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CAD simulation for stress and strain behaviour of wall constructions made of hollow ceramic blocks

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Abstract. Research results for analysing stress and strain behaviour of wall constructions made of hollow ceramic blocks are presented herein. FEM simulation for masonry construction is given. Application of CAD methods for masonry calculation as opposed to traditional ones enables us to evaluate more clearly the entire real stress and strain behaviour not of several partitions but of the building itself on the whole, to figure out stress redistribution and the most loaded areas which is of greater importance under loading intensification and using of new cavity walls. Application of current software packages is theoretically proved when analysing stress and strain behaviour of masonry constructions made not only of traditional wall materials but of hollow ceramic blocks. Comparative analysis between computer calculation and traditional "manual" calculation has been made taking residential varied-height buildings with different wall thickness as examples. The calculations have proved that hollow wall blocks manufactured by domestic enterprises may be applied in load bearing walls both inside and outside of low-rise and high-rise buildings (9-12 storeys).

1. Introduction

Over 70% of all thermal power generated in the Russian Federation is currently used for heating of buildings and facilities. It is stipulated not only by geographical position of Russia but due to great loss of heat under heating which is currently 30% of total thermal energy consumption in the country [1]. One of the most promising way for energy saving is decreasing of loss of heat in buildings considered as end-use energy consumers [2]. Building heat insulation requirements for saving energy under providing good hygiene practices and optimum environment and design life of enclosing structures around buildings and constructions have greatly increased nowadays. These requirements cover environmental protection and nonrenewable natural resources conservation issues, greenhouse effect minimization, and carbon and other dangerous substances emissions [3, 4].

2. Materials and methods

Problem for reducing heat loss in residential buildings is to be extensively solved, with full spectrum of steps being applied to achieve maximum efficiency [5, 6, 7]. Nevertheless, heat loss reduction through the enclosing structures is the principal way for energy saving in residential buildings. Now external walls of residential buildings are made of base layer and heat-insulation layer to achieve the required energy performance [8, 9, 10]. 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 as more predictable and reliable in maintenance [11, 12]. 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 [13, 14].

According to testing analysis it has been found that form, behaviour and relative position of ceramic components affect the mechanical properties thereof, and strength testing results over all three directions are required to get actual strength results [15]. The simulation is complicated by the fact that the masonry is non-uniform elastoplastic material. Both block and mortar in the masonry are in 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 [16].

3. Research

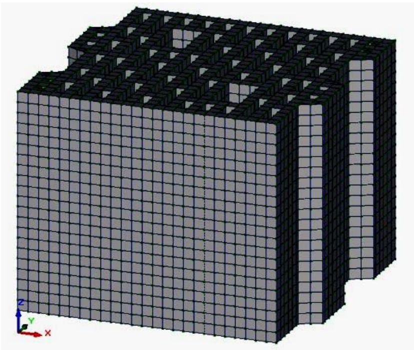
The aim of the research was simulation and calculation of hollow ceramic blocks and masonry made thereunder in SCAD software, making geometry parameters for the fault models and evaluation of repeatability results between computer calculations and experimental testing results, with further application of this software in teaching the “Construction” branch students with principles of structural engineering of housing and civil buildings made of masonry and reinforced masonry structures [17, 18].

4. Theoretical

A new brick factory “Amstron” Limited for the manufacturing of advanced and innovative ceramic porous blocks of PORIKAM (PORIKAM^{TM}) trade began operating in November of 2013 in Tolbazy settlement of Aurgazinsky region in Bashkortostan. 7NF Porikam standard ceramic block with 250x250x219mm in size and 48% hollowness was taken as an example. These blocks are manufactured by “Amstron” Limited of M100 and M125 grade by compressive strength.

7NF Porikam model was made by SCAD software (version 11.1) from six- and eight-node solid elements. Maximum grid size is 10mm, with the minimum one being 5mm (Fig.1). Subsequently the required connections have been established, stiffening behaviour of block material and loading upon solid elements have been set, and analysis for compression has been 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 [19, 20].

After consideration of 7NF hollow ceramic block (Fig.1) 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. 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 correspond to the uniform element without 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 [21, 22]. 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 broken, with the main core being preserved.


a)

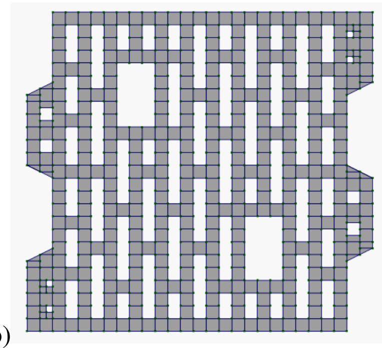

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Figure 1. Model of 7FM Porikam ceramic standard block in SCAD software: a) general view b) top view

5. Practical relevance, experimental results

Three series of hollow ceramic block samples were tested in the Research and Education Center for Innovation Technologies at Engineering Institute of Ufa State Petroleum Technological University to compare the results of analyzing the block model under load. 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.

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_{pasp}, kN	Ultimate strength $R_{u,cp}$, MPa	Elastic module $E_0 = \frac{\Delta\sigma}{\Delta\varepsilon}$, 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. Testing results suggest that fracture behaviour of the hollow block under load in SCAD software is actually the same as in the experiment. Behaviour of two-piece part of the masonry each 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 series of three two-piece parts of the masonry under similar conditions are presented in Table 2. In the course of masonry samples testing the values of both axial and lateral fractures of masonry were found with further calculation of Poisson's ratio and elastic module, crack loads and ultimate loads were fixed, and the comparison was done with theoretically found predicted performance of the masonry strength.

Table 2. Testing results of two-piece masonry samples

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

First cracking in two-piece part appeared at load up to 0.6 of ultimate load along the vertical ribs of samples from visible external sides of the block in the middle tension-compression area of the sample. Vertical cracking was propagating further at increasing of the load to 0.7-0.8 of the ultimate one, and diagonal cracks were propagating in near-support areas at 0.8-0.9 and then ultimate failure took place. It should be mentioned that values of ultimate strength to masonry compression (see Table 3) are 30% lower 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 [23].

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

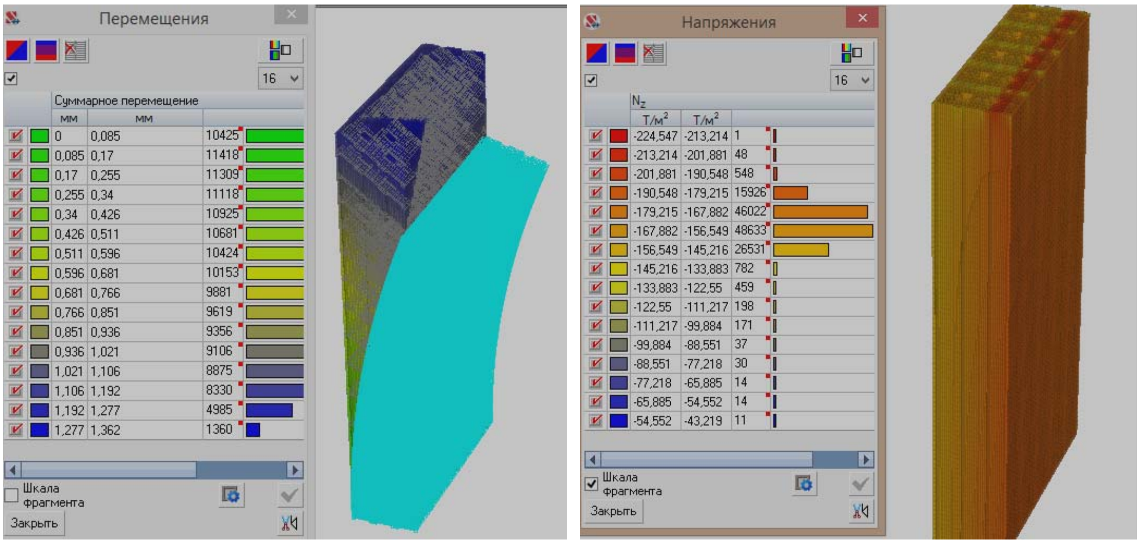
Design strength to masonry compression calculated experimentally, kN/cm^2	Design strength to masonry compression as per Onishchik formula by sample behaviour, kN/cm^2	Design strength to masonry compression by SP 15.13330.2012 considering reducing factors, kN/cm^2
0.23	0.17	0.162

A model of nine-storeyed residential building with 2.8m floor height and 40.8x12.6m in plan view was simulated to analyze usage of masonry made of hollow ceramic blocks as the base material for heat efficient external load-bearing walls. Only general evaluation of stress condition of load-bearing walls using the software complex is to be made to find high-load areas. And a separate partition of the ground floor considering stress found under general engineering of the building is to be simulated to directly evaluate the block behaviour within the masonry.

Membrane components of N_x or N_y stress only were used as the calculation results of stress and strain behaviour of both external and internal walls of the nine-storeyed building, with moments of slab-wall junction, wall thickness variation and wind moments being considered separately and added to the deduced membrane components of stress according to SP 15.13330.2012 and guide to SNiP II-22-81* rules. Shear behaviour of precast floor perpendicular to floor surface is excluded by reducing the floor elastic module by one order. Adjacent sections of walls are considered as connected with perfect elasticity, provided the normative documentation conditions limiting free deformation differences between adjacent wall sections are met.

Design efforts derived from analysis of stress and strain behaviour of both external and internal walls of the nine-storeyed 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 to evaluate failure of the masonry made of hollow ceramic blocks in details. The partition is made of 10.7NF blocks having b=1.175m, h=2.42m size, and 2.42m in height (Figure 2). The analysis results demonstrated safe behaviour of hollow ceramic blocks thereby providing the specified load-bearing capacity of the nine-storeyed residential building taken as an example. Stress appearing in exposed edge of the masonry therewith did not reach the crack values calculated experimentally.



a) Aggregate movements of the partition b) Nz stress of the partition

Figure 2. Wall partition behaviour under load

6. Results

We consider SCAD software to be advisable in teaching the "Construction" branch students with principles of structural engineering of housing 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 buildings models taken as an example, and the wall parts undergoing heavy load are to be considered separately by comparing "manual" calculations with the software data according to the above scheme.

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