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CAD analysis for stress and strain behaviour of masonries made of hollow ceramic blocks

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Abstract. Nowadays, one of principal directions to increase energy performance of both existing buildings and those under construction is application of thermal efficient enclosing structures. Therefore, hollow multislot ceramics is very promising material to be applied in exterior walls due to predicted properties thereof and operational reliability. The results of stress analysis and strain behavior of load-bearing wall structures are presented here in, and simulation and strength properties calculation of hollow ceramic blocks are made through SCAD software thereby making geometry parameters for the fracture models. Behavior of Bashkortostan-made hollow ceramic blocks under pressure is found under experimental research of masonries, with the expected fracture process being proposed. Modern software systems are demonstrated to be likely applied for analysis of stress and strain behavior of masonry constructions made of both traditional wall materials and hollow ceramic blocks. Comparative analysis of calculation results is made using PC and “manually”, with residential high-rise buildings and walls of different thickness taken as an example. Application of hollow wall items in load-bearing exterior and interior walls was confirmed both for high-rise and low-rise construction.

1. Introduction

Currently, problems of both energy saving and efficient use of resources are very important. Nowadays there are several directions to increase energy performance both of existing buildings: application of thermal efficient enclosing structures; modern ventilation and air conditioning system; improvement of layout and arrangement; increase of heating system efficiency; rehabilitation of residential buildings. All these methods are well known to specialists and if duly promoted, it may be well implemented to the construction practice. Problem for reducing heat loss in residential buildings is to be extensively solved, and all the indicated measures are to be applied in its entirety thereof. Main method for saving energy in residential buildings though is reducing of heat loss by using the enclosing structures. Now external walls of residential buildings are made of base layer and heat-insulation layer to achieve the required energy performance values [1, 2, 3]. However, these structural solutions include a number of hybrid items thereby decreasing reliability due to probable failures because of great number of things affecting functional reliability and durability thereof. In this respect external walls made of uniform load-bearing structural insulating materials are considered to be more predictable and reliable in maintenance [4]. Moreover, practice shows that buildings with enclosing structures made of hollow porous blocks as per specific heat-shield performance are not far below the three-layered wall constructions having ceramic solid bricks as the base layer and energy saving insulation layer [5], [6].

2. Bibliography

There are absolutely no problems with the materials bahaviour in high-rise framed buildings where hollow porous blocks act as non-bearing filler walls. But it may cause problems in frameless buildings where masonry of hollow ceramic blocks is the bearing one. As hollows in such blocks are stress concentrators thereby reducing area of the block cross-section, the behaviour of the material under stress is to be analyzed in details enabling to define the block dimensions influence, hollows form, strength and deformation properties of materials on stress and strain behaviour of the masonry on the whole and sequence of destructions under the pressure load.

Back in 1950s L.I. Onishchik proposed the working model of the brick with 25% of hollowness trying to explain elastic and mechanical properties of hollow bricks. The simulation is complicated by the fact that the masonry is non-uniform elastoplastic material. Both block and mortar in the masonry are under complex stress condition even under equal load distribution over the all cross-section of the compression element. They are equally exposed to eccentric compression, bending, tension, shear and bearing [7, 8]. The aim of the research was simulation and calculation of hollow ceramic blocks and masonry made there under in SCAD software, making geometry parameters for the fault models and evaluation of repeatability results between computer calculations and experimental testing results [9].

3. Materials and methods

7NF Porikam standard ceramic block with 250x250x219mm in size and 48% hollowness is taken as an example (Figure 1).

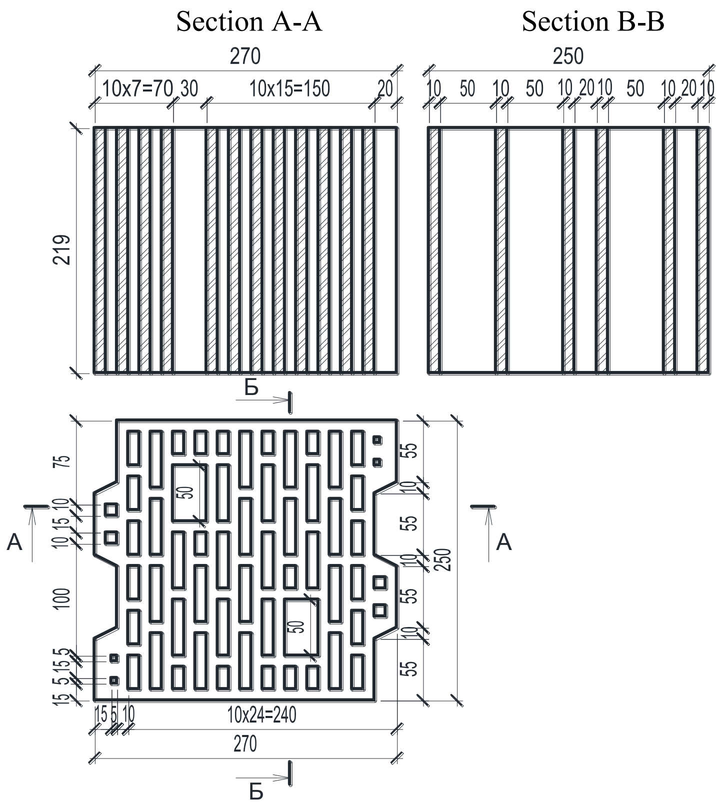


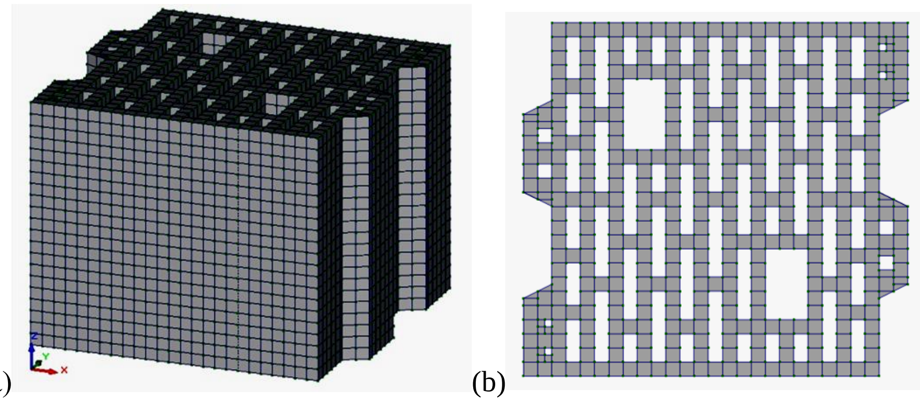
Figure 1. 7NF Porikam standard ceramic block with tongue-and groove.

7NF Porikam model was simulated by SCAD software (version 11.1) from six- and eight-node solid elements. Maximum grid size is 10mm, with the minimum one being 5mm (Figure 2. Model of 7FM Porikam ceramic standard block in SCAD software: (a) general view, (b) top view).

Subsequently the required connections were established, stiffening behaviour of block material and loading upon solid elements were set, and analysis for compression was done directly. The material under research is described through density, elastic module and Poisson's ratio in SCAD software. According to the analysis the stiffening behaviour of blocks were taken by the manufacturer’s data: block density ρ= 800 kg/m^3, Poisson's ratio ν=0.08-0.12 as recommended by some scientists.

After consideration of 7NF hollow ceramic block it may be deduced that stiffening behaviour of the material in SCAD software set by one parameter only, i.e. elastic module, which in its turn implies certain values for ultimate resistance of the material, may not correctly describe behaviour under loading [10, 11].

There are concentrations of horizontal tension stress in walls between hollows when the block is under load. On the whole stress pattern and intensity thereof along the block height do not correspond to the uniform element without any hollows which stress and strain behaviour contains no tension stress. Distribution of both compression stress and tension stress is varying when moving to the centre of cross-section [12, 13]. The first crack appeared in the external wall at 0.6 loading of ultimate N_{ult} load. Cracks in external walls of the blocks were forming in the loading range of 0.6 – 0.8 N_{ult} and cracks appeared in cross-walls. When loading exceeded 0.85 N_{ult} both external and then the internal walls all around the block have been broken, with the main core being preserved.



(a) (b)

Figure 2. Model of 7NF Porikam ceramic standard block in SCAD software: general view (a), top view (b).

7NF strength grade block corresponding to M100 was defined under the testing results. Average testing results by hollow ceramic block series are given in Table 1, while the sample damage behaviour is given in Figure 4.

Table 1. Testing results of hollow ceramic blocks under compression.

Test series No.	Average grade by strength of block series under compression	Crack load N_{crc}, kN	Ultimate load N_{break}, kN	Ultimate strength $R_{u,average}$, MPa	Elastic module $E_0 = \frac{\Delta_\sigma}{\Delta_\delta}$, MPa
1	100	243	478	7.65	10928.6
2	100	226	461	7.38	10542.9
3	100	209	444	7.10	10142.9

According to natural experiment cracking starts in the middle tension-compression area of the block at load of 0.5-0.7 of ultimate load N_{ult}, vertical cracks are propagating with formation of new ones at load of 0.7-0.9 of ultimate load N_{ult}, and diagonal cracks are developing and propagating in near-support areas at load of 0.85-0.95 of N_{ult}. Generally, fracture behaviour of samples is unstable [14, 15]. Testing results suggest that fracture behaviour of the hollow block under load in SCAD software is actually the same as in the experiment.

The behaviour of two-piece part of the masonry consisting of large-sized blocks with the vertical tongue-and-groove connection with overall dimensions of 250x250mm, 425mm in height in plan view (with mortar joint) was analyzed further. Testing results of three two-piece parts series of the masonry under similar conditions are presented in Table 2.

Table 2. Testing results of two-piece masonry samples.

Test sample	Strength of masonry materials, MPa		Crack load N_{crc}, kN	Ultimate load N_{break}, kN	Ultimate strength of masonry, $R_{u,average}$, MPa	Elastic module, MPa	Poisson's ratio, $\mu = s_{tran}/s_{long}$	Elastic response $\alpha = E_0/R_u$
	Block	Mortar						
1	7.4	14.8	272	430.3	6.9	7651	0.09	1100
2			200	375.7	6	8010	0.13	1340
3			190	329.7	5.3	7290	0.17	1375

It should be mentioned that values of masonries ultimate compressive strength made of materials under review found theoretically as per the normative technique (see Table 3) are 30% lower than the experimental results which is stated by other authors who in particular introduce a number of correcting coefficients under theoretical specification of the masonry strength behaviour made of hollow porous ceramic blocks [16, 17].

Table 3. Comparison of theoretical and experimental values of masonry design strength.

Design strength to masonry compression calculated experimentally, kN/cm^2	Design strength to masonry compression as per Onishchik formula by sample behaviour, kN/cm^2	Design strength to masonry compression by SP 15.13330.2012 considering reducing factors, kN/cm^2
0.23	0.17	0.162

A model of nine-storey residential building (Figure 3) with 2.8m floor height and 40.8x12.6 m dimensions in plan view was simulated to analyze application of masonry made of hollow ceramic blocks as the base material for heat efficient external load-bearing walls. Dimensions of windows are 1.3x1.4 m. Thickness of external 380mm walls of the building made of 10.7NF blocks was taken to analyze behaviour of the material under review [18, 19]. Due to large amount of components in the nine-storied building diagram, masonry to be made of the material analysis and it was simulated not as 8 or 6-node isoparametric finite solid elements but as 4 or 3-node plates with the given stiffness properties (elastic module and Poisson's ratio) accepted under test results of two-piece part of masonries described above.

Design efforts derived from analysis of stress and strain behavior of both external and internal walls of the nine-storey building model may be said to have fairly good repeatability with the "manual" calculation (within 12-20%).

A wall partition model with cells within the block was simulated for detailed evaluation of the masonry damage made of hollow ceramic blocks in details. The partition is made of 10.7NF blocks with b=1.175m, h=2.42m dimensions, and 2.42m in height (Figure 4) and consists of 8 or 6-node isoparametric finite solid elements.

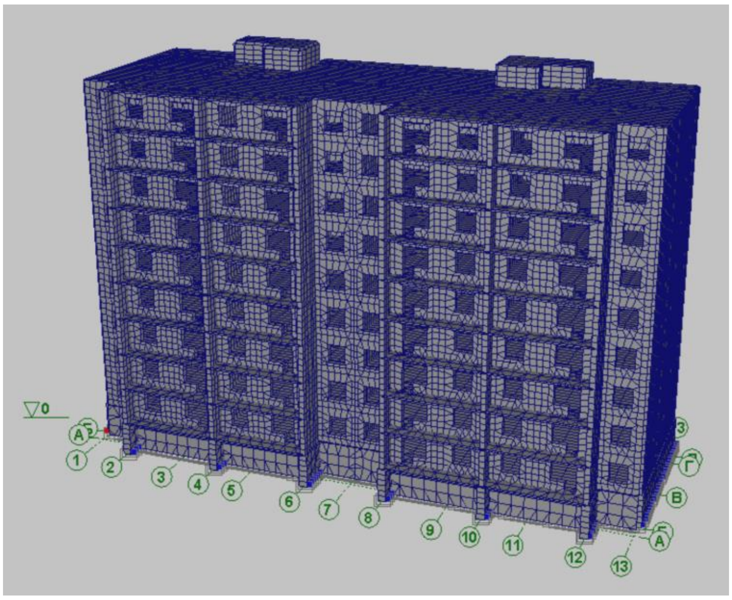
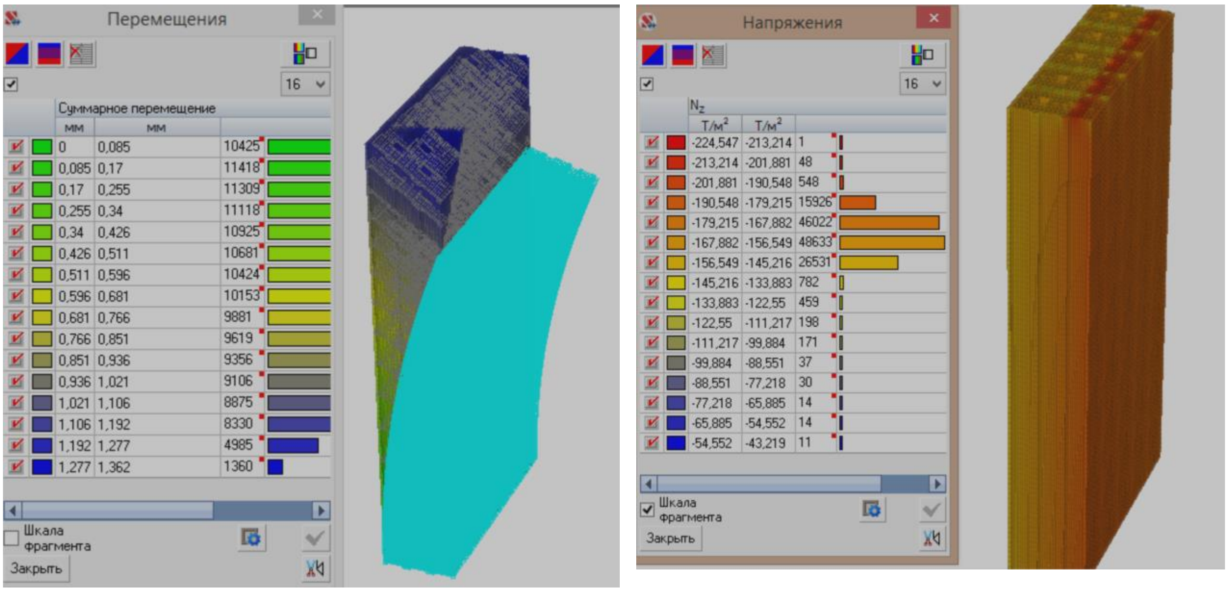


Figure 3. Computational model of 9-storeyed residential building within software complex.

Geometry and aspect ratio between finite elements within the block were being corrected while making one 10.7NF block by “triangulation upgrading” function. Stress related properties of the material were given by the manufacturer’s data and under results of field tests of the item and two-piece part of sample masonries. The partition was exposed both to uniformly distributed central load equivalent to load from upper eight storeys of nine-storied building and to eccentric load from one hollow core slab with support depth of 0.12m, calculated under analysis of stress and strain behavior of both external and internal walls of the nine-storey building described above [20].

The analysis results demonstrated safe behavior of hollow ceramic blocks thereby providing the specified load-bearing capacity of the nine-storey residential building taken as an example. Stress appearing in exposed edge of the masonry did not reach the crack values calculated experimentally.



(a) (b)

Figure 4. Wall partition behavior under load: Aggregate movements of the partition(a) and Nz stress of the partition (b).

4. Results

We consider SCAD software to be recommended in teaching the “Construction” branch students with principles of housing structural engineering and civil buildings made of masonry and reinforced masonry structures under general evaluation of stress condition in the load-bearing walls with housing and civil building models taken as an example, and the wall parts exposing to heavy load are to be considered separately by comparing “manual” calculations with the software data according to the above scheme.

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