ANALYSIS OF THE IMPACT AND MECHANICAL PROPERTIES OF A DAMPER MADE OF HYPERELASTIC MATERIAL

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Abstract. *The analysis of mechanical properties in the proposed model of the vibration damping element through the use of a layer of hyperelastic material was presented in the paper. The aim of the study was to analyse the behaviour of the structure under the influence of external forcing forces with the use of hyperelastic materials, which are characterized by high compressive fatigue strength. The model in its construction assumes the use of rubber as a material that acts as a vibration damper. The results presented in the paper include the stress-strain relationship and the vibration analyses. The paper contains the conclusions of the comparative analysis in relation to the reference model. The studies were performed using the finite element method using the ANSYS program. Mesh elements were adopted as 3D solid elements, adapted to the model, and properly densified in the places of contact of individual layers in the model. The Mooney-Rivlin material model, in order to analyze the middle layers, was adopted in the work.*

Keywords

Damper, stress-strain relation, Mooney-Rivlin model, dilatation.

1. Introduction

A hyperelastic material reflects the characteristics of an ideally elastic material for which the stress-strain relationship is nonlinear. Very large deformations are reversible, which affects a wide range of applications of this type of materials. Research on the use of hyperelastic materials is based on theoretical models.
Experimental tests on rubber materials are highly important in understanding static and dynamic behaviour [4]. On the basis of the experimental test results, the analytical models are easier to build. Such a models are very useful in analysing behaviour under different conditions, subjected loads, especially in hyperelastic materials. The first known generalized model of rubber behaviour under tension and compression has been established by Mooney [9]. The Rivlin model has been developed by Rivlin, in which formulation of the initial problem resulted in a reduction in the number of required inputs [11]. The Mooney-Rivlin material model is one of the most often used models for hyperelastic materials, from among Zahorski [5-6], Neo-Hoekan, Odgen, Gao [2]. There is no one model and one theory with which it would be possible to describe elastomers in the entire range of deformations. Accurate description of Mooney-Rivlin curves requires more constants, especially for thermoplastic elastomers. The problem of modelling such materials using the Mooney-Rivlin model and the finite element method was presented in [13]. In this work, the Mooney-Rivlin model was adopted.

Rubber with its incompressible properties is often applicable in order to reduce dynamic effects caused by external forcings [1]. From many different types of hyperelastic materials, there are two main groups of rubber with opposite properties in view of the application: hard and soft rubber [7]. Hard rubber represents materials, which are ineffective in elongation, and the influence of reducing dynamical impact are rather small. Soft rubber represents materials, which transfers tensile forces and significantly dampens dynamic effects. In [12] the proposition of procedure of characterization rubber-like materials were included, by means of optical methods applied in uniaxial and equi-biaxial tension tests. Optical methods are well suited for large deformation measurements. Dynamical effects may be difficult to observe. In [8] proposition of experimental test of dynamic interaction of building structures based on the ARAMIS SRX measurement system was included.

Elements of building structures undergo deformation during operation. In order to avoid negative irreversible effects of deformation in the form of scratches and cracks, and consequently its destruction, dilatation gaps should be used. This will ensure the independent operation of individual parts of the building. The paper proposes a model of filling, a fragment of a dilatation or a technological break, transferring the service loads.
Through the results obtained from experimental research and theoretical models formulated on their basis, it is possible to conduct numerical research in engineering programs, which is indispensable in preliminary scientific research. On the basis of the Yeoh constitutive model and large-deformation theory of rubber material, in [14] the analysis of test data was conducted by author's novel

method by using ABAQUS. The studies were performed for core material in blowout preventer.

In numerical modelling of linearly elastic materials, two material constants are given. From the definition of the hyperelastic material model, which was derived from the strain energy density function, additional material parameters should be defined [3]. Additional material parameters are determined empirically. A mathematical approach describes the model validation procedure for parameter estimation in hyperelastic material were described in [10]. The technique proposed by the author enables the validation of the fixed and complete model by grading with increasing deformation.

The aim of the study was to analyse the behaviour of the structure under the influence of external forces with the use of hyperelastic materials, which are characterized by high compressive fatigue strength, as a vibration damping layer. In the paper the analysis of stresses, strains and dynamical interactions of the modelled element was included.

2. Model Description

The paper proposes a solution presenting filling a fragment of a dilatation or technological gap in constructions, in especially in buildings by using a hyperelastic material as a middle layer. The proposed solution can be used, for example, in communication passages, corridors, with pedestrian traffic. The model of the analysis was schematically presented in Fig. 1.

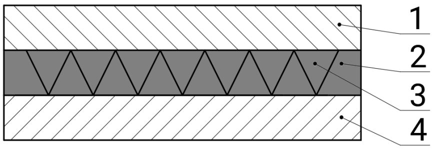

Fig. 1: Model of a vibration damper with a layer of hyperelastic material.

Layers 1 and 4 were made of polymer concrete. It is justified, since polymer concrete has better properties of tensile strength and flexural strength than concrete. Layers 2 and 3 were modelled from a hyperelastic material, and the cross-section was proposed in the shape of cuboids arranged along the element, with a triangle base (middle) and trapezoidal base (at the beginning and end). The layers were stacked on top of each other in a constant manner. The material used is a hard rubber. After completing the entire structure, the layers adhere tightly to each other.

The simplified view of the element with its dimensions in centimetres was presented in Fig. 2.

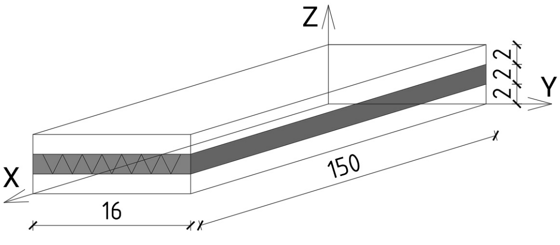

Fig. 2: Scheme of the modelled element.

The total length of modelled element is equal 1,5m, which can be easily adopted in communication corridors and passages. The cross section in placed in YZ plan of coordinate system, and along the X axis the length is applied. The shape of rubber layers was adjusted in cross - section to the equilateral triangle, with the length of the side of the triangle equal 20mm. On the left and right sides, the trapezoidal shapes were designed in order to fill the rest gap in between the polymer concrete layers.

The static analysis was performed for a reference model in order to indicate qualities of solution proposed in the paper. In reference model the middle layer was designed as a made of rubber with constant cross-section, with the same value of thickness in between the concrete layers. The reference model is presented in Fig. 3.

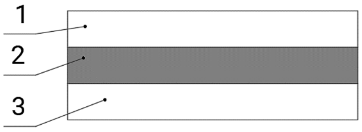

Fig. 3: Reference model of a damper.

Determining the behaviour of the designed elements resulted in static and dynamic parameters, and the character of changes in stress-strain relation, with the deformation under the same forcings in both analyses. The studies were performed on the basis of Mooney-Rivlin model with the use of finite element method in ANSYS environment, where many hyperelastic models are available. In the work, the 5-parameter variant of M-R model was adopted. The sample results obtained on the basis of the implemented numerical model were described in the next chapter.

3. Numerical Analysis and Sample Results

The nature of the static parameters in structures where middle layer is made of hyperelastic material can be predicted in a qualitative sense. However, if the made of hyperelastic material middle layer is design with non-constant cross section, the character of the parameters is more complex. In the results, gathered in this chapter, the character both in qualitative and quantitative sense are presented.

The finite element mesh was adjusted to the size and shape resulted from the adopted method of analysis. Performed analysis consist of the 3D element, and the of the middle layers of the damper and merge in the contact zone of the surfaces of the 2nd and 3rd layers with the concrete layers as well. 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. This forces the selection of the smallest possible iteration step so that the applied load grows slowly, which at the same time extends the calculation time.

In performed numerical experiment the contact conditions were defined. The contact between polymer concrete (1 and 4 layer) and the rubber (3 and respectively 2) were defined as frictional, with friction coefficient representing relation between polymer concrete and rubber with value 0.5. The main difficulty was to properly define the contact between the two rubber layers (2 and 3 fig. 1). This contact was defined as frictional, with static friction between the elements corresponding to the model of dry rubber- rubber friction with value 0.7. It was assumed that the friction surfaces of the rubber were smooth. The designed element will be filling to the technological gap or dilatation, and will transfer loads, but also minimize stresses and deformations, as well as dampen dynamic actions resulting from motion. The element was modeled by fixed support of the bottom surface. The boundary conditions in both proposed and reference models were likewise. The applied forcings were modelled on the top surface with components of surface load: in the Z-axis direction 1 kN/m^2, and in the Y-axis direction 0.2 kN/m^2.

The results of static analysis were obtained as equivalent on the basis Huber von Misses hypothesis. Results of stress contour lines for proposed system, with paying particular attention to the places of contact the 2nd and 3rd layers, were presented in Fig. 4.

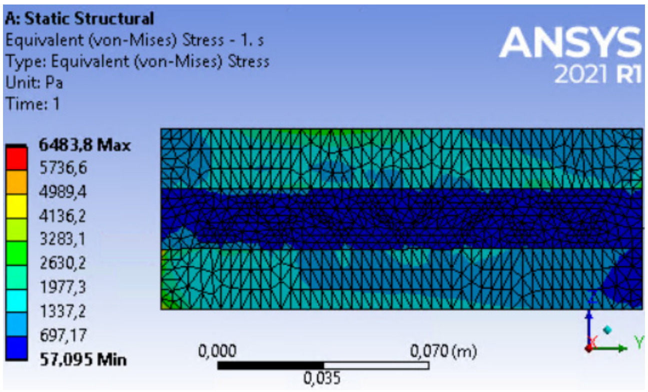

Fig. 4: Stress contours in static analysis in the proposed model.

The lowest values of stresses were observed in the contact between second and third layers. The greatest stresses occur in the places where load was applied.

The stresses values from the reference model were presented in the Fig. 5.

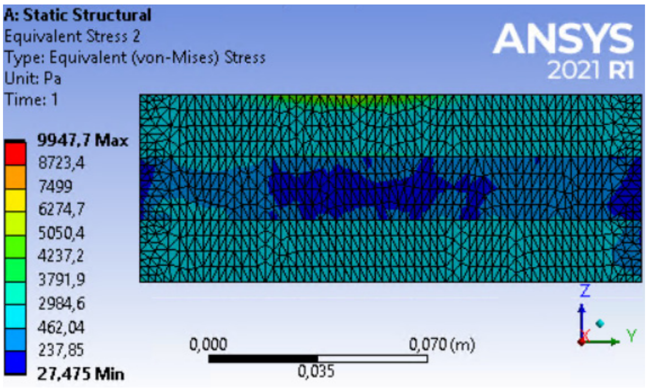

Fig. 5: Stress contours in static analysis in the reference model.

The maximum value of equivalent stresses in proposed model analysis was equal 6483.8 Pa, while in the reference model was equal 9947.7 Pa, where instead of 2 rubber layers with frictional contact only one layer of rubber was applied. The stresses in the model with the proposed two rubber layers are therefore 35% lower than the reference model. Results of strain contour lines for proposed system were presented in Fig. 6, and the reference strain values were presented in Fig. 7.

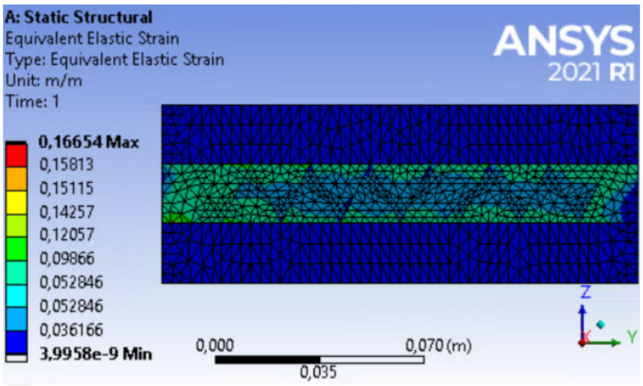

Fig. 6: Strain contours in static analysis in the proposed model.

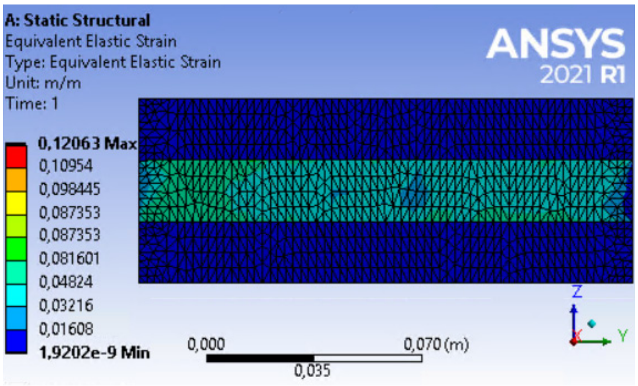

Fig. 7: Strain contours in static analysis in the reference model

In the hyperelastic layers values of strain should be higher than in linear material. In the proposed model the strain character in the contact is minimize in comparison to the reference model without contact between layers. The maximum value of strain in proposed model analysis was equal 0.16654 and in reference model was equal 0.12063. The stress-strain relationship for proposed model are presented in Fig. 8, and for reference model in Fig. 9.

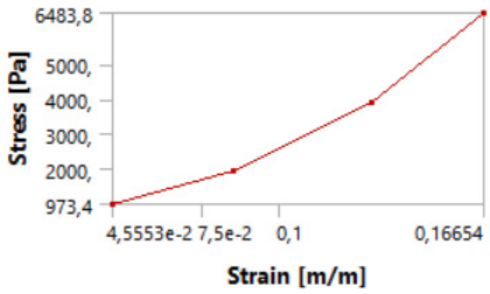

Fig. 8: Stress – strain relation in proposed model.

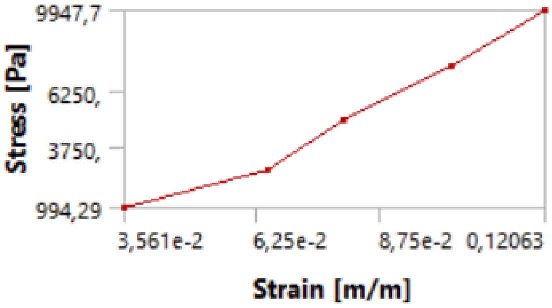

Fig. 9: Stress – strain relation in reference model.

The character of nonlinear properties of stresses and strain are preserved. The character of the relationship represents the equivalent course of linear dependence from polymer concrete and hyperelastic rubber, and in both analyses were qualitatively similar. The vibration analysis with the nonlinear material properties of the structure in ANSYS is limited. In the presented models, a vibration analysis was performed for the input in the form of vibration frequency from 100 to 200 Hz. The values of the frequencies were gathered in the table 1.

Tab.1: Frequency of modes in analyzed models.

Vibration mode	1	2	3	4	5	6
Proposed model frequency [Hz]	105,1	105,18	118,09	124,78	125,64	131,28
Reference model frequency [Hz]	136,19	136,19	138,36	148,39	146,84	148,39

For this range, the results were obtained for six modes of vibrations. The frequency values for the proposed solution are lower than in the reference model.

4. Conclusion

The performed analyses the character of stress-strain relations in two cases was included. Both models assumed adopting Mooney-Rivlin models for hyperelastic materials.

On the basis of the results, better stress behaviour with significantly less values of equivalent stress was in proposed model with two layers of rubber in the middle of the element. The values of stresses in the proposed model was significantly less than in reference model. The stain values are proportionally higher in proposed model than in reference model.

On the basis of the conducted preliminary research the model is base in developing different contact shapes or different number of layers of hyperelastic material, which can reduce values of stresses in the presented types of structures.

Using the hyperelastic material as a damper is a common matter, however, in this paper, the solution consisting in the use of middle layers with triangular filling is a new approach to the analysis of this type of structure.

In the dynamical analyses in both systems the vibration was obtain in form of the first six vibration modes. The frequencies for the forced system in both systems where similar, but for the proposed model values were smaller than in reference model.

The test stand is the basis for following numerical tests, and after their conduct, also for further experimental tests.

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