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Reduction of the dynamic mechanical impact in Fert floors with rubber filling

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ABSTRACT:
In this paper, a reduction in the dynamic mechanical impact in Fert ceiling blocks with rubber filling is discussed. The research is conducted with the use of numerical methods based on the Finite Element Method (FEM). In order to observe the mechanical wave propagation in the form of stress plots, ADINA software is used. The analysis is performed with the use of a dynamic explicit module. Three different configurations of Fert concrete blocks are analyzed: Fert 40, Fert 45 and Fert 60. It is assumed that each block is subjected to a dynamic compressive pressure load applied to the top surface. The boundary conditions applied to the blocks represent simplified support on the concrete joists. In order to check how the rubber filling changes the mechanical wave energy transfer, blocks with and without rubber filler are analyzed. Through the analysis, it is shown that the larger the block size with rubber filling, the higher the reduction of mechanical wave energy transfer. Owing to that, the height of the insulation layer could be reduced to keep the same acoustic insulation parameters. On the other hand, the proposed rubber fill raises the overall mass of the blocks, which may negatively affect the ceiling bearing capacity.

KEYWORDS:
rubber filling; ceiling blocks; dynamic impact reduction; concrete-rubber; explicit analysis

1. Introduction

Floors in buildings play a significant role, increasing the rigidity between walls, transferring the dead and live load to the walls, as well as functioning as a thermal and acoustic barrier between the two adjacent construction levels. There are many different types of floors i.e. beams-and-slabs, beams-and-blocks, hollow core slabs, reinforced concrete slab floors, etc. Depending on the floor type, advantages and disadvantages can be identified. In the case of wooden floors, the advantage is their mass, ease of montage and thermal conductivity. On the other hand, these floors are very susceptible to fire and have a relatively low bearing capacity in comparison to concrete floors. In the case of monolithic concrete floors, they are highly resistant to fire, but with the disadvantage that they are much harder to manufacture, due to the requirement of specially prepared steel reinforcement and formwork. Beam-and-slab or beam-and-block floors provide relatively good bearing capacity and have good resistance to fire. However, they also require formwork. In the case of beams-and-blocks floors or hollow core slabs, the empty spaces may be filled with a choice of materials providing enhancement to the thermal conductivity and/or soundproofing of the floor. In this paper, beam-and-block Fert floors with a rubber filling enhancing the acoustics and thermal conductivity of the floor are analyzed and discussed.

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Rubber is a material commonly used in Civil Engineering to reduce the influence of dynamic forces onto different structures. The most common solution are rubber bearings used in bridge structures, to prevent the transfer of significant dynamic forces and vibrations from the bridge to the pillars and supports. Rubber material is also used as pads under machines that cause significant vibrations. The topic of reducing dynamic effects via rubber material has been studied by many researchers. One of the basic methods of combining rubber with other materials has already been proposed by Eldin [1]. The author concerned, describes the addition of crumbed rubber and rubber chips from worn-out tires to Portland cement concrete. Two different groups of specimens with rubber replacement were taken into consideration. The first had coarse aggregate exchanged with rubber, whereas in the second, sand was replaced. Through the experimental tests it was shown that the greater the volume of rubber aggregate in concrete, the lower the obtained compressive and tensile strength of the rubberised concrete. In the case of stone aggregate replacement, the reduction of compressive/tensile strength was greater than in the specimens where sand was replaced. Moreover, it was shown that the rubberised concrete does not exhibit brittle failure and plastic absorption is greatly increased. The latest experimental studies into the mechanical and dynamic properties of rubberised concrete were performed by Gerges et al. [2]. In the study, 5÷20% of sand volume was replaced with rubber granulate showing that the mass density of the final specimen may be decreased and higher dynamic impact resistance was obtained. However, compressive strength was reduced. Aly et al. [3] studied the influence of rubber aggregate in geopolymer concrete. It was shown that by replacing as little as less than 10% of the total geopolymer concrete volume with rubber aggregate, may slightly enhance its compressive strength. Whereas greater volume improves dynamic resistance while simultaneously reducing compressive strength. The use of rubber granulate replacement in different concrete structures is widely discussed in the literature i.e. [4-8].

Mechanical wave propagation and its damping in different materials/different construction solutions is also a common research topic. There are many papers concerning the damping of vibrations in tall buildings, arising from earthquake induced ground motions or due to wind excitation i.e. [9-12]. Mechanical wave propagation in different materials is discussed in [13-15], whereas reduction of mechanical energy transfer in concrete-rubber and concrete-polyurethane composite blocks and walls is considered in [16-18].

2. Numerical model

In this paper, concrete floor blocks with rubber injected into the empty block spaces is numerically analyzed in terms of mechanical energy transfer reduction. For the analysis three different configurations of Fert blocks are adopted - Fert 40, Fert 45 and Fert 60. The block names indicate the axial width between beam supports. Accordingly, the total width of the blocks is as follows: Fert 40 (320 mm), Fert 45 (370 mm) and Fert 60 (530 mm). Each block has 200 mm height and 250 mm depth. At the bottom left and bottom right side of the blocks there are specially chamfered edges to provide support on joists. Blocks differs between each other with the internal concrete grid dimensions and with the number of grid projections on the top blocks' surface. The thickness of the concrete grid is equal to 10 mm. Block schemes with their dimensions are presented in Figure 1.

To the top surface of each block, a dynamic pressure load with the value of 1000 N/m^2 is applied. In order to observe the mechanical wave propagation, it is necessary to adopt a small value of time in which the loading is applied to the structure and then, a number of very small time steps to observe the propagation. Accordingly, the dynamic load rises from the 0 value up to the assumed 1000 N/m^2 at 1e^{-6} s. In further steps, the load is equal to zero. For the analysis, it is assumed that at least 100 steps with the time of 1e^{-6} s should be carried out, which allows the observation of the full wave propagation, its reflection, interference and refraction. For the numerical analysis, ADINA software fully based on the finite element method is chosen. The analysis is carried out with the use of a Dynamic-Explicit module.

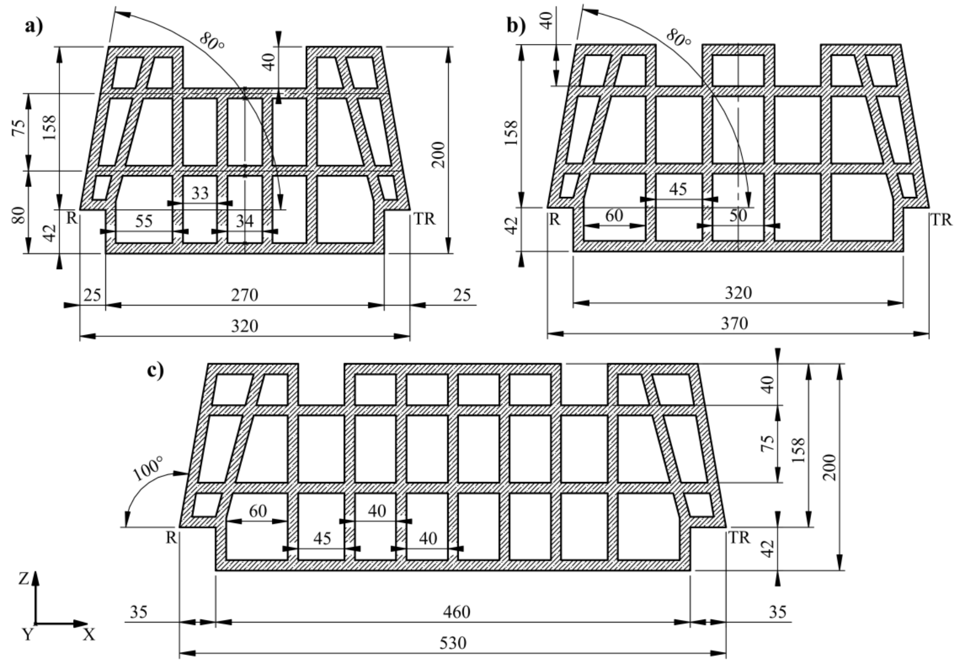

Fig. 1. Dimensions of analyzed Fert blocks; Fert 40 (a), Fert 45 (b), Fert 60 (c)

Actual boundary conditions corresponding to the block support on the joist should have been modelled with elastic springs. In this paper those conditions are simplified to simple supported systems. On the far left edge of each block marked with letter „R", *Y*-axis rotations are allowed, whereas on the far right edge marked with „TR", *X*-axis translations and *Y*-axis rotations are allowed. Proposed simplification gives more favourable deflection and stress distribution in the blocks under applied loading.

The blocks are meshed with (3D-Solid) 4-node tetrahedron finite elements and the mesh size is assumed to be 2 mm in any direction. For the blocks, C16/20 concrete grade is chosen for which the maximum compressive strength is 20 MPa, and the elastic modulus is equal to 29 GPa. In the ADINA program a concrete material model is used to describe the block elements. The following parameters are set: density 2450 kg/m^3, uniaxial cut-off tensile strength 1.3 MPa, uniaxial compressive strain −0.002 for maximum compressive strength 20 MPa, and −0.0035 for 15 MPa. The Poisson's ratio is 0.2, fracture energy of 200 N/m and the default Kupfer envelope for failure is chosen. In the case of rubber injects the Mooney-Rivlin rubber material model is adopted with the following parameters: density 1190 kg/m^3 and material constants C_1 = 62780 Pa, C_2 = 8829 Pa.

3. Numerical results and discussion

The first stage of the study concerns dynamic impact reduction via rubber injects in Fert blocks. For each Fert configuration two analyses are provided, in the first, solid concrete blocks without injects are considered, whereas in the second, the same blocks with rubber inject are analyzed. In each study time step, the mechanical Mises-Hencky stress (MHS) is plotted to observe, how the mechanical wave propagates through the blocks. Knowing that the wave starts to propagate from the top to the bottom surface of the block, the bottom surface is treated as a reference. The MHS reads as a maximum value from all analysis time steps and is compared between configurations in Table 1. The visual presentation of mechanical wave propagation in the Fert 60 blocks at a given time $t = 6.1\cdot10^{-5}$ s is presented in Figure 2.

Table 1
Comparison of maximum Mises-Hencky stress (MHS) obtained on the reference bottom surface in different Fert blocks configurations

Floor block injection	Mises-Hencky stress (MHS) [Pa]		
	Fert 40	Fert 45	Fert 60
None	312.33	302.88	316.89
Rubber	275.72	253.43	253.09

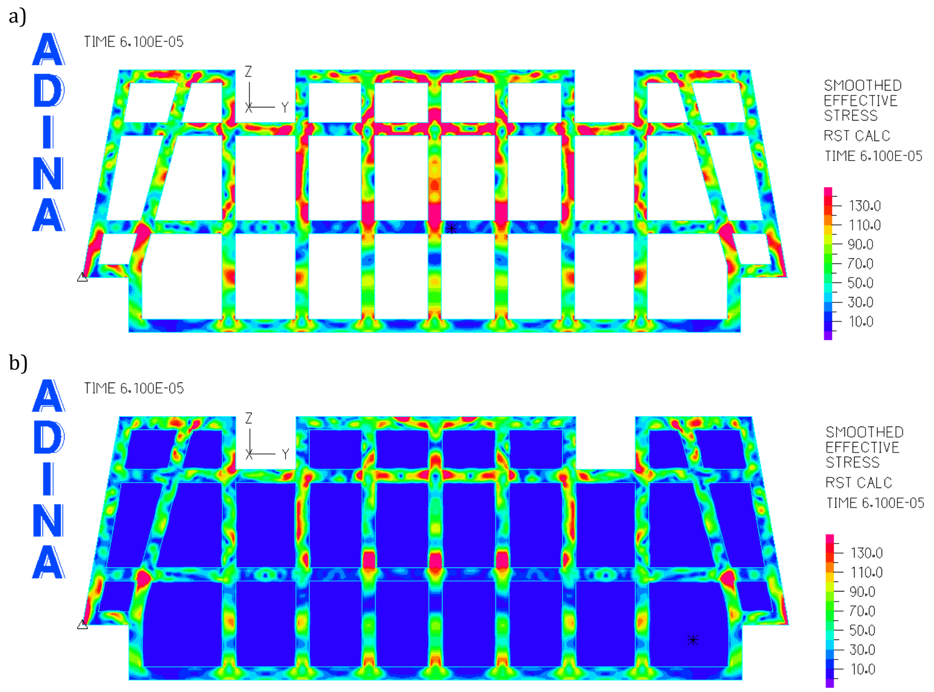

Fig. 2. Mechanical wave propagation in the form of MHS at $t = 6.1 \cdot 10^{-5}$ s in Fert 60. Solid concrete block (a), concrete-rubber (b)

Maximum values of MHS are observed near the applied boundary conditions that are shown with triangles in Figures 2a and 2b near the „R" support where only *Y*-axis rotations are allowed. It is shown, that between the boundary conditions and the top block surface, to which the dynamic load is applied, mechanical energy is transferred mainly through the concrete material. Accordingly, in order to decrease further mechanical energy transfer to the floor beams, special rubber pads should have been provided on the beam at the point where the Fert block is in contact. Moreover, one may notice the slightly different MHS distribution in the middle area of the concrete-rubber block in comparison to the solid concrete (compare Fig. 2a and Fig. 2b).

On the basis of Table 1, on the reference bottom surface in Fert blocks with rubber injects lower MHS readings are obtained when compared to the solid concrete blocks. The following percentage reduction in energy transfer is obtained: 11.72% in Fert 40, 16.32% in Fert 45 and 20.13% in Fert 60. On the basis of the presented results, it can be stated that the more volume of rubber in the block, the higher the percentage reduction of dynamic impact. In spite of that, the more rubber that is used, the heavier the construction element becomes. In the second stage of the analysis, a comparison of the blocks' mass is discussed. The increase of mass in the blocks with rubber injects is presented in Table 2. Knowing that expanded clay aggregate (ECA) is frequently used in Civil Engineering for floor blocks, it has also been taken into account in the discussion. For expanded clay aggregate the volumetric mass of 575 kg/m^3 is adopted.

Table 2
Mass comparison between concrete-rubber, concrete and expanded clay aggregate Fert blocks

Floor Block	Mass [kg]		
	Fert 40	Fert 45	Fert 60
Concrete	13.469	15.245	22.105
Expanded clay aggregate (ECA)	3.167	3.578	5.189
Concrete + rubber	22.626	26.849	39.647
Expanded clay agg. + rubber	12.324	15.182	22.731

On the basis of the presented results in Table 2 the expanded clay aggregate blocks are over 4.2 times lighter than the concrete blocks. However, their bearing capacity is significantly lower than the C16/20 concrete blocks. Filling the empty block spaces with rubber material increases the overall mass of a single block by: 9.157 kg in Fert 40, 11.604 kg in Fert 45 and 17.542 kg in Fert 60. By injecting rubber, the overall weight of a single concrete block is nearly doubled and in the case of expanded clay aggregate is nearly quadrupled. That leads to the statement that the rubber material is too heavy. Accordingly, foam with relatively low volumetric mass should have been taken into consideration.

4. Conclusions

In this paper, the reduction of the dynamic mechanical impact in different Fert floor blocks with rubber injects was discussed. A dynamic-explicit numerical analysis with the use of Finite Element Method based software (ADINA) was performed to observe the mechanical wave propagation in the form of Mises-Hencky stress plots.

Obtained numerical results shows that the rubber filling reduces the dynamic impact by around 12~20%. The greater the volume of rubber inject in the blocks, the higher the percentage of dynamic impact reduction. On the other hand, rubber filler significantly increases the mass of a single block. Despite the relatively high increase in the acoustic parameters of block-and-beam floors, the mass increase significantly reduces the floor's bearing capacity. Hence, after further consideration, a filling material with a lower volumetric density should have been taken into consideration.

Acknowledgements

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Redukcja oddziaływań dynamicznych w stropach typu Fert z wypełnieniem gumowym

STRESZCZENIE:
Omówiono redukcję oddziaływań dynamicznych w stropach Fert z wypełnieniem gumowym. Badania prowadzono z wykorzystaniem metod numerycznych opartych na metodzie elementów skończonych (MES). W celu zaobserwowania propagacji fali mechanicznej w postaci map naprężeń do analizy wybrano oprogramowanie ADINA. Analizę prowadzono z wykorzystaniem modułu analizy dynamicznej „Explicit". Pod uwagę wzięto trzy rodzaje pustaków Fert, tj. Fert 40, Fert 45 oraz Fert 60. Każdy z analizowanych pustaków poddano dynamicznemu obciążeniu ciśnieniem, przyłożonym do górnej powierzchni i oddziałującym w kierunku dolnej powierzchni pustaka. Zastosowane warunki brzegowe opisują uproszczone zamocowanie pustaków na belkach stropowych. W celu sprawdzenia, jak gumowe wypełnienie pustaka zmienia przepływ energii mechanicznej, każdy z pustaków analizowano bez, a następnie z wypełnieniem. Na podstawie przeprowadzonej analizy stwierdzono, że im większy bloczek stropowy, a tym samym więcej wypełnienia gumowego, tym wyższa wartość redukcji oddziaływania dynamicznego. W związku z powyższym wysokość warstwy izolacyjnej może być zredukowana przy zachowaniu tych samych parametrów akustycznych stropu. Z drugiej strony zaproponowane rozwiązanie pustaka z gumowym wypełnieniem zwiększa jego masę, co negatywnie wpływa na nośność stropu.

SŁOWA KLUCZOWE:
wypełnienie gumowe; pustaki stropowe; redukcja oddziaływania dynamicznego; beton-guma; analiza dynamiczna