Possibilities of evaluation of the masonry wall affected by the explosion

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Abstract At present, emphasis is placed on the safety and durability of building structures due to the effects of external loads. Among the various external influences of the load, we can also include loads caused by the blast wave. Structures subjected to extreme loads such as explosion are structurally disrupted in a manner different from that of static or dynamic external loads. In construction practice, we are sometimes faced with the question of how to evaluate the state of a structure after an explosion. The article is focused on the possibility of evaluating the masonry wall affected by the explosion in terms of the expression of residual bearing capacity based on the laboratory tests and inspection in-situ.

1. Introduction
The subject of the assessment is the identification of the extent of the damage with the aim of determining the residual bearing capacity of the masonry wall after exposure to a nearby explosion. The vertical wall masonry structure is made of ten layers of POROTHERM 44 P + D P10 ceramic building materials. There is a masonry mortar MVC 910 of strength class M10. Wall width 2310 mm, height 2470 mm, thickness 440 mm. Layers of masonry mortar in loading joints of approx. 10 mm thickness. The overall condition at the start of the diagnostic work is documented in Figure 1. The test masonry wall was built and tested by a Military Research Institute and subsequently removed to Brno University of Technology.

2. Scope of diagnostic and selected methods
The evaluated structural unit was gradually disassembled manually from the top layer of the masonry (on the layer designation Layer 1) to the last (foundation) layer. The diagnostic itself was performed by a proven combination of testing methods. They are:

- visual inspection,
- manual disassembly of the structure,
- sampling,
- laboratory testing.
2.1. Visual inspection
The construction is made of ten layers of POROTHERM 44 P + D P10 ceramic building materials. There is a masonry mortar MVC 910 of strength class M10. Wall width 2310 mm, height 2470 mm, thickness 440 mm. Layers of masonry mortar in loading joints of approx. 10 mm thickness [1].

The outer wall portions in contact with the circumferential metal stabilizing frame (layer 1 and 10, vertical edge lines) are heavily damaged by shear and pressure cracks in the inner structure of the billets. The blocks of the blocks are broken by cracks always over the entire height of the building material. These lines are loosely hand-disassembled after mechanical removal of the leveling layers of the mortar to the joints with the metal stabilizing frame. The nature of the damage is related to the bulging of the wall away from the effect of the explosion. The horizontal deformation of the rear wall surface reaches up to 30 mm in the extreme. The face of the wall is damaged by the separation of the ceramic shards of the side peripheral walls of the built-in vertical perforated blocks [2].

2.2. Manual disassembly of the structure
In general it can be stated that the internal defects of the walls (ribs) of the built-in luminaires and the masonry mortar in the joints are so extensive that the construction itself could be dismantled manually.

Sub-findings are listed and commented on the following images.

Figure 1. General view of brick wall element damaged by explosion effects (front and back view).
Figure 2. Loosely removable fragments of built-in lumber from layer 1. Pieces of lumps in contact lines with the stabilizing perimeter frame are damaged throughout the wall thickness.

Figure 3. Detail of damage to the internal structure of the ceramic blocks by manually disassembling layer 1.

Figure 4. Detail of the loading joint above layer 5 (overall view of FOTO 8). Total weakening of the wall thickness in the middle part from the original wall width 440 mm to the value of approx. 315 mm (ie 30% weakening).

Figure 5. Detail of the internal damage of the built-in pieces of the lower masonry layer during manual disassembly (Layer 10).

Figure 6. Detail of the internal damage of the built-in piece of building materials with stress at the "front" part of the wall section due to arched bulging in the direction of the "rear" face. In the layers at the "back cheek" a slight opening of the joints opens.

Figure 7. Detail of shear damage of built-in blocks in line with stabilizing frame. Furthermore, the damage to the masonry mortar in the bed joint - massive cracks in the contact joints of the building materials.
2.3. Sampling

Fragments, built-in vertical perforated blocks with varying degrees of damage can be removed from the inner wall area (layers 2 to 9) by manually disassembling the wall (light blue contour highlighted in the figure). A total of 12 pieces of built-in construction materials marked V1 to V12 were taken from this area. The collected samples were adapted to be transported to laboratories to diamond circular saws by finishing the lateral damaged wall on regular shaped bodies which are suitable for carrying out laboratory tests.

Figure 8. Schematic diagram of taken samples of bricks.

Figure 9. Brick wall after manual disassembly.

The real weakening of the wall thickness from the effects of the explosion is very different on the individual collected building materials. It is a percentage of the total weakening of the original width of 440 mm by 30% to 80%. Some lump construction materials fell apart spontaneously (especially in the case of line joints with the wall stabilization frame), figure 7.

2.4. Laboratory testing

From the inner wall area (layers 2 to 9), fragments of built-in vertical perforated blocks with varying degrees of damage were removable by hand dismantling the wall. A total of 12 pieces of built-in construction materials marked V1 to V12 were taken from this area. The collected samples were transported to the diamond circular saw after transport to the laboratory by finishing the lateral damaged wall on the bodies of regular shapes. Tensile strength tests according to ČSN EN 772-1 + A1 [5] were carried out on the modified test samples.

A total of five “reference” samples were delivered to the laboratory - POROTHERM 44 P + D ceramic blocks, which were not incorporated into the test wall. After taking over to the laboratories, the samples were labeled REF1 to REF 5. Tensile strength tests according to ČSN EN 772-1 + A1 [5] were performed on the supplied samples.

3. Results of the laboratory tests

The aim of the laboratory tests was to assess the impact of the damage of the removed blocks from the masonry of the test wall compared to the reference samples in the aspect of the effect on the final compressive strength of the evaluated piece building materials [4], [5]. The test results are summarized in the following Table 1 and Table 2.
Table 1. Results and evaluation of POROTHERM 44 P + D, reference samples.

| Sample marking | Critical force [kN] | Compressive area [mm$^2$] | Compressive strength [N/mm$^2$] | Individual | Average value (coeff. of variation [%]) |
|----------------|---------------------|-----------------------------|---------------------------------|------------|----------------------------------------|
| REF_1          | 1260                | 107568                      | 11.7                            |            |                                        |
| REF_2          | 1185                | 106085                      | 11.2                            |            |                                        |
| REF_3          | 985                 | 92250                       | 10.7                            |            |                                        |
| REF_4          | 990                 | 95160                       | 10.4                            |            |                                        |
| REF_5          | 980                 | 93480                       | 10.5                            |            |                                        |

Table 2. Results and evaluation of POROTHERM 44 P + D blocks, collected fragments.

| Sample marking | Critical force [kN] | Compressive area [mm$^2$] | Compressive strength [N/mm$^2$] | Individual | Average value (coeff. of variation [%]) |
|----------------|---------------------|-----------------------------|---------------------------------|------------|----------------------------------------|
| V_2            | 265                 | 40425                       | 6.6                             |            |                                        |
| V_3            | 545                 | 79380                       | 6.9                             |            |                                        |
| V_4            | 345                 | 64660                       | 5.3                             |            |                                        |
| V_5            | 460                 | 65636                       | 7.0                             |            |                                        |
| V_6            | 380                 | 64904                       | 5.9                             |            |                                        |
| V_7            | 575                 | 71050                       | 8.1                             |            |                                        |
| V_8            | 505                 | 61250                       | 8.2                             |            |                                        |
| V_9            | 275                 | 54145                       | 5.1                             |            |                                        |
| V_10           | 520                 | 59048                       | 8.8                             |            |                                        |
| V_11           | 245                 | 57096                       | 4.3                             |            |                                        |
| V_12           | 405                 | 70110                       | 5.8                             |            |                                        |

4. Evaluation of the survey and recommendations

If the test wall is loaded and modeled the structural design of the masonry vertical structure, then the loaded structure would collapse after the explosion effects.

The built-in model (for example, perimeter walls in the structural support structure) has demonstrated the ability to significantly deform the structural member without overall structural collapse. The effects of the explosion were extensive surface damage by separating the fragments of the side walls of the built-in lumps. The extent of total damage (including the internal structure) and the massive sagging of the compressive strength prove that the real construction would be irreparable in terms of mechanical resistance requirements. It would be necessary to dismantle it (remove) and build a new built-in structure [3].

The "frontal" surface of the wall (face at the blast) is damaged by the separation of fragments of the ceramic body of the side peripheral walls of the built-in vertical perforated blocks of the exterior face of the structure. The vertical deformation of the "rear" wall surface reaches up to 30 mm in the extreme.
5. Conclusion
In view of the findings of the pathological-defectoscopic analysis, the results of laboratory tests on the collected fragments of lumps of construction materials and the supplied reference samples of the supplied blocks can be stated as follows.

The internal defects of the walls (ribs) of the built-in piece of building materials, the overall strongly uneven weakening of the original cross-section (thickness), the damage and depletion of the bonding strength of the bonding bridge between the mortar and the built-in piece of construction in the loading joints show the exhaustion of the mechanical resistance in the test wall after the effects of the explosion on more than 70%.

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References
[1] Technical data sheets of used POROTHRM 44 P + D P10 and MVC 910 M10 mortar.
[2] ČSN ISO 13822 2014 Principles of Structural Design - Evaluation of Existing Structures
[3] ČSN 73 0038 2014 Evaluation and verification of existing structures - Supplementary provisions
[4] EN 772-16 Test methods for masonry elements - Part 16: Determination of dimensions
[5] ČSN EN 772-1 + A1 Test methods for masonry units - Part 1: Determination of compressive strength.
[6] Ahmad S et al 2013 Mater. de Construcc. 64 313 e007 p11
[7] Doerr A et al 2012 The effect of near, contact and embedded detonations on masonry structures, Proceedings 22nd Internationals\ Symposium.
[8] Eamon C D et al 2004 J of Engin. Mechanics 130 9 pp 1098-1106, doi: 10.1061/(ASCE)0733-9399(2004)130:9(1098).