ANALYSIS OF FORCED VIBRATION DAMPING WITH THE USE OF HYPERPLASTIC MATERIALS

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Abstract. *A solution of forced vibration damping through the use of hyperelastic materials have been proposed in the paper. Most structures can be easily simulated on the basis of a linear elastic material model. However, when linear elasticity ceases to be sufficient, then nonlinear models are adopted, e.g. hyperelastic materials. The aim of this study was to investigate the behavior of the structure under the influence of external forces with the use of materials showing high fatigue resistance to compression with simultaneous consideration of vibration damping. The model presented in the paper has been subjected to an excitation in form of displacement. The paper presents a dynamic analysis using the finite element method in the ANSYS program. The comparison concerned the use of hyperelastic materials with the use of the deformation energy model of hyperelastic incompressible materials according to the Mooney-Rivlin model.*

Keywords

Forced vibrations, damper, Mooney-Rivlin model.

1. Introduction

Mechanical vibrations are, in most cases, an undesirable phenomenon. Due to the fact that in many cases it is impossible to remove the source of vibrations, various methods of their suppression and minimization are used. The method of determining the parameters of dynamic interactions occurring in structural systems depends primarily on the size of the analyzed object. When designing the structure of e.g. stands or a ski jump, an object is not built only for the purpose of carrying out dynamic tests and obtaining data. Then, physical and mathematical models are used, and recently numerical models with the use of computer methods and dedicated programs have become particularly useful. An example is the analysis of stands exposed to dynamic impact due to the movement of crowds [11]. Such models are indispensable in preliminary analyzes of objects, before starting the implementation of a laboratory test stand or direct implementation of the structure. The use of computer techniques using the finite element method, enable discretization of continuous systems, and allow simulation of system vibrations, which is difficult to observe in the case of particularly small vibrations. Hence, many studies conducted in order to understand the factors of dynamic interactions in the structure concern the application of FEM, which is beneficial not only due to the above-mentioned factors, but also speeds up the design process [15]. In experimental research, real objects, made on a small scale, are often used. An example of this are the modal and experimental tests of the steel bridge structure presented in [10].

The reduction of vibrations in systems is performed in a way that results both from the determination of the source of vibrations, their nature and occurrence, but also due to the constraints of the structure. The methods of reducing vibrations include, among others for vibration reduction through propagation, vibration energy dissipation or for active reduction methods. In the case of active methods that use additional energy sources, vibration and noise are compensated by vibrations and sounds from additional sources. With regard to passive methods, by modifying the parameters and structure of the systems, limitations arise which result in a low effectiveness of vibration reduction in the low frequency range and are often sensitive to changes in operating conditions.

However, these are solutions that, due to the fact that they do not require the use of an additional energy source, are irreplaceable in some cases. The solution presented in this paper concerns passive methods, which in its form use the model of a hyperelastic material in order to limit the impact of structure vibrations.

Effective solutions to reduce vibrations include various types of dynamic vibration dampers. The use of pendulum vibration dampers in practice, incl. in the case of tall towers, chimneys, buildings and bridges, allowed to partially eliminate vibrations caused by wind or caused by earthquakes. The research with the use of a pendulum damper was carried out and described in [5], in which the author proposes a solution to reduce vibrations caused by harmonic excitation and the impact of pedestrians. In the work [8] reducing the vibrations of the building frame was proposed with the use of mass vibration dampers, where considered object was exposed to strong wind fluctuations.

The wide range of use of dampers and vibro-isolators is described in [2]. The solutions included there relate to vibration absorbers, also in the application of sound absorption. With regard to the methods of active vibration damping in structures, the work [14] describes the analysis carried out with the use of the ADVA shock absorber, which detects the excitation frequency of the system and calibrates the parameters to obtain the required stiffness. The analysis of the selection of appropriate vibration damping parameters with the use of optimization and determination of the objective function was presented in [6].

In [16], the dynamic characteristics of rubber were determined with the use of experimental methods. The authors paid special attention to the determination of the damping properties of rubber, defining the measure of these properties as the tangent of the phase shift angle occurring between the stress and deformation (the so-called loss angle). In [13], the authors described a method of experimental determination of the characteristics of a hyperelastic material, which can be used in the Mooney-Rivlin model. Paper [12] presents a mathematical approach to the best way to structure hyperelastic models applicable to incompressible rubber-like materials and describes the model validation procedure for parameter estimation. The technique proposed by the author enables the validation of the fixed and complete model by grading with increasing deformation.

The use of hyperelastic materials is of particular importance. On the basis of the wave equation, the authors of [3] carried out calculations for the anisotropic material according to the Monney-Rivlin model which represent superpositions of homogeneous or inhomogeneous plane waves. Among the material solutions we deal not only with hyperelastic materials, but also others, of which the great application in the context of vibrations concerns viscoelastic materials. Research on the possibility of using viscoelastic materials, taking into account the reduction of accelerations and dynamic displacements of the structure, is presented in [7]. Viscoelastic materials dissipate energy during form deformation caused by the movement of steel plates in relation to each other. Viscoelastic materials are characterized by the dependence of their properties on temperature and frequency of excitation.

In [1] a practical approach for determining optimal and adequate hyperelastic models was presented and applied to some classical data for establishing the Rivlin polynomial-expression for rubber-like materials.

This paper presents the results of numerical tests carried out in the ANSYS / Mechanical software, the dynamic interactions were determined and a vibration damping solution was proposed.

2. Material model

This paper proposes a solution for vibration damping through the use of rubber-based materials, which are referred to as incompressible materials. In the case of modeling linearly elastic materials according to the FEM theory, it is enough to define two material constants (Young's modulus and Poisson's number). Hyperelastic materials are able to undergo large elastic deformations under the influence of forces, but show nonlinear behavior and their deformation is not directly proportional to the applied load [4]. For hyperelastic material models, define additional material parameters. The material characteristics of typical hyperelastic materials are shown in Fig. 1.

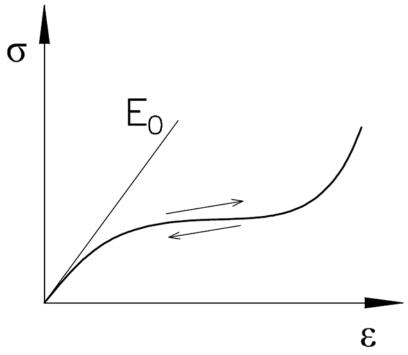

Fig. 1: Stress-strain characteristic of typical hyperelastic materials [9].

Based on this dependence and taking into account the deformation range in the simulation, a model of the deformation energy of hyperelastic incompressible materials was selected. In the deformation range from 10% to 300% deformation, the best approximation is provided by the Mooney-Rivlin model, the form of which is presented in the general formula:

$$W = C_{10}(I_1-3)+C_{01}(I_2-3), \quad (1)$$

where: I_1 and I_2 – invariants describing the strain energy density, C_{10} and C_{01} – material constant.

The undoubted advantage of using hyperelastic materials is, above all, a high damping coefficient of mechanical vibrations and the ability to dampen sounds.

3. Model of analysis

In the case studies of structures with a high degree of complexity, an analysis should be made in terms of the occurrence of places most exposed to loss of load capacity or loss of stability. In the context of determining these places, structure elements can be separated, which can then be subjected to static and dynamic analysis. This work proposes a solution for vibration damping with the use of hyperelastic materials according to the Mooney-Rivlin model. The analysis was carried out on the basis of a simple design solution, the scheme of which is presented in Fig. 2.

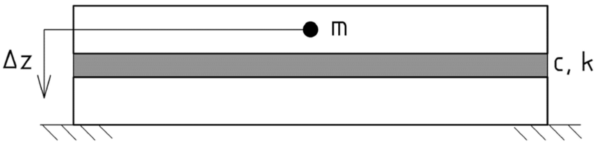

Fig. 2: Scheme of the analyzed system

The problem concerns the vibration damping under the influence of compression of two concrete cubes separated by a hyperelastic material. The aim is to eliminate vibrations that can contribute to noise.

When defining hyperelastic material models, first define the rubber material constants. Rubber-based materials deform quickly under light loads and require a slow initial loading. Due to the strong non-linear behavior of rubber-like materials, rapid load increases usually lead to numerical instability or divergence during the equilibrium iteration. Hence, displacement control may prove to be more effective than force control.

The results presented in the paper include the results of static analysis taking into account the excitation in the form of displacement, and modal analysis with the use of FEM and ANSYS Mechanical software.

4. Results of numerical studies

The model adopted for the analysis is presented in Figure 3. In the first part, a static analysis was performed with particular emphasis on the nature of the deformation of the hyperelastic layer.

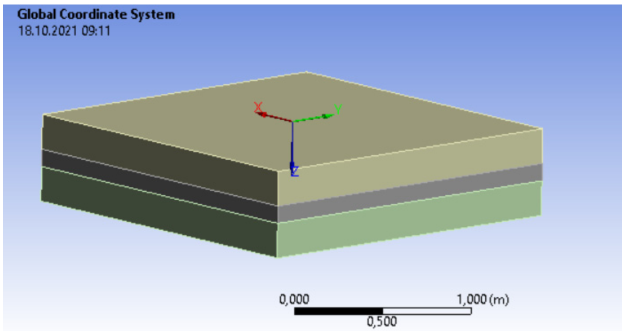

Fig. 3: The analyzed model in the adopted reference system

The nature of the deformation is shown in Fig. 4.

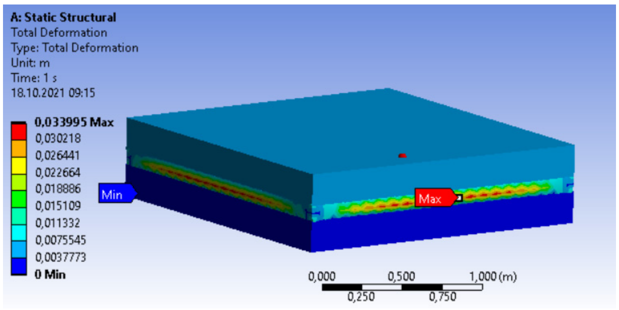

Fig. 4: Deformations of the system due to the applied displacement

The C25 / 30 concrete slabs with dimensions of 2m x 2m x 0.2m were separated with a 0.1 m thick layer of hyperelastic material. The plate was attached to a non-deformable substrate along the two lower parallel edges.

On the example presented in the paper, the nature of the deformation can be presented in a very simple way, and the nature of the deformation can be predicted in a qualitative sense, but as for the values, the determination of which is necessary to determine the effects on the structure, such analyzes, even in a slightly complicated scope, are necessary.

By taking into account the Mooney-Rivlin model, it was possible to take into account the properties of the hyperelastic material in the middle layer of the analyzed structure. As a result, the stress-strain relationship was obtained for the entire structure, shown in Fig. 5.

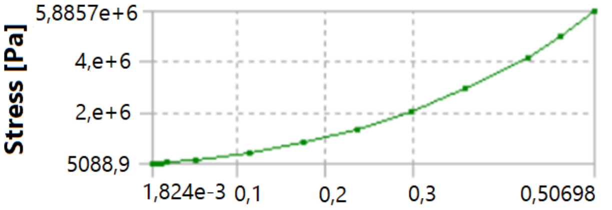

Fig. 5: The stress-strain relation of a system with the use of a hyperelastic material

For comparison, a stress-strain diagram is also included (Fig. 6) in the case of using a linearly elastic material in the middle layer.

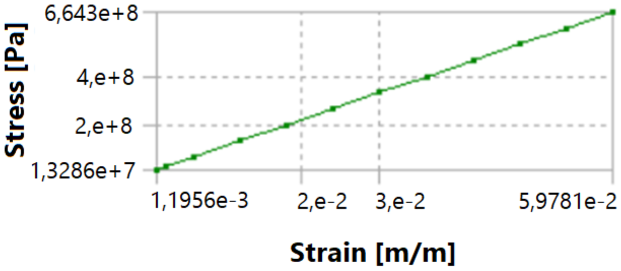

Fig. 6: The stress-deformation relation of a system with the use of a linearly elastic material

As a result of the proposed use of the hyperelastic material, the vibrations in the system were limited. The set exciting force is 100 N with a frequency of 100 Hz. The value of the force transmitted by the system was limited due to the assumption of damping, and the values of this comparison are presented in diagrams 7 and Fig. 8.

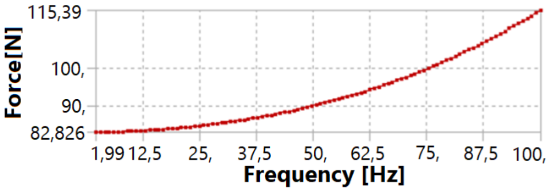

Fig. 7: The relation of force - frequency without damping

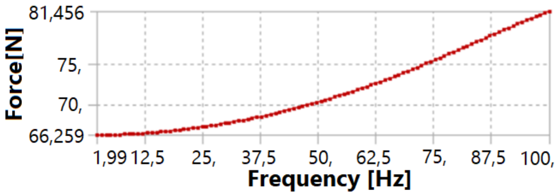

Fig. 8: The relation of force - frequency with damping

For structures whose system is complex, they require longer modeling time and require more computing power. The value of the force transmitted by the vibration damping system is lower than that of the system in which the damping was not used.

5. Conclusion

The analysis carried out in the paper concerns the study of vibration interactions and dependencies in systems in which damping with the use of hyperelastic materials was applied. Based on the results obtained from the analysis, it is possible to confirm the positive effect of the use of the Mooney-Rivlin model hyperelastic material in a simple structure. The test stand is the basis for further numerical tests, and after their conduct, also for experimental tests.

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