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INNOVATIVE CONCRETE-POLYURETHANE COMPOSITE BLOCKS LOCATED IN THREE-LAYER WALL – THERMAL NUMERICAL ANALYSIS

M. Major[*], K. Kuliński[**], I. Major[***]

Abstract: *In this paper thermal conductivity numerical analysis of an innovative blocks made of concrete with polyurethane inserts/injects, located in a three-layer wall was performed. Mentioned polyurethane cross pads were assumed to be inserted or injected in specially formed holes in the process of production. Moreover, it was assumed that the wall should meet the conditions of building intended for continuous human presence. In order to estimate the percentage warmth comfort improvement and thermal conductivity the same wall with the use of solid concrete blocks was investigated. On the basis of obtained results one can state that the heat resistance was only slightly improved via the polyurethane cross pads inserts/injects in comparison with solid concrete blocks, whereas measurable benefits could only be observed in the wall without separate insulation layer. Presented numerical analyses were performed with the use of finite element method based software – ADINA program.*

Keywords: ADINA, Thermal analysis, Heat flow, Concrete-polyurethane, Composite.

1. Introduction

Nowadays a wide access to computers and the finite element method based software allow to perform experimental tests of almost any model without the necessity of purchasing expensive research equipment and materials. Utilization of such software not only allows to solve simply stated boundary problems, but also allows to identify other various types of phenomena. According to that due to the simple thermal load acting in construction, results not only concerning thermal conductivity, heat flow/flux can be obtained, but also results concerning stresses, displacements etc. can be investigated. As an example wave propagation phenomenon in simple elastic structures was discussed in (Major and Major 2014). It is worth to notice that finite element method solutions may be utilized in almost any area of life sciences – statics, dynamics, fluid flows, electromagnetics etc.

Today composite materials are frequently used in civil engineering due to their special mechanical properties. The most common composites in civil engineering are concrete with steel and also steel with rubber. Such utilization of two different materials allow to combine advantages of separate materials into an individual composite. In the first mentioned case i.e. concrete with steel, the compressive load bearing capacity of concrete with the high tensile load bearing capacity of steel provide composite material with relatively high resistance to the both types of loading. In the second case i.e. utilization of steel and rubber allow to obtain composite with high vibrations damping factor at relatively high bearing capacity. Appropriate composite materials arise mainly due to a special market demands for materials with determined properties.

In this paper composite block made of concrete with polyurethane inserted/injected pads located in a three-layer wall in terms of thermal conductivity was investigated. Such wall comprised of bricks with mortars as an exterior layer, wool insulation in the middle of the wall and mentioned composite blocks as an interior layer, respectively. In considered composite, concrete blocks in the production process might

[*] Assoc. Prof. Eng. Maciej Major, PhD.: Department of Steel Structures and Building materials, Częstochowa University of Technology, Akademicka 3 street; 42-200 Częstochowa; PL, mmajor@bud.pcz.czest.pl

[**] Eng. Krzysztof Kuliński, M.Sc.: Department of Concrete Structures and Geotechnics, Częstochowa University of Technology, Akademicka 3 street, 42-200 Częstochowa; PL, kkulinski@bud.pcz.czest.pl

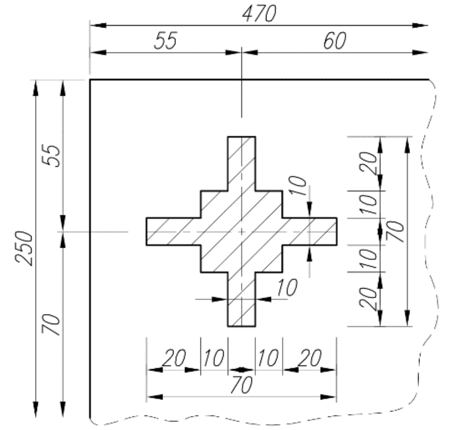
[***] Assoc. Prof. Eng. Izabela Major, PhD.: Department of Technological Mechanics and Engineering Graphics, Częstochowa University of Technology, Akademicka 3 street; 42-200 Częstochowa; PL, imajor@bud.pcz.czest.pl

have embedded special forms and after it removal, polyurethane cross pads could be inserted or injected. For the analysis purposes it was assumed that the wall had to meet the conditions of building intended for continuous human presence. In order to estimate the improvement of heat conditions in the composite wall and on the inner building surface, additionally a reference model made of exactly the same wall with solid concrete block was investigated. It is worth to notice that discussed composite block allowed transferring significant compressive forces – load bearing capacity of such block in comparison with solid concrete block was only slightly reduced via specially prepared holes. Due to the lack number of research concerning utilization of concrete with polyurethane inserts/injects, presented in this paper material may be treated as innovative. In order to solve stated heat transfer problem, finite element method approach with the use of ADINA program was chosen.

2. Numerical model

In order to perform numerical analysis of thermal conductivity and temperature redistribution, section of a wall made of bricks with mortars as an exterior layer, wool insulation in the middle and composite blocks as an interior layer was adopted. Separate bricks had following dimensions: length equal 0.25 m, width 0.12 m and height of 0.065 m, where mortars were assumed to be 1 cm thick. Thickness of wool insulation was assumed as 0.10 m. Separate composite block had: length equal 0.47 m, width 0.25 m and height equal 0.22 m. Mentioned dimensions were presented with respect to the Cartesian coordinate system, where length was measured along Y-axis, width along X-axis and height along Z-axis, respectively. The polyurethane cross pad inserts dimensions and their arrangement was presented in Fig. 1a, whereas whole numerical model was presented in Fig. 1b. Four different temperature measurement points were adopted on the top surface of composite block, which was presented in Fig. 2. Due to the boundary condition i.e. infinite length of model in both Z-axis directions, the precise location of measurement points on Z-axis had no meaning. Values of temperature from specified measurement points were read-out at four different time steps of the analysis i.e. t = 6, 12, 18 and 24 hours.

a)



b)

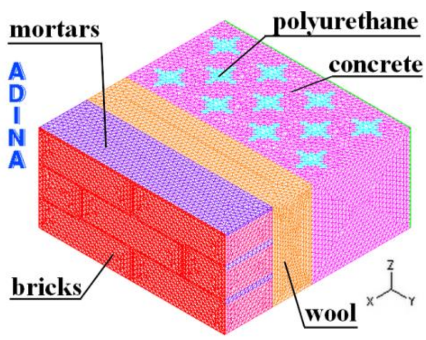


Fig. 1: Three-layer wall: a) arrangement and dimensions of polyurethane cross inserts/injects; b) discretized numerical model of the wall with composite block.

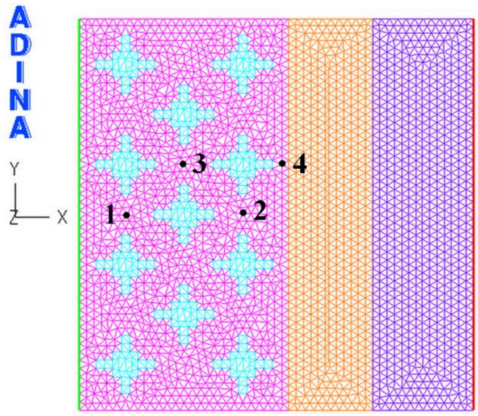


Fig. 2: Localization of temperature measurement points 1-4 on the top surface of the wall section.

Due to the fact that the wall had to meet conditions of a building intended for continuous human presence, on the basis of the polish standard of heat flow analysis PN-EN ISO 12831:2006, on the exterior wall surface temperature equal 20 °C was adopted, whereas on the exterior surface of the wall temperature of -20°C, respectively. Moreover, it was assumed according to the polish standard PN-EN ISO 6946:2008 that the convection on boundary surfaces (interior and exterior surface of the wall - “YZ” plane) acts horizontally. The heat resistance for the inner wall surface was adopted as R_{si} = 0.13 and for the exterior wall surface as R_{se} = 0.04. Thermal properties for each utilized in the wall material were adopted in accordance with PN-EN ISO 6946:2008.

3. Results and discussion

According to the Polish standard PN-EN ISO 12831:2006 the coefficient of heat transfer for any partition is given via the following formula:

$$U = \frac{1}{R_{si} + \sum_{i=1}^{n} R_i + R_{se}} \tag{1}$$

where: R_{si} – denotes the thermal resistance of inner convection, R_i – denotes the thermal resistance of i-th material and R_{se} – thermal resistance of exterior convection, respectively. Knowing that $R_i = d_i / \lambda_i$, where d_i - denotes the i-th material thickness and λ_i is the i-th material thermal conductivity coefficient, it was possible to determine the composite heat transfer coefficient. For the solid concrete block mentioned λ coefficient was equal 2.00 W/m·K, whereas for the composite block 1.686 W/m·K, respectively. The percentage decrease of thermal coefficient was equal 15.7%, which in fact should significantly affect the temperature redistribution. The heat transfer coefficient for the whole wall section where composite was used stood at 0.341 W/m^{2}K, whereas for the section of the wall with solid sandstone 0.344 W/m^{2}K was obtained, respectively. It is worth to notice that for the separate concrete block heat transfer coefficient was equal 3.390 W/m^{2}K, whereas for composite 3.142 W/m^{2}K was obtained. The difference between mentioned values of heat transfer in the three-layered wall was minimal i.e. 0.003 W/m^{2}K, while more significant difference of 0.248 W/m^{2}K was obtained in case of single-layered wall made of only composites or solid concrete blocks. The other main advantage of composite blocks was good noise damping factor and relatively high compressive load bearing capacity in comparison to the solid concrete blocks. Obtained temperature values for four different time steps of the analysis and at four specified measurement points were presented in Tab. 1.

Tab. 1: Temperature values obtained at specified measurement points and time steps on the composite and solid concrete block located in the three layer wall partition.

Temperature [°C]					
Model	**Point**	**t = 6 h**	**t = 12 h**	**t = 18 h**	**t = 24 h**
Composite	**1**	6.587	9.263	11.086	12.480
Solid	**1**	5.553	8.152	10.092	11.624
Composite	**2**	1.566	4.260	6.620	8.519
Solid	**2**	1.983	4.769	7.096	8.971
Composite	**3**	3.705	6.614	8.801	10.507
Solid	**3**	3.546	6.357	8.549	10.293
Composite	**4**	1.469	4.137	6.495	8.395
Solid	**4**	1.948	4.722	7.047	8.921

According to the presented values in Tab. 1 one can state that the composite block accumulates more heat near the interior side (compare point 1 for solid concrete block and composite at any time step) in comparison to the solid concrete block. That phenomenon was connected with the volume of concrete material. Knowing that the initial condition for all the layers of the wall was temperature equal 0 °C, concrete material with lesser volume absorbed more heat from the interior, according to the rule that smaller area/volume is easier to heat in relation to the object with higher area/volume.

Moreover, the longer the way from the interior side the temperature started to change between two considered numerical models i.e. temperature near the wool insulation (compare point 2 and 4 at any time step) in the composite block was lower than for the solid concrete. That was connected with the conductivity of material used and lack of different material with lower conductivity embedded inside the solid concrete block. Comparing temperatures obtained in point 3 and 4 for both considered blocks at $t = 24$ h, one can state that the difference in temperature for the composite block stood at 2.112 °C, whereas in the solid concrete 1.372 °C, which means that the temperature in the building interior would be easier to retain in case of composite blocks utilization.

The heat flux in the whole wall partition for both composite and solid concrete blocks at t = 24 h was presented in Fig. 3.

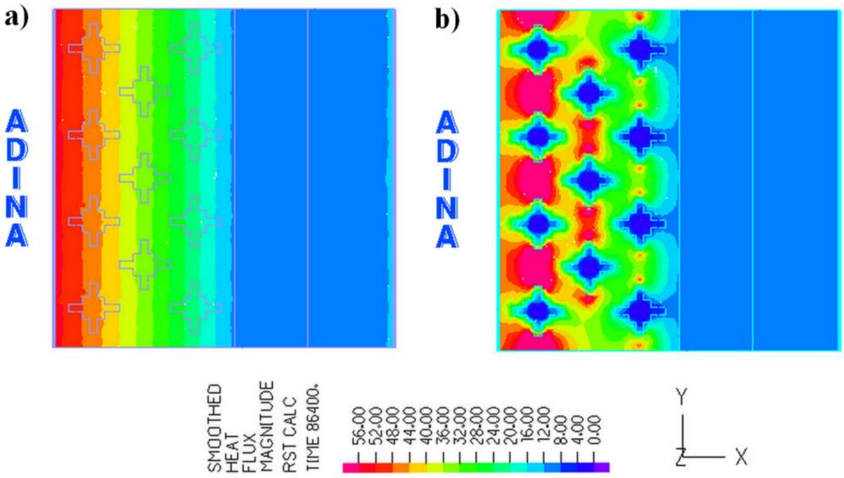


Fig. 3: Heat flux: a) three layer wall with solid concrete blocks;
b) three layer wall with composite blocks.

4. Conclusion

The finite element method approach today is very often utilized as an introduction to the expensive experimental tests. Via this method it is not only possible to analyse mechanical stresses and displacements but also other types of phenomena such as heat/fluid flow, effects of electromagnetics etc. Mentioned finite element method is not only used for small scaled problems but also in engineering problems such as validation of adopted solutions in building constructions (Cajka and Krejsa 2014; Melcer and Lajčáková 2014), bridges constructions (Vican and Sykora 2013) etc.

In this paper proposition of composite made of concrete with polyurethane foam cross inserts/injects was investigated in terms of thermal conductivity in three-layer wall. Due to the lack number of research concerning such connection of materials, presented composite may be treated as an innovative solution. It was shown that the composite in the three layer wall slightly changed the isotherms redistribution and there is slightly lesser heat loss. Moreover, it should be noted that presented solution have significantly better noise damping factor and comparable compressive load bearing capacity in relation to the solid concrete block.

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