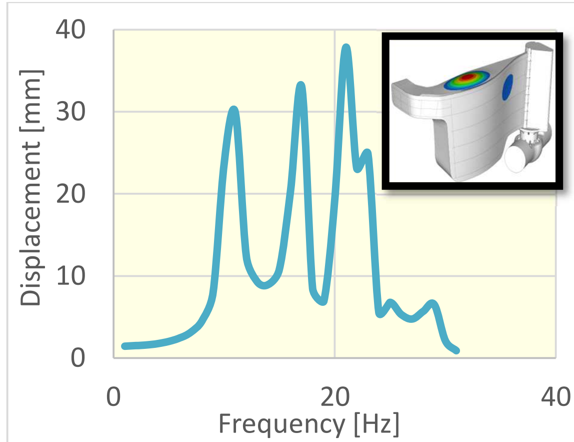

Fig. 12. Displacement of point P5

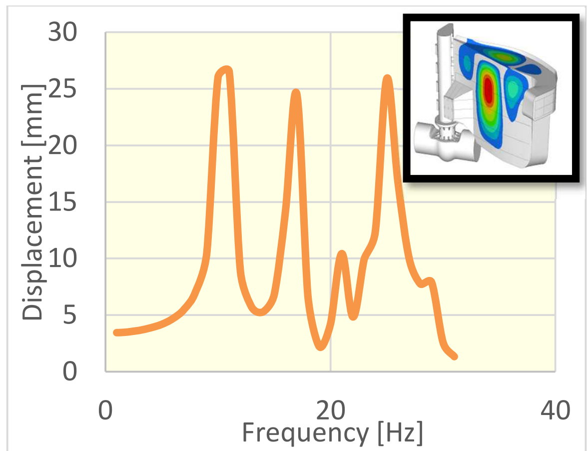

Fig. 13. Displacement of point P6

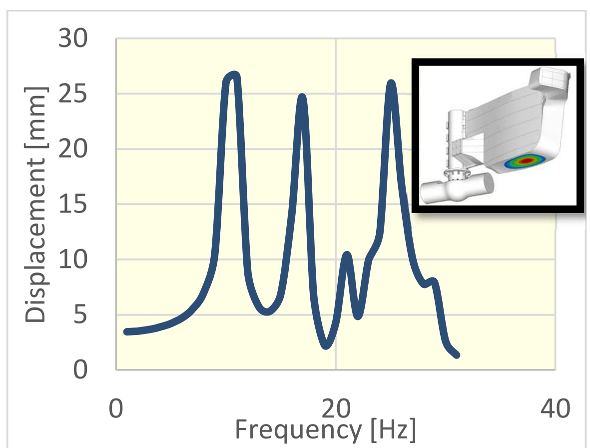

Fig. 14. Displacement of point P7

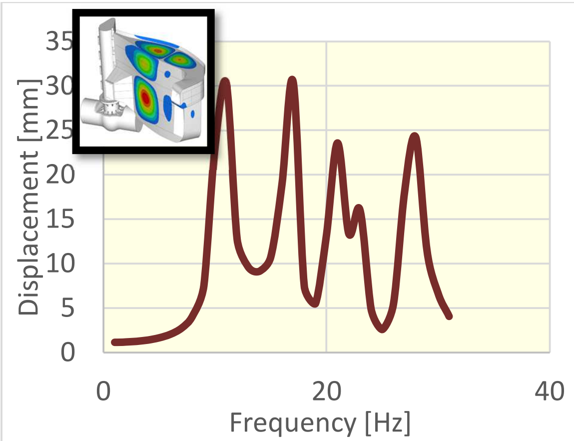

Fig. 15. Displacement of point P8

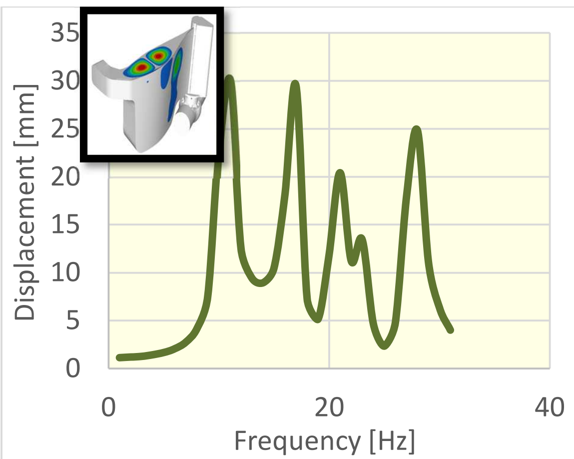

Fig. 16. Displacement of point P9

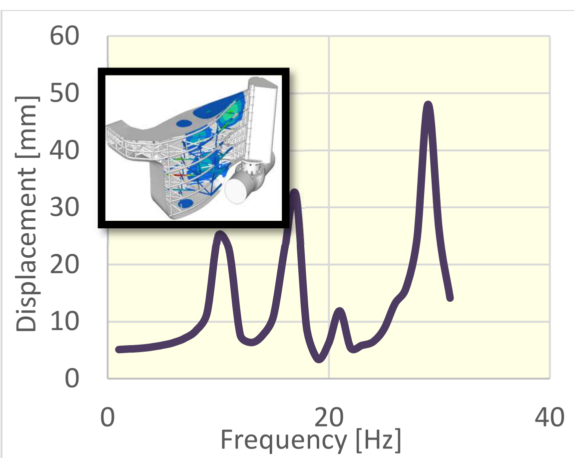

Fig. 17. Displacement of point P10

The natural causes that could excite the structure of the dam are generally below this value (for example, the frequencies of the earthquake in 1977 in Romania are (most of them), below the value of 5 Hz). It would result from this that the forced vibrations, in the case of the studied dam, should not significantly.

5. CONCLUSION

As part of the work, an analysis was made of the natural vibrations and the forced vibrations for the gates of a dam. The method used to perform the analysis is FEM. The dam, representing an innovative dam solution, consists of two identical gates that close if the downstream water level rises above the permitted limit. The resulting project is represented by an extremely simple solution from a constructive point of view. This determines a simple construction and a low cost price. The water level will control the closing and opening of the gates. The actuation of the gates is based on the Archimedean forces.

The gates are clad in a metal skin placed over a resistance structure made of bars. In the work, the resonance frequencies and the response were determined, in several points considered important for the behavior of the structure, in the case of gate excitation with a variable frequency in a range. The conclusion can be formulated that, since the maximum transmissibility for the studied cases is obtained at high frequencies in relation to the excitation frequencies that can demand the structure, these excitations are not dangerously amplified by the structure. The analyzed structure will therefore have a good behavior to external excitations.

At the same time, a comparison was made regarding the eigenfrequencies of the dam gates if three types of different materials are used. It is found that in the case of a covering with composite material, the natural frequencies decrease to almost half of the value obtained in the case of a metallic skin. In the case of using such a material, an additional vibration analysis is required.

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Controlul riscului la inundatii cu un nou tip de poarta de baraj: analiza la vibratii

Rezumat: Protejarea unor regiuni împotriva inundațiilor necesită construirea unor baraje, care sunt construcții complexe, capabile să reziste la diverse solicitări, în principal din cauza creșterii nivelului apei peste anumite limite. Barajele cu poarti mobile sunt adesea folosite în acest scop iar lucrarea își propune să studieze efectul vibrațiilor care apar la o astfel de poartă. Analiza se face pe un proiect inovator al unui baraj cu pivot central oscilant. Pentru sistemul studiat se determină frecvențele și modurile de vibrație. Analiza se face pentru trei tipuri de material utilizat pentru acoperirea structurii din bare. Se efectuează și un studiu al vibrațiilor forțate, determinând răspunsul unor puncte sensibile ale barajului la o excitație periodică. Pentru obținerea rezultatelor s-a utilizat Metoda Elementelor Finite.

Calin ITU, Dr.hab., Professor, Transilvania University of Brasov, Department of Mechanical Engineering, calinitu@unitbv.ro, B-dul Eroilor, 29, Brasov, 500036.

Sorin VLASE, Dr.hab., Professor, Transilvania University of Brasov, Department of Mechanical Engineering, svlase@unitbv.ro, B-dul Eroilor, 29, Brasov, 500036.

Marin MARIN, Dr.hab., Professor, Transilvania University of Brasov, Department of Mathematics and Informatics, m.marin@unitbv.ro, B-dul Eroilor, 29, Brasov, 500036.