Analysis of the Mechanical Wave in the Composite Made of Concrete and Rubber - Numerical Analysis

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Abstract. *In this paper dynamic numerical analysis concerning mechanical wave intensity reduction via rubber material insert/inject in a typical wall concrete block is discussed. Numerical model consists of a single block with a rubber strip and rounded cuboids inserted/injected from the top to the bottom surface of that block. Due to adopted rubber inserts/injects dimensions and cross section area, influence on concrete block compressive strength can be neglected. Mechanical wave propagation is forced through an impact of inclined concentrated force applied to the front block surface on the offset from side block surface. That impact load arises in a very small time step and furtherly its value is changed to zero. According to that mechanical wave propagation may be observed in the form of stress plots plotted in a given time step. Through the numerical analysis it is shown that in case of composite made of concrete-rubber there is a possibility to reduce the mechanical wave propagation by around 25% in comparison to the solid concrete block.*

Keywords

Composite, concrete-rubber, FEM, hyperelastic materials, mechanical wave.

1. Introduction

Incompressible materials static and dynamic behaviour has been the subject of interest by many researchers. The first professional revisions of experimental tests made on rubber materials reaches the second half of nineteenth century. In 1864 de Saint-Venant summed up other researchers' achievements and conclusions concerning discovers in theory of elasticity. With growing technological development, nearly one hundred years later, there were performed some significant experimental tests on rubber materials. With the obtained experimental tests results it was easier to determine the analytical model concerning rubber behaviour under different external conditions. It is believed that the first generalized model of rubber behaviour under tension and compression has been estabilished by Mooney in 1940 [1]. In the subsequent years, analytical model has been furtherly improved to formulate the problem with less required number of inputs and to better correlate the model with actual rubber behaviour. One of the most known researchers from that period of time is Rivlin, who furtherly improved the Mooney model. There are many Rivlin's papers concerning different aspects or rubber material experimental and theoretical research i.e. [2], [3], [4]. After many attempts done by Mooney and Rivlin in the rubber material behaviour generalized description, Mooney-Rivlin material model has been established in which the energy function requires at least two constant parameters. That description well describes the two-fold rubber material elongation and 50% compression. Today we know many different models describing rubber i.e. Zahorski [5], [6], Neo-Hookean [7], Arruda-Boyce [8], Ogden [9], Susmann-Bathe [10] etc.

Nowadays in many engineering structures, rubber material is used mainly to reduce the dynamic effects resulting from external factors. It may be found in i.e. bridge structures - reduction of dynamic forces transfer onto the supports resulting from wheel transportation and pedestrians, structures built on seismic terrain etc. It should be noted that the reduction of mechanical and acoustic waves depends on rubber properties. One may indicate two groups of rubber materials: hard rubbers and soft rubbers. The first group consists of materials which are ineffective in elongation and only slightly reduces the mechanical/acoustic waves. In the second group, material has relatively small compressive strength, but well behaves to elongation forces and significantly damps the dynamic effects.

Rubber material from past two decades is subjected to the recycling process, where 95% of waste rubber is again recovered. The recycling process is based on crumbling wasted rubber and using it as a surface under children playgrounds, football fields etc. Moreover, crumbled rubber may be once again used in civil engineering structures. After heating up, it may be melted and then cooled in a form with desired shape. In this paper a fresh method of connection between concrete block and rubber is proposed. Presented in literature typical connection of rubber with concrete concerns mainly cases, where crumbed rubber is added as a mixture to the concrete mix i.e. [11]. Moreover, some of research concern enhance of the dynamic damping property with the utilization of rubber in structure elements i.e. [12]. It should be noted that Finite Element Method is also used to different problems from Civil Engineering i.e. [13].

In this paper a fresh method of rubber integration with concrete blocks is proposed and numerically solved. Despite adding crumbed rubber to the concrete mix, a concrete block with desired shape can be firstly produced. After that, prepared hollows may be injected with melted rubber or an appropriately shaped rubber element may be inserted. It should be noted that melted rubber would be better solution, due to the resulting contact between concrete and rubber material. Dynamic numerical analysis is performed to estimate the percentage damping of mechanical wave intensity resulted from applied impact load in comparison to the solid concrete block.

2. Analysed model

As a model, an actual single solid concrete block has been adopted, which is commonly used to arise building walls. Its dimensions are 470 mm (length) x 250 mm (width) and 200 mm (height). In order to enhance that block mechanical wave damping properties, it is assumed that at the beginning of the concrete block forming process, when concrete mix is poured into cuboid form, an additional special form is placed, in order to provide appropriate hollows under the rubber material. The scheme of concrete blocks with hollows is presented in Fig. 1. As shown the concentrated force point of action is located on the front block surface mid-height and on 12 cm offset from the left side surface. Force value arises from 0 N at the start of the analysis and rising up to 5000 N at $t = 1.0\times10^{-5}$ s. Then the force value drops to zero at $t = 1.1\times10^{-5}$ s. That force impact results in mechanical wave propagation, thus no further force oscillations are being analysed. It should be noted that the applied load value is treated only as a reference for comparative analysis between the composite and solid block. Twelve different sensor points are adopted, to read-out the value of Mises-Hencky stress (MHS) at a given time step. As shown in the Fig. 1 in A-A view, there is visible six sensor points on the front block surface. Points marked with "F" letter denote points laying on the front block surface, whereas letter "R" denotes exactly the same points, however laying on the rear surface, respectively. Three different time steps are taken into considerations, where stress is being read-out i.e. $t = 1.0\times10^{-5}$ s, 5.0×10^{-5} s and 9.0×10^{-5} s, respectively. Due to the fact, that analysed concrete block may be used to arise a building walls, following boundary conditions are assumed: on the top and bottom XY surface Z-axis displacements is fixed. On the side YZ surfaces, both X and Y-axis displacements are fixed.

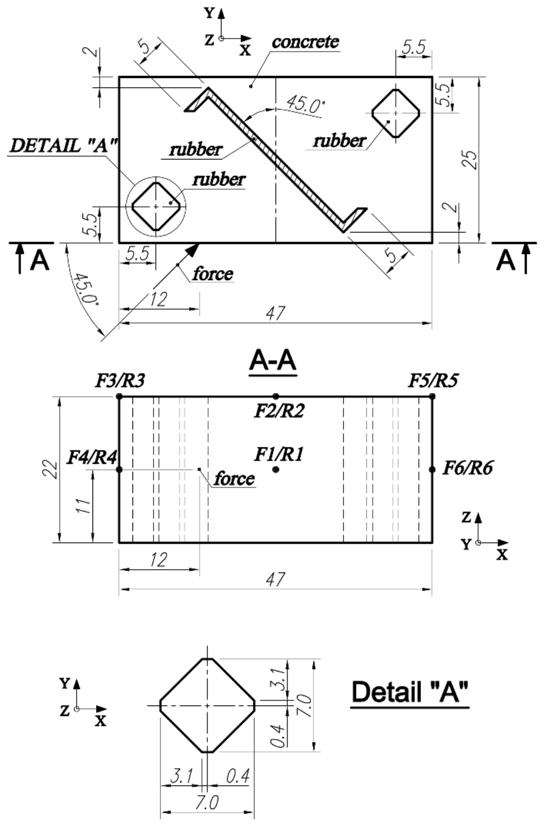

Fig. 1: Concrete block with hollows injected with rubber material (Description in text).

Presented model is solved with the ADINA code based on Finite Element Method (FEM). For the rubber elements Mooney-Rivlin material model has been adopted with the following constants [14]: $C_1 = 62780$ Pa, $C_2 = 8829$ Pa. Density of that rubber is 1190 kg/m^3. In order to describe concrete, special ADINA concrete material model is used. It is assumed that in the analyzed structure C16/20 concrete class is used. According to that, in ADINA concrete material model, following constants are provided: Poisson's ratio equal 0.20, density 2400 kg/m^3, tangent modulus at zero strain: 50.75 GPa, uniaxial cut-off tensile stress: 1.9 MPa, maximum compressive strength 20 MPa at -0.002 strain and 17 MPa compressive strength at -0.0035 strain. To describe the solid concrete model 153972 (3-D solid concrete) finite elements are used, whereas in the concrete-rubber block, 134504 (3-D solid concrete) and 19468 (3-D solid rubber) finite elements respectively. Dynamic analysis is performed, with total number of 60 steps. First 10 time steps ($t_s = 1\times10^{-6}$ s) shows the results when the force value is getting higher, then 50 steps with a value of $t_s = 2\times10^{-6}$ s shows the mechanical wave propagation in the form of MHS plots.

3. Results and discussion

MHS results for the $t = 1.0\times10^{-5}$ s, 5.0×10^{-5} s and 9.0×10^{-5} s in the solid concrete block are presented in Tab. 1, whereas in the concrete-rubber composite in Tab. 2, respectively.

Tab.1: MHS at given time steps in the solid concrete block

Point	Time		
	$t = 1.0\times10^{-5}$ s	$t = 5.0\times10^{-5}$ s	$t = 9.0\times10^{-5}$ s
	[Pa]	[Pa]	[Pa]
F1	3244	68370	46820
F2	1216	77700	79230
F3	312	74520	56410
F4	544	61560	63590
F5	0	2	51814
F6	0	39	65124
R1	0	37090	16060
R2	0	110	35430
R3	0	1	21930
R4	0	24	22390
R5	0	0	22640
R6	0	0	14120

Tab.2: MHS at given time steps in the concrete-rubber composite

Point	Time		
	$t = 1.0\times10^{-5}$ s	$t = 5.0\times10^{-5}$ s	$t = 9.0\times10^{-5}$ s
	[Pa]	[Pa]	[Pa]
F1	3244	59803	32779
F2	1155	70583	58836
F3	197	64206	42245
F4	109	53163	46376
F5	0	2	36436
F6	0	35	45404
R1	0	26711	12090
R2	0	100	24996
R3	0	1	15671
R4	0	22	16419
R5	0	0	16668
R6	0	0	10421

Some of the fields in Tab. 1 and Tab. 2 contains zero values, which is connected with the fact, that the wave has not propagated yet to the particular sensor point. At $t = 1.0\times10^{-5}$ s wave head propagated only to four points located on the front surface (F1/F2/F3/F4). At $t = 5.0\times10^{-5}$ s wave head propagated to the first sensor point (R1) located on the rear block side and the values of MHS in first four points located on the front block surface increased significantly, whereas at $t = 9.0\times10^{-5}$ s mechanical wave propagated through all adopted sensor points. Comparing the values in point R1 at $t = 5.0\times10^{-5}$ s one may notice, that in the concrete-rubber composite the value is approximately 27.98% lower than in solid concrete block (comp. point R1 in Tab. 1 and Tab. 2). That shows that the rubber diagonal strip significantly damped mentioned propagation. The most valuable results are in the column where $t = 9.0\times10^{-5}$ s (wave propagated through the analysed blocks). MHS values in the concrete-rubber block are approximately 25-30% lower than in the solid concrete block. Minimum percentage damping is obtained in point R1 which is equal 24.72%, whereas maximum value is obtained in point F6 equal 30.28%. Maximum percentage damping value on the rear side of composite block in comparison to the solid concrete one is obtained in point R2 and is equal 29.45%. Comparison of wave head propagation in solid concrete and concrete-rubber block is presented in Fig. 2. One may notice, that transferred mechanical energy from applied dynamic force is significantly dissipated throughout the rubber material.

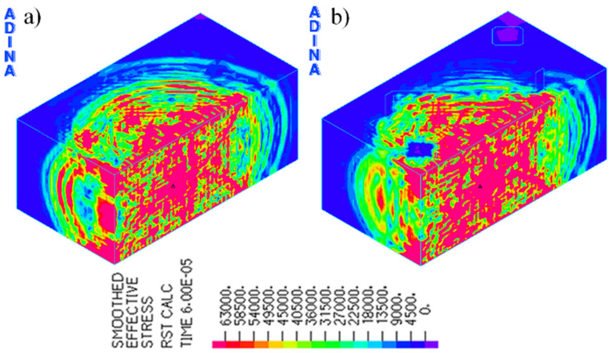

Fig. 2: Difference in the mechanical wave propagation between solid concrete block (a) and concrete-rubber (b).

On the basis of presented in this paper results one can state that the injected in the hollow block rubber material, significantly changes the dynamical properties of block, making it more efficient for damping the acoustic/mechanical waves from the external environment.

4. Conclusion

The article discusses the propagation of a mechanical wave in an original concrete-rubber composite, from which a wall with intended strength parameters can be built. According to the numerical analysis, it was shown that propagation of the mechanical wave in the composite block can be significantly suppressed. The propagation wave on the back side of the considered composite has been reduced in the range of about 25-30% compared to a block made of solid concrete. Such values of mechanical wave damping can be obtained thanks to the mechanical energy absorption properties of the rubber used for this composite. From the engineering and design point of view, the composite presented can be easily used in civil engineering, especially in areas exposed to minor shocks, machine vibrations or to reduce acoustic waves. The presented composite gave satisfactory mechanical damping results by means of numerical analysis, and experimental investigations should also be carried out to estimate the actual bearing capacity and other material properties not specified in this document.

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