



Reduction of mechanical wave propagation in a wall made of concrete blocks with rubber filling - a numerical analysis

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ABSTRACT:

The paper presents a numerical analysis of the propagation of a disturbance in the form of a mechanical wave caused by a concentrated force applied perpendicular to the plane of the wall fragment analyzed in the work. Numerical tests were carried out on a numerical model of concrete blocks with rubber filling and on hollow concrete blocks, as a reference model. The impact of using concrete-rubber hollow bricks on effective stress values obtained in two time steps was assessed. Stress distributions are presented graphically in two perpendicular cross-sections of the wall (vertical and transverse) at the location of the application of the declared concentrated load. The results obtained are summarized in the table. The rubber used as the filling was modeled as Zahorski's hyperelastic material. A numerical analysis was performed in the ADINA program.

KEYWORDS:

FEM; composite wall; ADINA; hyperelastic material; rubber; damping

1. Introduction

Composites, based on a combination of steel and rubber, for example, steel-rubber bearing units are designed in many technical solutions. In this way, it is possible to effectively reduce vibrations arising from the movement of vehicles or machinery. Nowadays, technological and material solutions regarding the use of composites, to a very small extent, relate to the testing of concrete and rubber materials, for which rubber from recycling, e.g. car tires, can be used [1]. Such studies, using numerical methods based on the finite element method, were undertaken in [2-4] and [5, 6], where the impact of the adopted solutions on the effectiveness of reduction of dynamic interactions was assessed. Thanks to currently used numerical research techniques, it is convenient to observe phenomena that are visually difficult to see and which are extremely important for assessing the impact of dynamic interactions on structures. As a result of such interaction, a mechanical wave's energy propagating in the material can be reduced by limiting the range of its impact, e.g. by damping or dispersion. Currently used numerical research techniques allow the analysis of mechanical wave propagation in linear and non-linear materials depending on material libraries available or implemented in a given FEM program. It is then possible to study rubber and rubber-like materials as hyperelastic materials with various forms of elastic potential [7, 8].

It is assumed that the precursors of research on hyperelastic rubber materials were Mooney and Rivlin, who developed a constitutive equation for this type of material [9, 10]. Zahorski continued this research and proposed modified elastic potential (see [11, 12]). Modeling of

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wave phenomena in the hyperelastic materials of Mooney-Rivlin and Zahorski with the help of numerical methods based on the finite element method is presented in [13, 14]. In addition, there are many publications describing the use of the finite element method in civil engineering and mechanics, e.g. [15, 16], which confirm the validity of the numerical analysis path chosen in this publication for the discussed problem of dynamic impact reduction. The adopted construction and material solution is based on a concrete-rubber composite, in which the load-bearing skeleton is made of concrete and rubber is the filling. Hollow concrete blocks carry compressive loads in the wall, and the damping rubber insert is embedded in them during the technological process. The selection of the right shape of the rubber insert makes achieving the assumed properties reduced mechanical impact possible and enables a correct and convenient production process. The hollow blocks in the wall were connected with cement mortar and the structure was subjected to a dynamic force perpendicular to the wall surface. The impact of the interaction impulse causes the propagation of a mechanical wave that can be observed when analyzing the effective stress diagrams on two mutually perpendicular cross-sections of the tested wall, carried out in the place where the force is applied. Damping of the mechanical wave propagation then becomes clearly visible and allows the evaluation of the effectiveness of the adopted solution.

The numerical analysis presented in this work was conducted to estimate the damping range of the propagating mechanical wave in a wall made of the hollow concrete-rubber blocks in relation to a wall made of hollow concrete blocks, which is a control model. The percentage values of damping at selected points of the declared cross-sections of the wall in two time steps are presented. The ADINA program, which is based on the finite element method, was used to perform the numerical analysis. The methodology of the solution can be compared with [13, 17, 18]. Rubber was defined as Zahorski's hyperelastic material, while hollow concrete blocks were modeled from C20/25 concrete adopted as ADINA concrete material. The joints of the hollow blocks were modeled with a 4 MPa mortar and defined as DF concrete.

2. A constitutive relationship for Zahorski's hyperelastic material

The constitutive relationship describing Zahorski's material [12] can be written in the following form

$$W(I_1, I_2) = C_1(I_1 - 3) + C_2(I_2 - 3) + C_3(I_1^2 - 9) \quad (1)$$

where C_1, C_2, C_3 means elastic constants, while I_1, I_2 are invariants of the deformation tensor. The non-linear expression $C_3(I_1^2 - 9)$ in equation (1) allows a more accurate analysis and better quality of results useful for describing wave processes. Zahorski's constitutive relationship very well reflects rubber behavior in the case of major deformation even for $\lambda = 3$, while satisfactory results for the Mooney-Rivlin and neo-Hookean material are obtained only for $\lambda \leq 1.4$ [7]. Elastic constants for Zahorski material are shown in Table 1.

Table 1

Elastic constants for Zahorski material [8]

| Constant | C_1 | C_2 | C_3 |
|------------|--------------------|--------------------|--------------------|
| Value [Pa] | $2.099 \cdot 10^5$ | $1.275 \cdot 10^4$ | $3.924 \cdot 10^3$ |

3. Model and numerical analysis

3.1. Hollow block and wall models

For numerical tests, a virtual model of a hollow concrete block with rubber insert with dimensions of 48 cm length, 22 cm width and 25 cm height was developed, according to Figure 1.

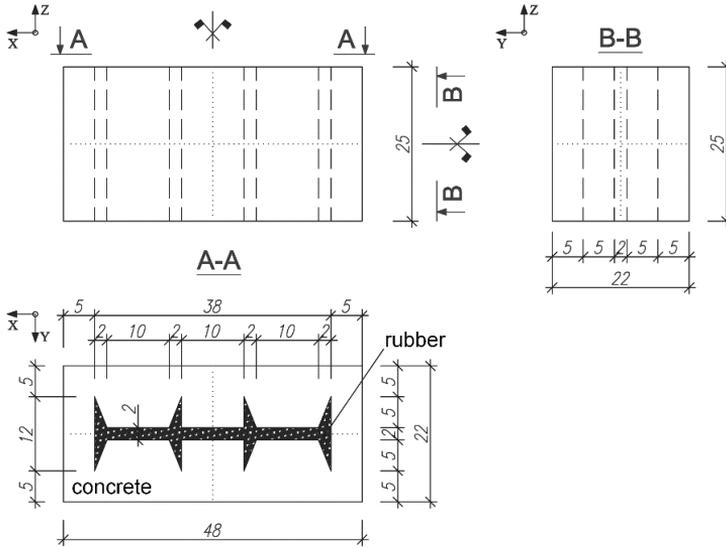


Fig. 1. Diagram of the hollow concrete-rubber block analyzed

A wall of three blocks wide, and a height of five blocks, connected with 1 cm thick joints in accordance with Figure 2, made from hollow concrete-rubber blocks was modelled. In this way, a wall model was obtained with a length of 148 cm, height 114 cm and thickness 22 cm, i.e. the thickness corresponding to the width used for numerical testing of the hollow concrete-rubber block Figure 3.

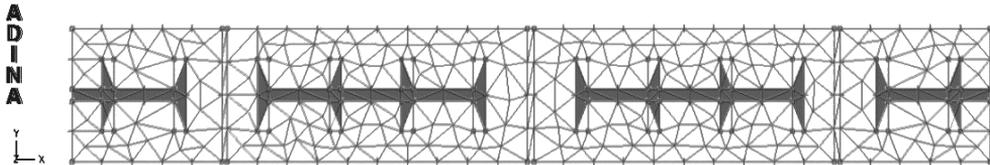


Fig. 2. Numerical model of a wall made of hollow concrete blocks with a rubber insert - top view

For the considered model, the bottom wall plane was rigidly fixed. The discretization of the hollow concrete blocks skeleton was carried out with the use of 4-node finite elements of the 3D type (tetrahedrons), generating a grid every ~ 0.05 m. Using the automatic function of the program, the rubber fillings of the hollow concrete blocks and masonry joints were discretized. 10354 nodes and 44730 finite elements were obtained. The analysis was carried out using the automatic module (ATS). A concentrated force (dynamic force) of 1 kN was applied perpendicular to the side of the hollow block wall on the second row from the top at the intersection of the block symmetry axis (Fig. 2).

The target value of 1 kN is obtained by force for time $t = 1 \cdot 10^{-5}$ s, after which its value decreases to 0, which corresponds to the sudden disappearance of the force after the above-mentioned exposure time. As a result of the applied impulse, the mechanical wave propagates, the course of which can be observed in subsequent time steps by analyzing the distribution of effective stress. In the analyzed example, the reading results were carried out in two time steps for $t = 1 \cdot 10^{-5}$ s and $t = 6 \cdot 10^{-5}$ s.

3.2. Numerical calculations results

The maximum and minimum values of the effective stress obtained for the wall being analyzed (Fig. 3) are summarized in Table 2.

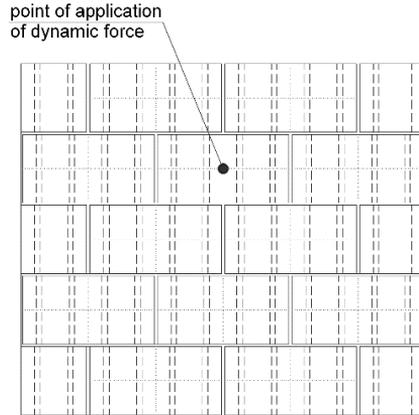


Fig. 3. Diagram of a wall made of hollow concrete-rubber blocks (view)

Table 2

Comparison of maximum and minimum effective stresses obtained in two time steps in a hollow concrete-rubber blocks wall and in a wall with hollow concrete blocks

| | Effective stress [Pa] | | | |
|---------|---------------------------------|--|---------------------------------|--|
| | $t = 1 \cdot 10^{-5} \text{ s}$ | | $t = 6 \cdot 10^{-5} \text{ s}$ | |
| | hollow concrete-rubber blocks | hollow concrete blocks (reference model) | hollow concrete-rubber blocks | hollow concrete blocks (reference model) |
| maximum | 15367 | 15367 | 12107 | 7487 |
| minimum | 1.238E-12 | 1.238E-12 | 3.975E-06 | 11.705E-06 |

The stress values obtained for the hollow concrete-rubber blocks were compared to the wall in which the blocks were made without rubber. The wall without the rubber filling was taken as a reference model, enabling the assessment of the effectiveness of rubber material placed in the hollow concrete-rubber blocks, which has the task of dispersion and damping energy resulting from the impact of the declared force impulse. According to the values presented in Table 2, the efficiency of stress reduction for the mechanical wave propagating in the wall in the second of the analyzed time steps, i.e. for $t = 6 \cdot 10^{-5} \text{ s}$, can be clearly seen (see Fig. 5). At the initial stage of impact, i.e. for $t = 1 \cdot 10^{-5} \text{ s}$ (Fig. 4 and Table 2), there is no difference in the values of effective stress in the concrete-rubber wall and the reference concrete wall model.

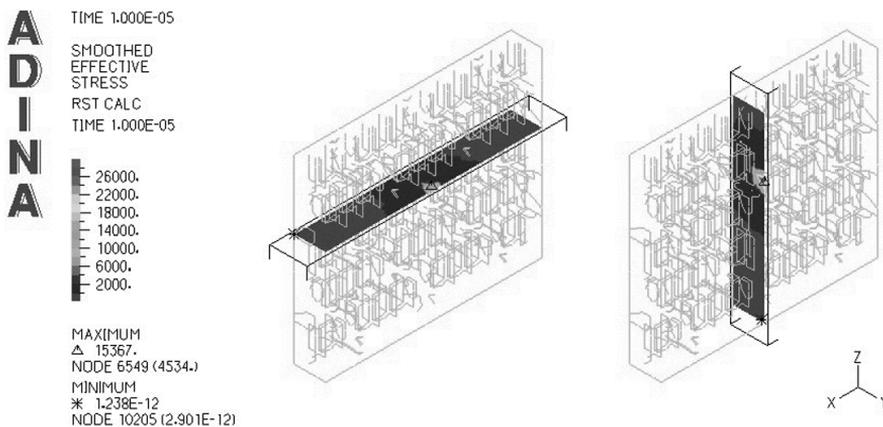


Fig. 4. Propagation of a mechanical wave in the analyzed concrete-rubber wall for $t = 1 \cdot 10^{-5} \text{ s}$

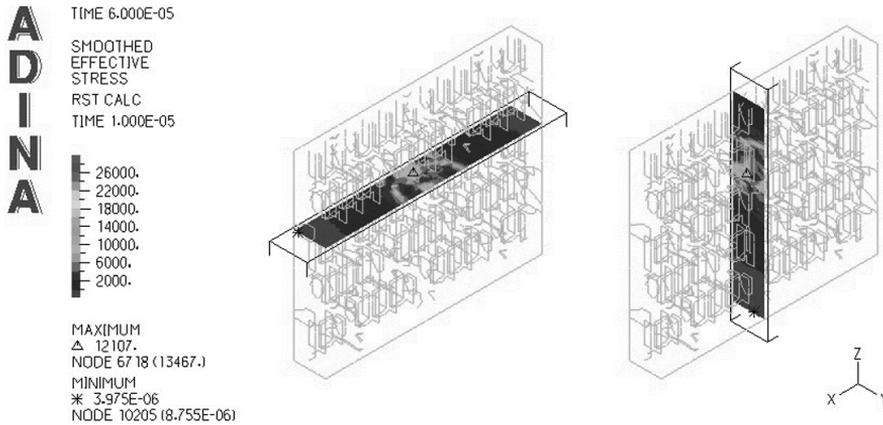


Fig. 5. Propagation of a mechanical wave in the analyzed concrete-rubber wall for $t = 6 \cdot 10^{-5}$ s

4. Conclusions

The paper presents a numerical analysis of the phenomena of damping mechanical waves in a hollow concrete block with rubber inserts. Analyzing the obtained results, it can be indisputably stated that the use of rubber inserts for hollow concrete blocks reduces the maximum stress after $t = 6 \cdot 10^{-5}$ s by a percentage of $\sim 38\%$ in relation to the reference model made only of concrete. This result allows us to assume that the hollow concrete-rubber block wall described in this paper is able to effectively reduce mechanical impacts and can also be effective as a barrier against unwanted vibrations from machines or other sources of mechanical impact. The applied solution enables the transfer of compressive loads occurring in the masonry structure, and the rubber batch used can be utilized as a material for damping the influence of external vibrations or other sources of impacts causing propagation of mechanical waves in the wall. Production, exploitation and then dismantling of the structure from developed hollow concrete-rubber blocks does not adversely affect the natural environment, because both rubber and concrete can be further recycled. At present, the idea of a concrete-rubber wall is only a conceptual model, which can be treated as an introduction to further modifications and necessary experimental research, which will certainly lead to practical application.

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Redukcja propagacji fali mechanicznej w murze wykonanym z pustaków betonowych z gumowym wypełnieniem - analiza numeryczna

STRESZCZENIE:

Przedstawiono analizę numeryczną propagacji zaburzenia w postaci fali mechanicznej wywołanej oddziaływaniem, które stanowiła wymuszająca siła skupiona, przyłożona prostopadle do płaszczyzny analizowanego w pracy fragmentu muru. Badania numeryczne przeprowadzono, wykonując model numeryczny z pustaków betonowych z wypełnieniem gumowym oraz z samych pustaków betonowych, z których mur stanowił model referencyjny. Oceniono wpływ zastosowania pustaków betonowo-gumowych na wartości naprężeń efektywnych uzyskanych w dwóch krokach czasowych. Rozkłady naprężeń przedstawiono graficznie w dwóch prostopadłych względem siebie przekrojach muru (pionowym i poprzecznym) w miejscu przyłożenia deklarowanego oddziaływania skupionego. Uzyskane wyniki zestawiono w tabeli. Gumę użytą jako wypełnienie zamodelowano jako hipersprężysty materiał Zahorskiego. Analizę numeryczną wykonano w programie ADINA.

SŁOWA KLUCZOWE:

MES; mur betonowo-gumowy; ADINA; materiał hipersprężysty; tłumienie