EVALUATION OF THE FIRE SEPARATING WALL AFTER THE FIRE
Technical assessment of the loadbearing masonry wall exposed to high temperatures

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Abstract
The paper presents a procedure for an assessment of the technical condition of the loadbearing fire wall made of hollow silicate blocks after the fire. The wall in addition to its fire-separating function was one of two loadbearing walls in the three-story office building, carrying the load from the roof and intermediate floors. The wall was designed as structure satisfying the requirements of REI120 class. During the severe fire the wall fulfilled its task, and its technical fire parameters in reality turned out to be better than projected ones. As a result of the fire which, in spring 2011 completely destroyed the adjacent part of the warehouse building (Fig. 1), and as a result of the two-day intensive fire-fighting, the integrity of the wall was violated. The wall suffered extensive damage, which decreased the strength parameters, and its ability to carry loads.

Keywords: technical assessment, firewall, fire, masonry, silicate, carbonation, sample, test

INTRODUCTION

The building described in the paper was built in 2006 as part of the complex consisting primarily of warehouse and the administrative-office part, which was playing a supporting role to the warehouse facility. The administrative part of the building was designed in shape of the elongated rectangle with dimensions of approximately 7.0 x 174.0 m as a building of three storys above the ground, without a basement, with traditional masonry construction of walls, and with reinforced concrete floors, made mostly of precast hollow panels, (Fig. 1).

Fig. 1 View of the complex during the firefighting (internet source); in the foreground the administrative-office part of the building is seen

The main loadbearing system of the building consists of two longitudinal loadbearing walls made of hollow silicate blocks 6 NFD W+W, grade 15, (Fig. 2) insulated from the outside with polystyrene plates. One of these walls, located on the side of the warehouse, was designed as a typical firewall satisfying the requirements of REI120 class, separating two zones with different purposes.

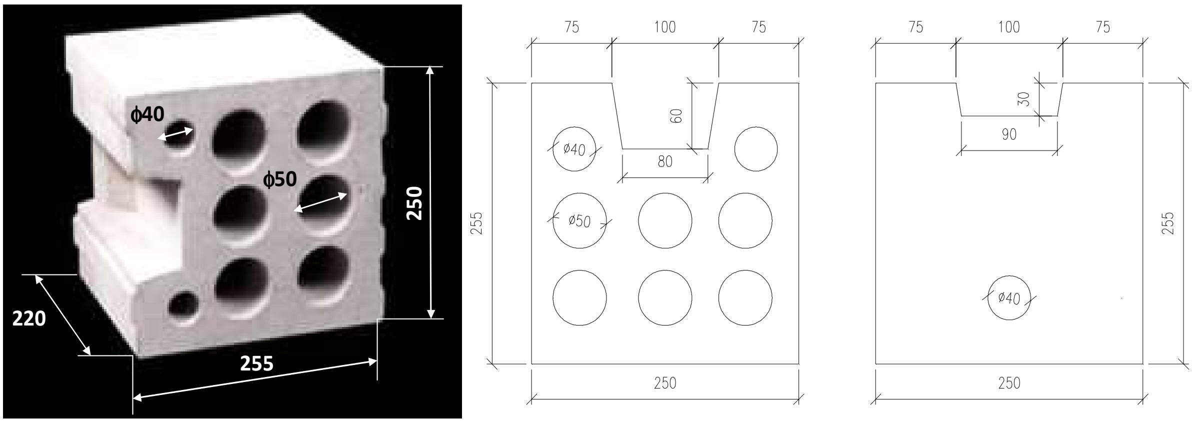

Fig. 2 The shape and nominal dimensions of the silicate block, type 6 NFD W+W

The building was divided on its length by four expansion joints, spaced about 30 m. The aforementioned warehouse burned down in a fire, which broke out in the building on May 10, 2011, (Fig. 1). The rescue action lasted uninterrupted for more than two days. Due to the presence of fire separation wall located between two parts of the building and smoothly conducted firefighting, flames did not spread to an office premises, but the construction of the wall - in a result of the simultaneous action of high temperatures and coolant - suffered quite extensive damage, which decreased the strength parameters and its ability to carry loads.

1 DESCRIPTON OF THE WALL'S DAMAGES

On a large wall area it has been observed a violation of its structure through the crack spreading along the designated location of hollow channels in the silicate blocks, (Fig. 3). Some parts of the wall have suffered mechanical damage, most likely as a result of being hit by the falling roof structure elements. Relatively large lateral displacements of individual silicate blocks observed on site reinforced this assessment, (Fig. 3).

Quite similar picture of damage, but occurring in the middle of the floor, could be seen on the fragments of the wall, located near the middle of the distance between expansion joints. Here, however, the deformation of the wall was more uniform in nature and tended to indicate wall buckling out of its plane – rather than other reasons - as a result of inability to compensate for the thermal elongation strains due to too long distance between the expansion joints. Deformation of the wall that was measured on the height of a single story reached about 20 mm whilst the standard deviation limits allowed for thick walls (> 24 cm) should not exceed 6 mm. The deformations that occurred as a result of thermal effects were so significant that existing compensation joints were not able to compensate for them, leading to pressing interaction between the two wall portions, located on opposite sides of the joint. To be more strict, with temperature increase of 400°C, the wall 30 m long and made of silicate blocks is able to increase its length of about 12 cm, which confirms the observations made on site, during inspection, (Fig. 3).

In addition, as a result of high temperature exposure of the floor ring beams, there was a concrete spalling observed, not only within the concrete cover, but also in the deeper layers. Due to the explosive nature of the phenomenon of spalling, on certain passages also some silicate wall blocks were significantly damaged, especially those ones located in the immediate vicinity of the ring beam. In many places, the wall material losses reach about 50% of the wall thickness, (Fig. 3). There could be also found some wall sections in which, for various reasons, the wall thickness defects reached even 75-80% of its original thickness. Not only spalling itself but also the concrete color change indicated during the inspection proved the change of the internal structure and mechanical properties of concrete paste. Some secondary damage within the wall material was caused by the firefighting itself, causing dampness of walls, destruction of internal gypsum plasters, lime efflorescence and mold beginnings.

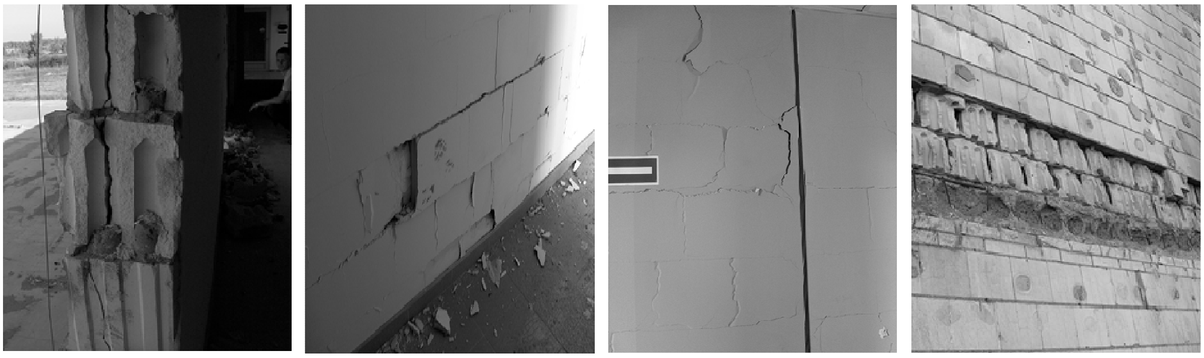

Fig. 3 Examples of the structural damage to the wall

2 LABORATORY TESTS ON SAMPLES OF THE WALL MATERIALS

2.1 Tests on silicate wall blocks

During sampling, it was found out that due to the significant degree of cracking only just below 20-30% of items were suitable to be used as a material for carrying out further research. Totally five selected silicate blocks were collected. Despite the pre-selection in the wall on site, only three out of five blocks collected were qualified to the strength tests. The degree of cracking of two elements prevented unambiguous determination of their mechanical properties, and there were no further testing done on those components.
The nominal strength of silicate blocks obtained during tests reached, respectively, (PN-EN 771-2:2006 and PN-EN 772-1:2011):

- for test sample No. 1: 12.33 N/mm^2
- for test sample No. 2: 8.16 N/mm^2
- for test sample No. 3: 13.03 N/mm^2
- average value: **11.18 N/mm^2**

The compressive strength can be recalculated for the purposes of computing to the normalized strength, f_b. The normalized strength for tested samples, following the available conversion procedures, has achieved the following values, (PN-EN 772-1:2011):

- for test sample No. 1: 11.04 N/mm^2
- for test sample No. 2: 7.32 N/mm^2
- for test sample No. 3: 11.68 N/mm^2
- average value: **10.01 N/mm^2**

The tested blocks were certified for the declared strength of class 15, which meant that the average normalized compressive strength should not be less than 15.0 N/mm^2. This condition in case of tested samples was not met. Silicate masonry elements examined could be classified at most to class 10. It should be pointed out, that in case when the manufacturer declares an average compressive strength or class, the individual values of normalized compressive strength within the sample should not be less than 80% of the declared value (in this case 80% x 15.0 N/mm^2 = 12.0 N/mm^2), which was not met in any case of the samples in question. It should be also noted, that the results for the sample marked No. 2 stands out quite significantly from the values obtained for sample No. 1 and No. 3 If the results of these studies were the nature of the statistical surveys, the results should be formally discarded and not included when calculating the average value. Due to the small sample size, the result obtained for the test item No. 2 is a valuable source of information on differentiation of the strength parameters of the various elements, depending on the individual level of damage of each of them.
On the basis of the tests results it can be said that the silicate masonry blocks did not meet the requirements assumed in the design project of class 15. At most, in the present state they can

be classified as class 10. Such a value of the normalized compressive strength was adopted in the calculations carried out in the next step to check the capacity of the wall damaged by fire.

2.2 Tests on drilled concrete cores

In addition some test were also carried out on four drilled concrete cores with a nominal diameter of 95 mm and a depth of about 300 mm each, taken from the ring beam surrounding the floor above the ground floor, just to verify its strength parameters. Average compressive strength of the inner layer of the ring beam achieved the level of 36.10 N/mm^2, while the same parameter assessed for the surface layer reached only the value of 21.91 N/mm^2, which is about of 40% lower. Based on the test results and the code procedures the characteristic value of compressive strength of the concrete built into the structure was specified, which in the analyzed case was equal, respectively to:

- for inner layer: 29.10 N/mm^2
- for surface layer: 14.91 N/mm^2

According to PN-EN 13791:2008 testing of the drilled concrete cores of length equal to the nominal diameter yields a value corresponding to the characteristic strength $f_{ck,is,cube}$ for the cubic standardized sample. Based on the results and according to PN-EN 13791:2008 the concrete samples satisfy the following classes of concrete compressive strength developed according to PN-EN 206-1:2003:

- for inner layer: C25/30 ($f_{ck,is,cube}$ < 31 N/mm^2)
- for surface layer: C12/15 ($f_{ck,is,cube}$ < 17 N/mm^2)

Fig. 4 Discoloration depth corresponding to the depth of destruction of the drilled concrete cores

As can be seen from the above given analyzes the concrete surface layer has been destroyed in a result of high temperatures exposure and sudden cooling down, and its strength was significantly reduced by 3 classes.

Sample # 1 Sample # 2 Sample # 3A Sample # 4A

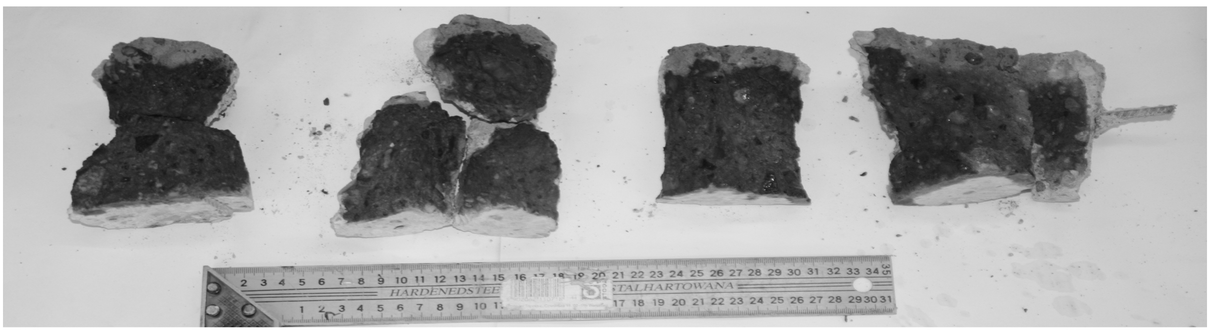

Fig. 5 Depth of carbonation in drilled core breakthroughs

Since, during sampling, some clear discolorations of subsurface of cores were observed and in addition to strength testing also some detailed visual analysis of the four samples were carried out, (Fig. 4). It was supposed that the visible discoloration was the most likely caused by the damage of concrete internal structure. To accurately determine the depth of discoloration, samples were evenly moistened, and then after 3 minutes the destruction range was marked with the marker. Discoloration depth corresponding to the depth of destruction reached from 1.5 up to 5 cm. After the cores destruction an additional test of concrete carbonation depth of breakthroughs were done. The depth of carbonation ranged from 1.5 to 2.5 cm. In addition, it was found that the extent of carbonation range in sample No. 1 has already reached more than a size of concrete cover of stirrups, which may cause rapid corrosion of reinforcing steel, deprived of protective covering layer, (Fig. 5).

3 ANALYTICAL EVALUATION OF THE LOADBEARING CAPABILITIES

3.1 Assumptions for the calculations

Wall loadbearing calculation analyzes were carried out for two design situations:

- for the wall in perfect technical condition (as initially designed) and
- for the real wall in the weakened condition reflecting the destruction after the fire.

Calculations performed in perfect technical conditions, assumed the initial characteristics of the wall material and strength parameters of the idealized structure, were carried out totally consistently with the original design documentation. In the second design situation, the reduced strength values of the silicate blocks, based on the results obtained from the real compression tests of the wall elements, were adopted. Additionally, due to the numerous vertical cracks parallel to the wall surface, for the calculation model it was assumed, that the wall is made with longitudinal mortal seam, which allows for the inclusion in the procedure of computing the potential danger of delamination of the wall through its thickness. Furthermore, for each of the variants, the calculations were performed twice - including the articulated (simple) model of wall in which the wall is modeled as the separate bar, pivotally supported by a horizontal slabs or alternatively - a model of a continuous wall.
Having regard to the current state of the building and its exclusion from the use after the fire, all the calculations (due to legal expectations) were carried out in accordance with the actual state of standardization, (Eurocode 6, 2010). In addition, after the declaration of conformity it was adopted that the wall blocks correspond to the parameters established for the Group 1 (for which the capacity of all openings shall not exceed 25% of the gross volume) and Category I of masonry elements. Additionally, a category B of the masonry works execution standard was assumed, which affects the size of the partial safety factors to be adopted in the calculation of the wall.
Calculations were carried out assuming the vertical wall straightness, without taking into consideration any deviations or eccentricities measured during an on-site inspection. Their influence, in fact, increases the level of capacity utilization of the wall in relation to the values obtained from the calculations, and presented in the further part of this study.

3.2 Results of calculations for the assumption of perfect technical condition

After the calculations, the following results reflecting the capacity utilization level of the fire separating wall were achieved:

- for a simple model, pivotally supported by slabs; wall considered as the inner structure (without the wind load): 50.8 %,
- for a simple model, pivotally supported by slabs; wall considered as the external structure (with the wind load applied): 59 %,
- for the continuous model of the wall, considered as the inner structure (without the wind load): 118.5%,

- for the continuous model of the wall, considered as the external structure (with the wind load applied): 135.6%.

3.3 Results of calculations reflecting the real weakened condition of the wall, after a fire

After the calculations the following results reflecting the capacity utilization level of the fire separating wall were achieved:

- for a simple model, pivotally supported by slabs; wall considered as the external structure (with the wind load applied): 98 %,
- for a continuous model of the wall, considered as the external structure (with the wind load applied): 162%.

4 SUMMARY AND FINAL CONCLUSION

Based on the conducted analyzes the following summarizing conclusions can be formulated:

- the capacity utilization rate of the wall evaluated taking into account the damage caused by the fire and the reduced value of a standard compression strength of the wall material exceeded by 62% the maximum acceptable values in terms of design standards and could not be considered safe,
- through the degradation of the concrete ring beams and the decrease of the mechanical properties of reinforcing steel bars, some basic principles of legal certainty and predictability of the behavior of the structure have been violated, in particular:
  - the stability of structural elements (walls and floors),
  - the expected level of reliability,
  - performance and load-carrying mutual cooperation between the structural elements,
- there was a concern that the ring beams, whose job was to ensure the overall compactness of the object, and - if necessary - recreation of the secondary supporting structure of the building in the event of local damage (e.g. collapse of the wall underneath the ring beam), may not satisfy its role,
- the wall that suffered the poor technical condition after the fire, because of the number of defects and leaks, no longer could serve as a reliable fire separating partition.

On the way of expert activities a few different variants of the wall and office building restoration were considered. Due to the nature of the building construction and the unsatisfactory condition of the wall, the majority of the proposals to extend the life of the object have been dismissed as technologically difficult or unjustified because of economic reasons. Finally, the building inspection authorities decided to pull down the entire building.

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