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ScienceDirect

Procedia Engineering 190 (2017) 223 – 230

Procedia Engineering

www.elsevier.com/locate/procedia

Structural and Physical Aspects of Construction Engineering

Analysis of the Mechanical Wave in the Composite Made of Sandstone and Rubber

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Abstract

The paper presents numerical analysis of the mechanical wave propagation in the composite made of sandstone and rubber. For the analysis purposes sandstone block with dimensions 15×15×15 cm was adopted. Special circular holes were hollowed in front block faces, in which steel rods were inserted concentrically. In the free space between rods and sandstone material, rubber could be injected or inserted. Three different cases were investigated, where the number of holes and steel rods with rubber cover corresponded to the number of directions in which dynamic loads were simultaneously acting. It was assumed that rubber was described by Mooney-Rivlin and Zahorski material model. Both materials are incompressible hyperelastic materials, i.e. nonlinear materials, which are described by the hyperelastic potential. Sandstone otherwise was modelled with the utilization of an elastic isotropic material. Obtained numerical results allowed to evaluate the sustainability of the considered composite to damp the dynamical effects, especially for places where sandstone is utilized as a construction material.

Peer-review under responsibility of the organizing committee of SPACE 2016

Keywords: Mechanical wave; sandstone, rubber; composite; hyperelastic materials;

1. Introduction

Sandstone is a fine-grained, solid sedimentary rock formed by cemented grains of quarts, mica, other rocks and minerals with the use of clay, silica, limestone and iron binder. At the beginning process of industrial treatment sandstone is rather a soft material, which permits an easy processing, while after water evaporation hardens significantly. In our climate, marbles and limestone should rather not be used as an exterior stone cladding. It is connected with these materials are mainly formed of calcium carbonate, thus without proper chemical protection,

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Peer-review under responsibility of the organizing committee of SPACE 2016
doi:10.1016/j.proeng.2017.05.330

deterioration progress in a short period of time. It should be noted that in summer stone slabs on southern facades may heat up to 70 °C, whereas in winter may be cooled to -30°C. Taking into account such objections, on the external claddings are preferred granites, slates and sandstones. In contrast to marbles and limestone, utilized in civil engineering variants of sandstone are mainly formed from relatively more physically resistant ingredients than other mentioned materials. Moreover sandstones are often frost resistant, but whether the stone can withstand repeated freeze and defreeze of water in pores, decide in principle not only same porosity, but also the interconnection of pores. The more pores are connected with each other, the higher freeze resistance. It is connected with equalization of stress arising during ice formation inside the stone slab via intergranular spaces, not via rigid granular structure of a stone.

On the seismic terrain such as upper Silesian region in Poland with many working mines, building elevations made of sandstone slabs are exposed to additional loads with dynamic nature. In order to mount the stone slab on building facade, special supporting anchors (mainly made of steel material) have to be embedded in the previously drilled holes on the main insulated wall. After that all the holes are covered with the mineral wool, in order to ensure the integrity and continuity of isolation. It is worth to notice here that stone slab is connected with steel anchor directly, therefore the insulation reduce the dynamical effects insignificantly. Hence stone slabs during earth shake may be easily broken or may crack near the anchor areas due to transferred dynamical loads. According to that in this paper an innovative composite material made of sandstone and rubber (injected or inserted directly with the steel rod) in joints is proposed. Such connection should allow reduce the dynamical effects transferred via steel anchors on the sandstone slabs. In order to estimate the percentage damping of proposed composite in relation to the solid sandstone the numerical analysis with the use of finite element method based ADINA program was performed. A great number of researchers have used numerical analysis to examine behaviour of building construction or its components (see [1-4]). For the analysis purposes a small section of sandstone slab was adopted. Three different load cases were considered, where the number of hollowed holes and steel rods covered with rubber correspond to the number of investigated applied dynamical load directions. Models were subdivided into three groups: the first and the second group contained composite models made of sandstone with additional layer of injected/inserted rubber in the free space between sandstone and steel rods. In the first group Mooney-Rivlin material model was analysed, whereas in the second group Zahorski material model, respectively. In the third group solid sandstone numerical models with directly embedded steel rods were investigated. It should be noted here, that Zahorski material is not originally implemented in the ADINA program, therefore Mooney-Rivlin library was modified by authors in order to obtain appropriate rubber elastic potential.

2. Incompressible materials – Mooney-Rivlin and Zahorski model

As the precursor of rubber material research are believed Mooney and Rivlin [5], who in forties and fifties of XX century took the first steps to determine the constitutive relationship describing rubber and rubber-like materials behaviour. In 1951 Rivlin and Saunders [6] proposed a general form of elastic energy function describing mentioned materials. That deformation energy function depends on the first two invariants of the deformation tensor and two additional constants. In 1959 Zahorski proposed modified function of deformation energy for incompressible material, described via non-linear dependency of deformation tensor invariants [7]. On the basis of Zahorski considerations it became possible to describe the elastic behaviour of rubber and rubber-like materials at large deformations. The constitutive relationship of hyperelastic Zahorski material (see [7]) was described by the equation

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

where C_1, C_2, C_3 are material constants and I_1, I_2 denote invariants of deformation tensor. For Mooney-Rivlin material C_3 constant is equal zero [5]. Moreover in the following years it was proved that the relationship proposed by Zahorski allows to perform a more complete analysis of wave propagation in hyperelastic incompressible materials in comparison with the material model presented by Mooney-Rivlin. It should be noted that the constitutive relation with all three constants (Zahorski material model) reflects behaviour of rubber for the principal strain even for $\lambda = 3$, whereas for strain greater than $\lambda > 2$ rubber material based on two constants C_1, C_2 (Mooney-