Problem of the crack formations in the area of intersecting loadbearing walls built with AAC masonry unit

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Abstract: In the paper the attempt of determining the influencing factors of the formation of typical cracks in the area of loadbearing walls corner made of ACC masonry unit was made. Numerical calculations were conducted and they showed that with extreme self-weight loads, imposed loads, environmental and rheological loads the corner of the walls was exposed to the damage. At different level of loads and different geometry of walls the size of shrinkage deformations, by which the crack formations in the area of intersecting loadbearing walls won't take place was given.

Keywords: AAC masonry, crack resistance, masonry shrinkage, FEM model.

1. INTRODUCTION

The problem of crack formations in the AAC masonry walls under the influence of rheological and thermal loads has already been withdrawn repeatedly. Due to the shrinkage and thermal deformations the length of walls, at which cracks should not appear, has already been determined [1, 2, 3, 4]. The problem of the crack formations in walls corner is often omitted. And after all in these areas concentrations of stresses occur and therefore these zones are exposed to damage.

In the paper the attempt at determining the influencing factors on the typical crack formations in AAC masonry walls corner were made. For that purpose a three-dimensional model was built in the program based on FEM and computational analyses were conducted.

2. INFLUENCE OF RHEOLOGICAL AND THERMAL DEFORMATIONS FOR AAC MASONRY

The AAC blocks masonry, as the majority of building materials, characterize shrinkage and increase volume under the influence of thermal loads. PN EN-1996-1-1 norm [5] takes the size of rheological deformations from the shrinkage and expansion of the AAC wall on the level $\varepsilon_s = -0.4 \div +0.2$ mm/m. Coefficient of thermal expansion was defined on the level $\alpha_t = (7\div9)\cdot10\text{-}6/K$. These values are similar to the parameters of walls made of other materials. Only concrete and light concrete walls characterized by a greater shrinkage, however walls made of ceramic units usually have a smaller shrinkage.

Hums in the [1] showed, that at the 0.2 mm/m shrinkage level, the length of non-cracking walls was 12.0 m. However this value was appointed without taking into account the influence of self-weight and imposed loads and the influence of the temperature. Schubert in [3], further to German norm DIN 1053-1 [6], proposed a simple way of determining the distance between expansion joints in walls due to shrinkage and thermal deformations. This distance, determined as l_r is possible to appoint from the relation:

$$l_r \le -\ln\left(1-\frac{\beta_{Z,mw}}{E_{Z,mw}\varepsilon R}\right)\frac{h_{mw}}{0,23} \tag{1}$$

where:

- $\beta_{Z,mw}$ – masonry tensile strength towards the length of the wall
- $E_{Z,mw}$ – masonry modulus of elasticity at tension towards the length of the wall
- ε – total strain (including rheological and thermal influences)
- R – coefficient taking into account the influence of friction in the joint between masonry and another materials (e.g. concrete-masonry joint R = 1, building paper-masonry joint or foil-masonry joint R = 0.6)
- h_{mw} – height of the wall

Formula (1) is giving correct results at the ratio of the distance between expansion joints to the height of the wall $\frac{l_r}{h_{mw}} \le 5$.

Value of the masonry modulus of elasticity at tension $E_{Z,mw}$ depends on the value of tensile stress in the wall. At the maximum value of tensile stress $E_{Z,mw}$ is for the half smaller than at 1/3 maximum value of tensile stress. Therefore a masonry modulus of elasticity at tension $E_{Z,mw}$ is recommended to appoint on the 70% level of the maximum value of tensile stress. According to Schubert's it is possible to accept, that the masonry tensile strength $\beta_{Z,mw}$ to masonry modulus of elasticity at tension $E_{Z,mw}$ ratio, will take out: $\frac{\beta_{Z,mw}}{E_{Z,mw}} = \frac{1}{22000}$.

In the paper [4] authors are trying to include the influence of vertical loads, thermal loads and friction forces in the concrete-masonry joint (connection of ceiling and wall) on the masonry crack resistance. Stress pattern in the AAC block masonry wall loaded vertically on the base [4] is showed on fig. 1.

The wall and ceilings of the upper and bottom storey were analysed (fig. 1). According to authors [4] the cracks in masonry walls depend on values of shrinkage deformations, vertical loads, friction forces in the concrete-masonry joint and of course of the size of the wall. On the basis of conducted calculations the diagrams of the relation between the walls longs and the vertical loads to masonry compressive strength ratio were created. Graphs were drafted for AAC units of 3 strength classes and masonry with filled and unfilled perpend joints. The analysis were carried out at assuming the final value of the shrinkage level ε_s = 0.2 mm/m and ε_s = 0.3 mm/m. From presented diagrams it appears that as a result of thermal and rheological deformations the AAC masonry walls can be damaged by length about 5 m in at ε_s = 0.3 mm/m and by length about 8 m at ε_s = 0.2 mm/m. The influence of the unfilled perpend joints is emerging particularly at the final value of shrinkage ε_s = 0.3 mm/m already on the level 0.4 of maximum vertical stresses to the masonry compressive strength ratio.

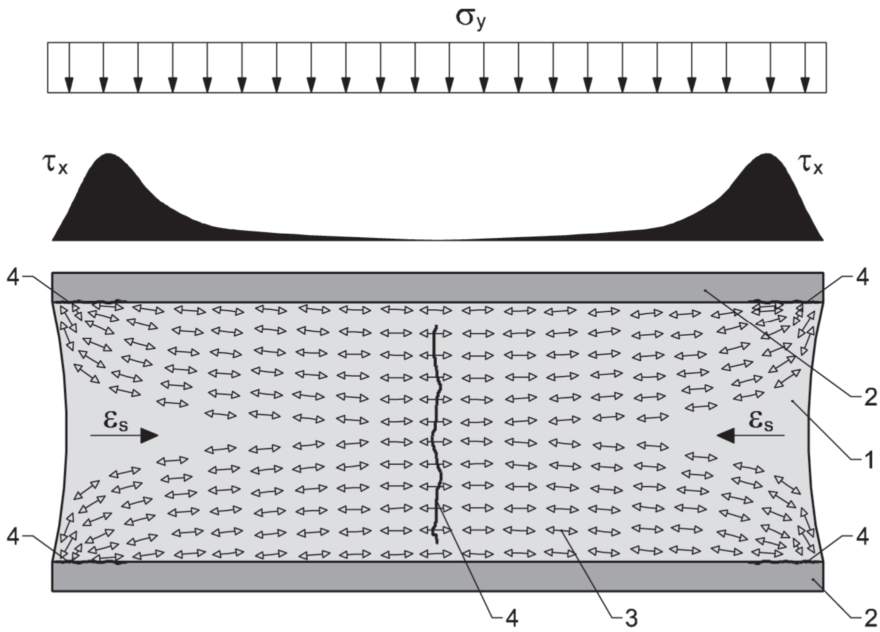


Fig. 1. Analyzed wall-ceiling model, according to [4]: 1 – wall, 2 – concrete ceiling, 3 – masonry tensile stresses, 4 – possible cracking

3. DAMAGING IN THE AREA OF INTERSECTING LOADBEARING WALLS BUILT WITH AAC MASONRY UNIT

Discussed in the previous point the methods of determining the walls longs, in which the cracks for thermal and rheological deformations won't take place are limited to deliberations above one wall about the drawn length, the thickness and the height. Analyses aren't conducted in the zone of intersecting loadbearing walls. In this area concentration of stresses appears. Therefore the crack formation in the walls corners is a considerable problem of AAC walls. Such cracks can appear in the corner or in the low distance from it. In extreme accidents cracks comes into existence even while building the walls, not to say before concreting the ceiling in (fig. 2a and 2b). However they more often become apparent during the use after the first heating period (fig. 2c and 2d).

a) b) c) d)

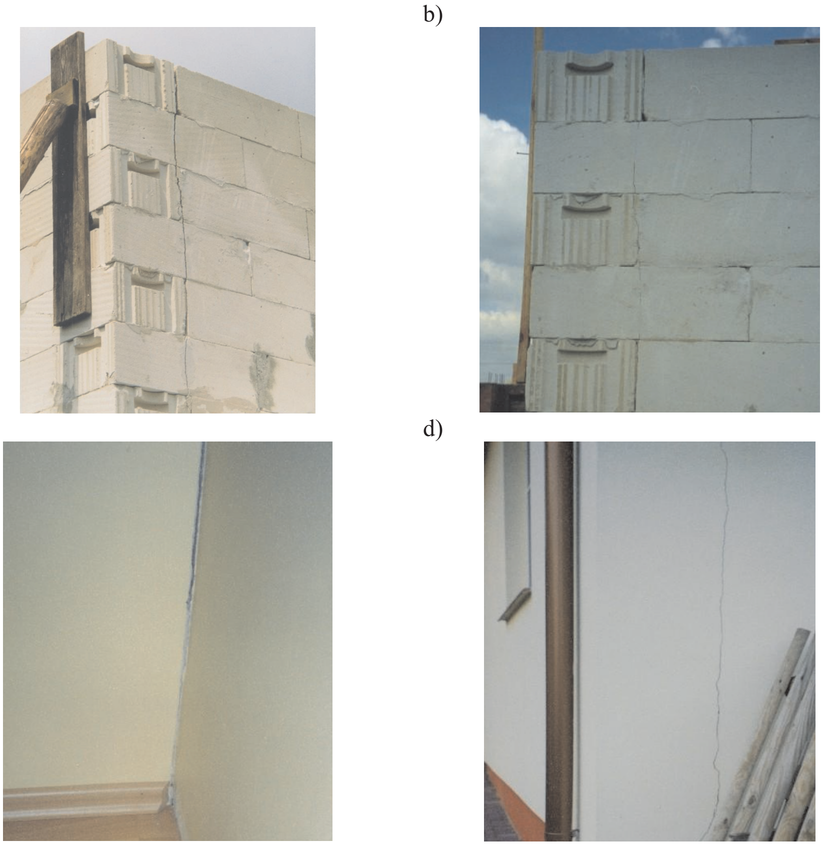


Fig. 2. Examples of cracks in walls corners (description in the text)

4. FEM MODEL

The aim of the paper is to determine the influences in the masonry corner zone and setting the length of walls, by which cracking won't take place. In the opinion of the author apart from recalled higher influences from shrinkage deformations, the size of vertical loads, friction forces in the concrete-masonry joint and dimensions of the wall is also affecting no damage coming the diversified vertical lads from ceilings and the roof passed on to walls gathering in the corner and changes of thermal loads in different seasons.

In order to calculate the length of uncracked walls in ABC OBJEKT program the FEM three-dimensional model was built. According to the conclusion of the paper [4] the smallest objects, in which the size of vertical stresses in walls is much lower than the masonry compressive strength are exposed to the cracking. In such situations low friction forces are arising in the concrete-masonry joint and the effects for reducing shrinkage deformations are small. Therefore a small object was analysed. It was calculated of a residential building with the functional attic. For analyses a connecting between gable wall and the oblong wall was accepted. It was assumed that the structure of the roof applies a load only an oblong wall, and the solid slab floor applies a load on both walls.

A symmetrical excerpt of a corner of a building was modelled (fig. 3). Two FEM models were made about diversified geometry. A relationship walls long was accepted equal of L1/L2 = 6/4 m (model I) and L1/L2 = 4/3 m (the II model).

Both models are loaded:

- q_1 – roof loads (resulting from conducted separate calculations at establishing the wooden collar beam rafter framing, warming the roof, roofing with the ceramic roof tile and environmental loads),
- q_2, q_3 – loads of oblong and gable walls,
- q_4 – imposed loads on floors,
- q_5 – self-weight loads of ceiling and floors,
- self-weight loads of ceiling and walls (accepted automatically in ABC OBJEKT program),
- shrinkage loads – 0.3 mm/m
- q_6 – friction forces in the concrete-masonry joint (friction factor they were accepted equal 0.7),
- loads from thermal influences. Heating the inside part of the walls to the +20°C and cooling outside to – 20°C,
- loads from thermal influences. Heating the inside part of the walls to the +20°C and outside to +40°C (load excluding each other from with the outline above).

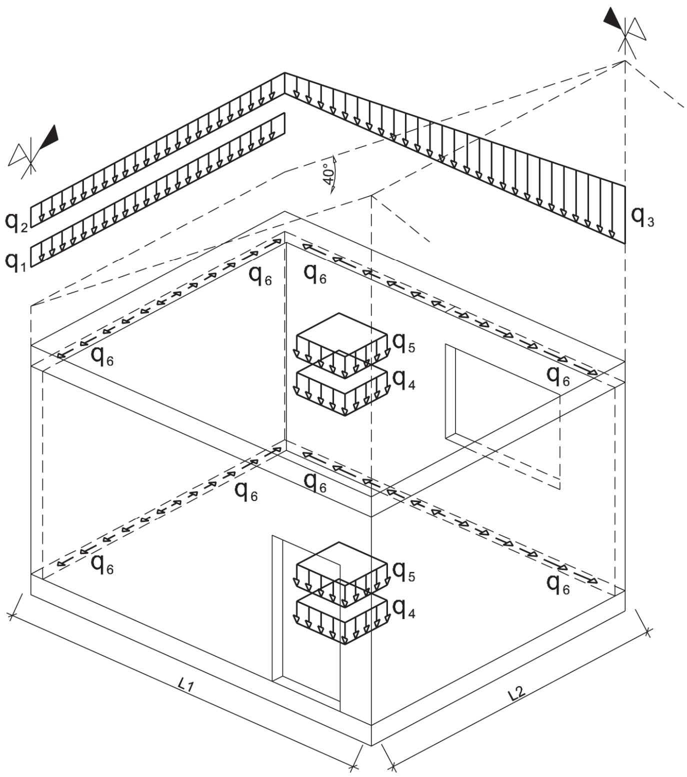


Fig. 3. Schemat obciążenia modelu obliczeniowego

Calculations were conducted at accepting linear material characteristics of concrete and the masonry. Coefficient of thermal expansion was assumed on the level $\alpha_t = 8 \cdot 10^{-6}$/K. Value of the modulus of elasticity and the density of the masonry accepted on the basis of conducted examinations [7]. Numerical models had appropriately to the size 1128 and 1926 finished elements (fig. 4). Thickening of elements was applied near the walls corner and at connecting the walls with ceiling (fig. 5). The model isn't taking into account non-linear material parameters of concrete and the masonry and the influence of unfilled perpend joints.

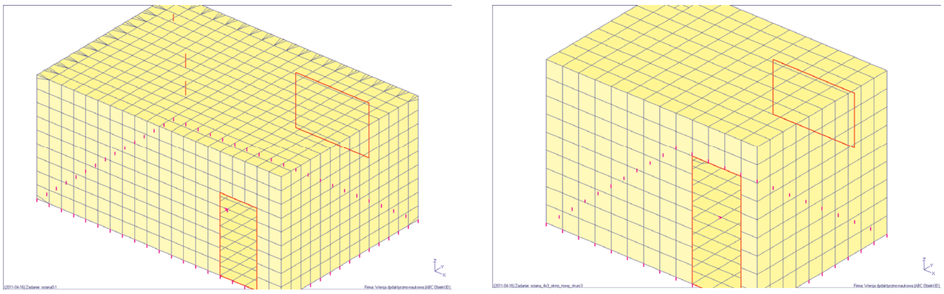


Fig. 4. View of FEM models: I (right side) and II (left side)

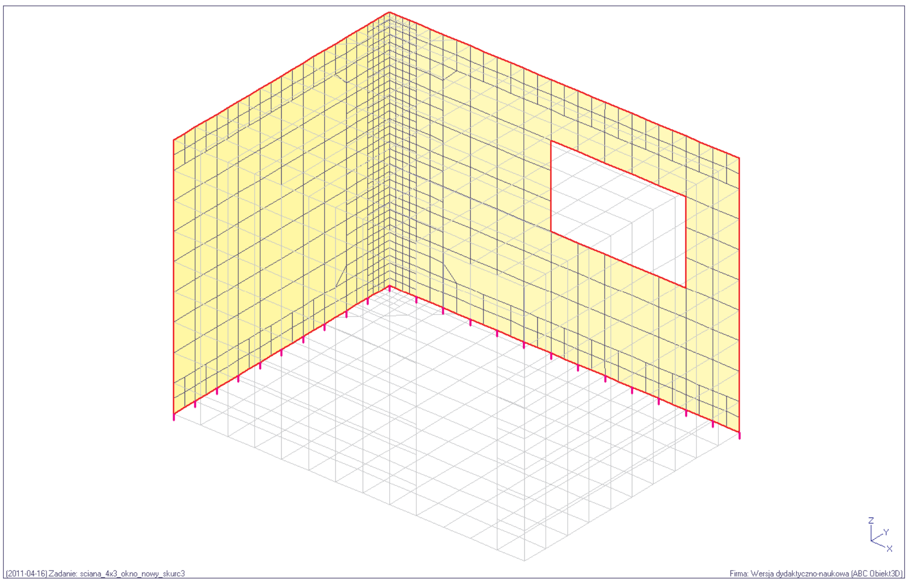


Fig. 5. Fragment of the corner of the FEM model II

5. RESULTS OF NUMERICAL ANALYSES

Values of deformations and stresses in the model were analysed. Image of the maximum deformations of the corner of the models are showed on fig. 6a, however of the II model on the fig. 6b.

a)

b)

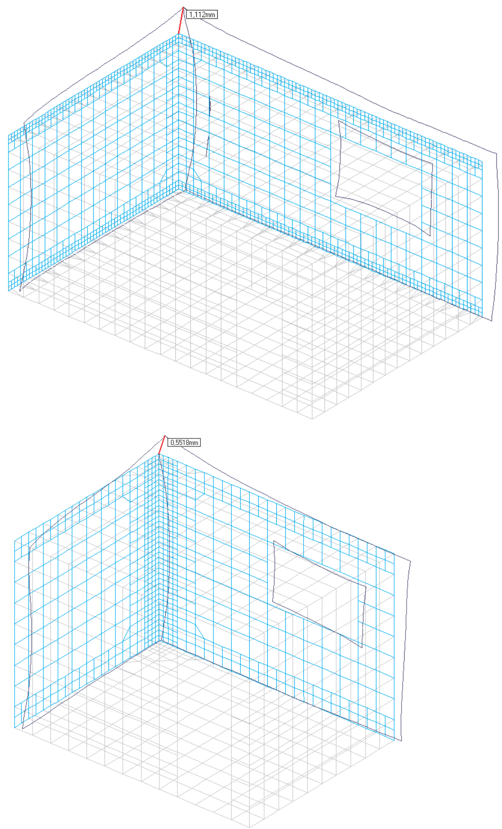


Fig. 6. Displacement of models: a) model I, b) model II

A double criterion to the crack formations was adopted: excess of masonry tensile strength and excess masonry shear stresses. The value of masonry tensile strength, by which cracks appeared in ACC masonry, was accepted to [2] equal of 0.2 N/mm^2. The value of masonry shear strength were established on the level 0.18 N/mm^2 on the basis of research made in Silesian Technical University in Gliwice, partly published in [8]. On fig. 7 maps of the maximum horizontal stresses in the corner walls area of both models were showed. Elements, in which value of masonry tensile strength and masonry shear strength were exceeded, were removed from the maps. Removed elements depict cracking areas of the wall.

a)

b)

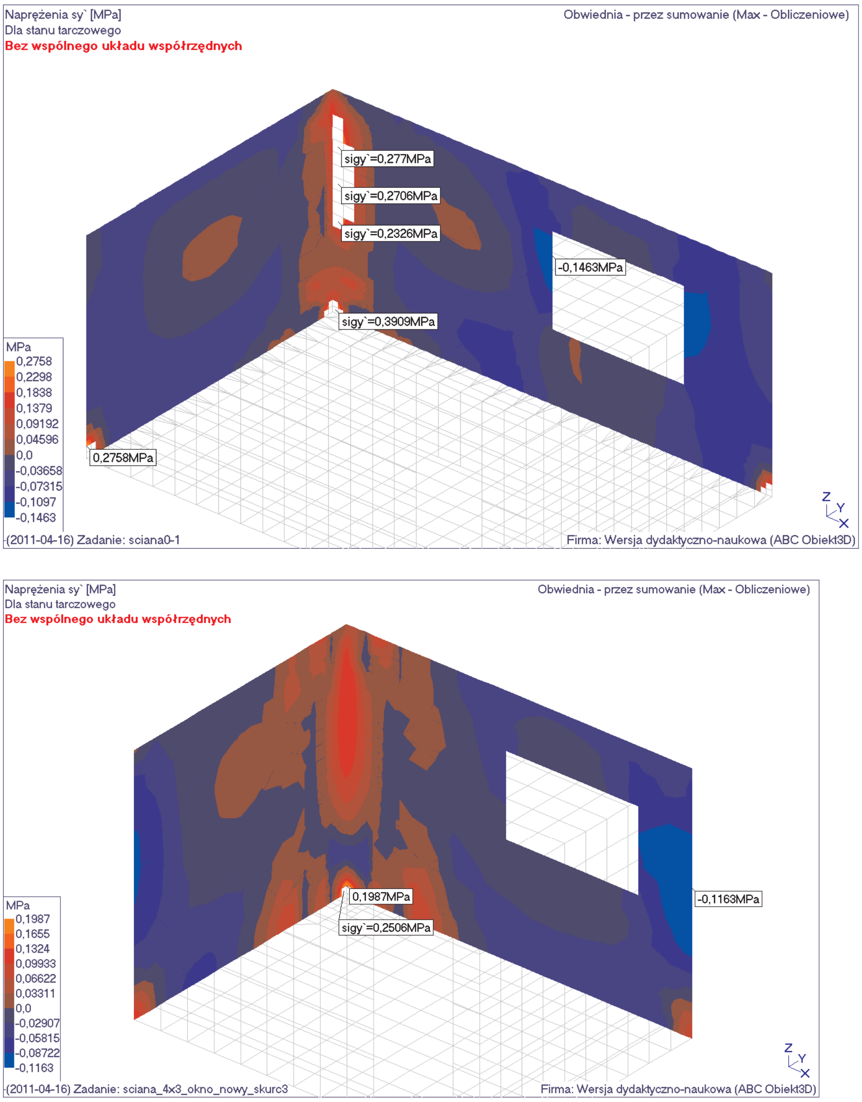
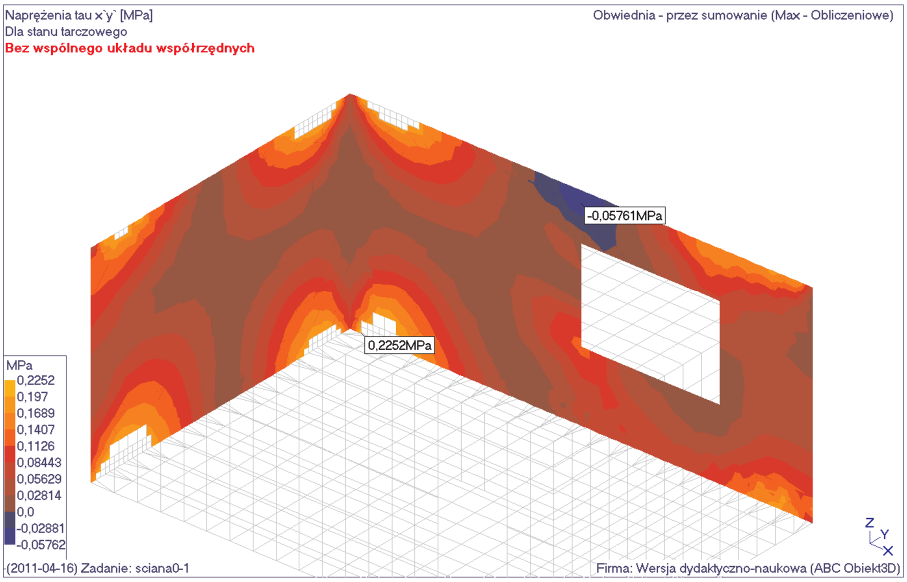


Fig. 7. Horizontal stresses in walls corners: a) model I, b) model II

On fig. 8 maps of shearing stresses were shown. As similarly as above elements, in which the exceeded value of shearing strength stayed, were removed from the model. This way the areas of potential cracking were depicted a)



b)

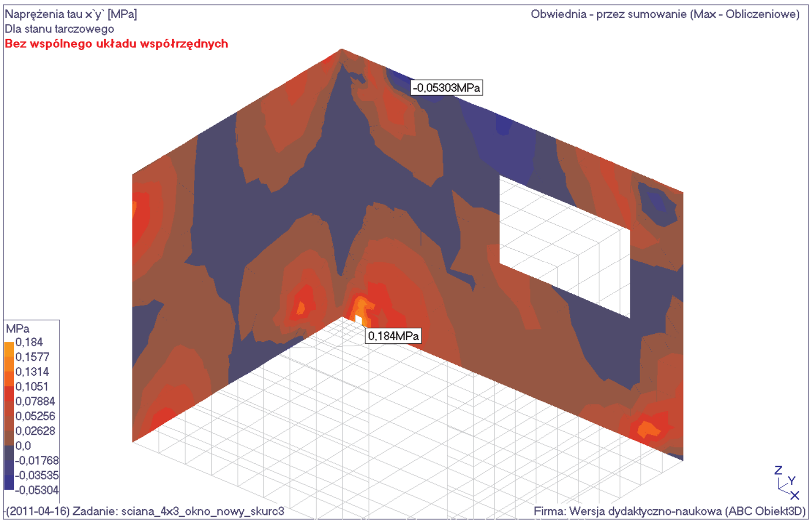


Fig. 8. Shearing stresses in walls corners: a) model I, b) model II

Conducted calculations of the I model demonstrates that at the walls on the length 6.0 and 4.0 m occurring exceed both established cracking criteria. The crack is running through the entire height of the wall. Reducing dimensions of the wall to 4.0 and 3.0 m (the II model) results in reducing tensile and shearing stresses. In the model only local places of possible cracking are observed.

6. CONCLUSION

Conducted calculations showed that cracks in wall corner could take place a little bit earlier than it is given in the literature [1, 2, 3, 4]. Walls with the length above 4.0 m can already be exposed to the crack formations. Cracking is an effect of not only rheological deformations and the temperature, but also results from geometry and the way of walls loading. On the base of conducted analyses the limiting of shrinkage of AAC units before building them in into the wall is significant [9]. Because it is the only type of the load which we can affect. Units should be seasoned, and packing them and sending to the building site directly after leaving the autoclave are inadmissible. It is important so that producers declare the value of the shrinkage of their elements on the basis of conducted cyclically tests. This problem was indicated in the paper [10].

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