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Analysis of Historic Brick Walls' Strengthening Methods

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Abstract

Analysis of the behaviour of historical brick walls is difficult and complicated. However, computer calculations are being increasingly used in the evaluation of cultural heritage buildings and some of their elements. The aim of this paper is to analyze the historic brick walls reinforcement. Different methods of strengthening are compared and discussed. Numerical analysis, based on finite element method, was conducted on the assumption of three methods of wall strengthening: using the steel element (I-beam), overall relaying and partial relaying the wall with new bricks. Analysis of the wall without any intervention was made for comparison. Characteristics of strengthening of historical brick walls are described in the paper. The information should allow for a better understanding of the behaviour of brick wall in this research.

Calculations were performed in Abaqus software, for the garrison arrest's prison yard at Bohaterów Monte Cassino Street in Olsztyn in Poland. In this object, prison's yard will be covered with the glazed roofing, resting on the perimeter walls. This is the reason why load transmitted to the wall is increased and why strengthening is needed. Survey allows to calculate displacements and the results are used to select the most appropriate methods of strengthening brick wall in this object. A comparison analysis has been performed and possible directions for further research in this field have been indicated.

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Keywords:numerical analysis, FEM, historical buildings, brick wall strengthening.

1. Introduction

The renovation and adaptation of historic buildings for obtaining a new utilitarian functions are an interdisciplinary undertaking requiring cooperation and involvement all of the investment process participants. Restoration of former

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splendor to these unique buildings often necessitates striking a balance between protection of the structure original substance and the utilitarian needs of future users.

Among numerous valuable monuments of Olsztyn, the building of former garrison arrest situated at 3, Bohaterów Monte Cassino Street, may be mentioned. On basis of the adaptation project from 2015 it is converted into office and exhibition facilities. According to the assumed concepts the space of the prison's yard will be covered with the glazed roofing resting on the perimeter walls. Therefore, the implementation of the wall strengthening, which will withstand the load of the mentioned roofing, will be necessary. The choice of strengthening method which will enable the increase of the bearing capacity of the brick wall and at the same time will reduce the interference into the historic substance of the structure, requires an individual approach to the problem and discerning analysis of suggested solutions.

2. Description of the garrison arrest

At the end of nineteenth century Olsztyn was the most significant military center in East Prussia. As first, within the city boundaries, "*baroque barracks*" were formed with seat on the present Grunwaldzka Street and in subsequent years the garrison was continually extended on new military units including "*infantry barracks*" on the present Artyleryjska Street [1]. Between years 1899 and 1900 on the north-east side of this historic military complex the building of the garrison arrest had been erected (Fig. 1a). The longitudinal axis of the three-storey building with partial basement beneath, was laid in an east-west direction. With a monumental neo-gothic style, it clearly refers to fortified architecture.

a) b)

Fig. 1. Building of the garrison arrest: (a) from the south, (b) from the north with the perimeter wall encircling the prison yard.

For over 100 years the building served as the military arrest as a part of Military Property Agency estate with the Military Court in its western and prison-cells in its eastern part. Owing to this, the ranges of changes to its historic substance was inconsiderable whereas the degree of conservation of the original elements including furnishing, is relatively large. In year 2013 the property became the possession of new owners who decided to return it to its past greatness.

The northern side of the building was extended on prison yard (Fig. 1a) that was built on the trapezium plan with a shorter base - east wall. Fencing spans with buttresses regularly deployed along the whole length of the walls (the axial distance is 265 cm), were made of face bricks and are 445 cm high. The perimeter walls were built in two stages and their original height may be seen due to considerably stronger soiling and surface coating of the older part of the brick wall by lichens [2]. Fencing encircling the courtyard were put on a 40 cm high foundation made of filed stones, bricks and concrete in depth from 0,90 m to 1,80 m below the ground level [3].

3. Adaptation of the prison yard for exhibition purposes

The functional-utilitarian program required creating an office and exhibition area that were adequately located in

the main part of the building and in the space of former prison yard.

a) b)

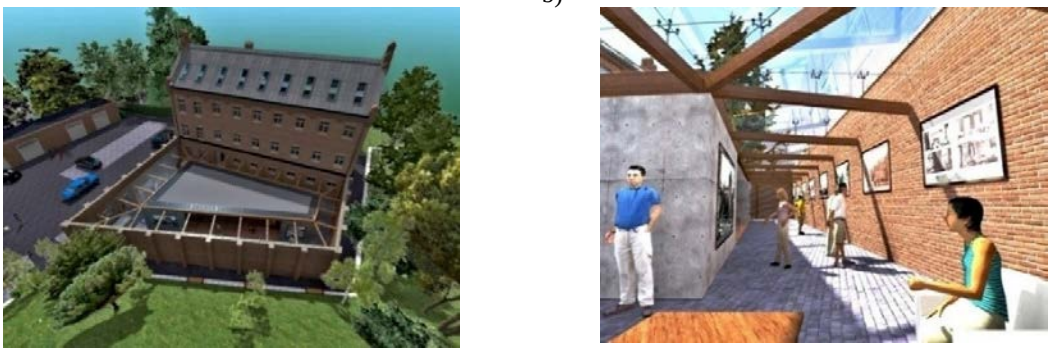

Fig. 2. Visualization of: (a) projected roofing; (b) courtyard arrangement for the exhibition purposes.

However, the main difficulty of the design process was finding the way to reconcile modernity with the historic value of the building. In order to create an attractive, multifunctional space for organization of exhibitions, lectures, training courses etc. (Fig. 2b), authors rested the glazed roofing on the perimeter walls of the courtyard and north facade of the building. It was possible due to four glazed roof surfaces with a slope in the direction of centrally located concrete flat roof (Fig. 2a). Thus, the historic character of the garrison arrest will be preserved as any element of the projected roofing will not project beyond edge of the perimeter wall and consequently it will be invisible from the ground level and [4].

4. Strengthening of the historic buildings brick walls

Damages to historic brick walls are often result of their long-term exploitation and are mainly caused by the aging of building materials. Another reason may be also incorrect exploitation of the structure. The influence of external factors such as: additional load, change in use, change in subsurface and groundwater conditions, settlement, often lead to damages as cracks, failure and deformations such as rotation or deflection [5].

Prevention of historic buildings degradation combined with its functional modifications requires changes to the original structure, which determine the necessity of applying an appropriate methodology to the proceedings that will improve bearing capacity and aesthetics of strengthened structures. The most familiar strengthening methods are: partial and overall re-laying of the wall, steel tie-beams, low- or high-pressure injection, strengthening steel bars stacked into the wall's joints or strengthening by the use of steel and concrete elements. The most commonly used method is re-laying of damaged part of the wall i.e. demolition and re-construction of a wall part by the use of similar building materials (Fig. 3a).

The utilitarian changes may result in the load increase that historic walls cannot withstand. Then steel or reinforced concrete elements (Fig. 3b) shall apply to strengthen the brick wall. Additional stiffening, in case of strongly loaded walls, is achieved by the use of compressing steel tie-beams application of which do not require huge financing outlays and interference into historic substance of the structure. Another popular method used to repair cracks in the wall is low- or high-pressure injection (Fig. 3c). It helps not only to increase the bearing capacity of the strengthened element but also provides protection from dampness and aggressive fumes [6].

Unlike newly built structure, the static work of the strengthened historic monument depends on many phenomena. In such a case, the verification of three limit states: serviceability limit state, ultimate limit state and limit state for the connection between strengthening and strengthened elements, is required [7].

One of the most significant undertakings in the area of historic conservation are undoubtedly renovation and strengthening works of historic properties as they allow to adapt buildings to a new utilitarian function, improve their historic value and develop resistance to degradation processes.

5. Numerical analysis

Not all of the currently available design guidelines of the brick wall were known in the past. In many cases the construction of buildings was based on former builders' knowledge, experience and intuition. Therefore, the structure of many historical buildings are often not adequatelydurable and require strengthening.

a) b) c)

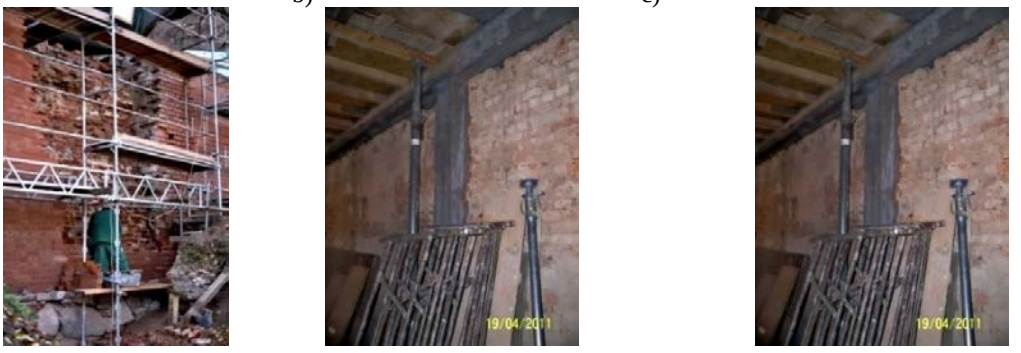

Fig. 3. Strengthening of the wall by the use of: (a) partial re-laying in the Warmia Chapter's Castle; (b) reinforced concrete frame in the building at 6, Staromiejska Street in Olsztyn; (c) low-pressure injection in the buiding at 3e, Artyleryjska Street in Olsztyn.

The aim of this paper is conducting a numerical analysis of the historical brick wall on which glazed flat roof will be supported (Fig. 4). The comparative analysis of three strengthening methods: wall reinforced with steel I-beams (Fig. 5c), overall re-lying with new brick using cement-lime mortar (Fig. 5a) and partial re-lying (Fig. 5b). For comparison a numerical analysis of the wall without any interference, were carried out.

a) b)

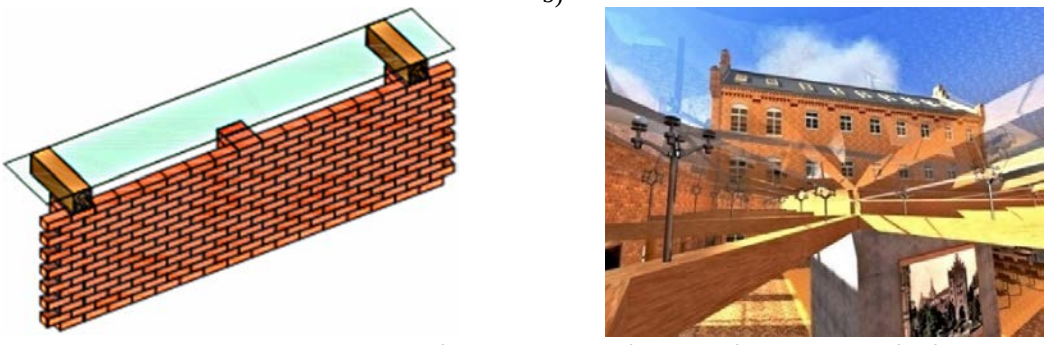

Fig. 4. Perimeter wall encircling the courtyard: (a) model of supporting glazed roof, (b) detail of placing glazed roof surfaces on the wooden beams.

The numerical analysis of historical wall was performed in Abaqus software. Model of the wall was prepared on the basisof design documentation [4]. Numerical analysis, based the finite element method, was conducted for four wall models. Calculations were performed for the part of the perimeter wall which consists of four spans. Since the spans along the entire wall have different length, to calculations the worst case was selected. The most disadvantageous situation is in the northern part of the wall where the length of each span is 2.65 m. The 4.45 m high wall was charged by projected load on every second pillar. Cross-sectional dimensions of the pillarwere equal to 0.39 x 0.39 m^2. The wall was modelled by the use of solid elements with 6 degrees of freedom at each node (3 translations and 3 rotations). The mesh of the FE model has been created with quadrangle prisms. The number of nodes is equal to 8843and number of elements is as large as 5982.

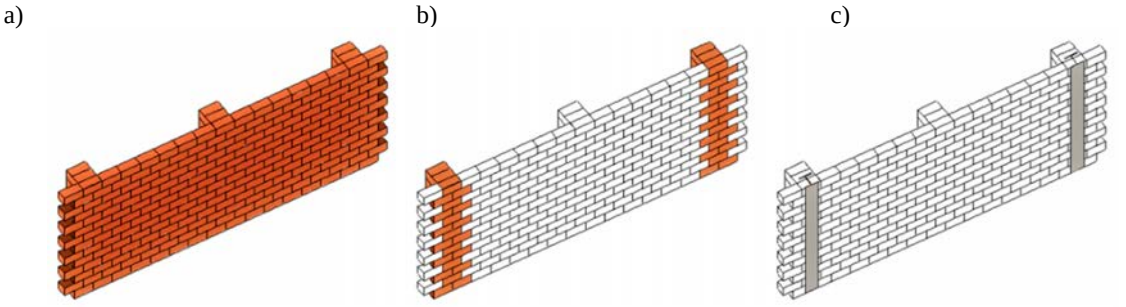

Fig. 5. Strengthening of the brick walls:(a) use of steel I-beams, (b) overall re-laying, (c) partial re-laying.

Numerical analysis was performed in order to collect information about deformation of brick wall with different types of strengthening. Displacement map, summarized in Fig. 6 a) - d) shows, respectively: model without strengthening, model strengthened with I-beams located inside pillars, wall overall and partial re-laying. Wall, without any strengthening, was showed displacement of around 2 cm. The best possible result was achieved for the strengthening by the use of I-beams with displacement reduced to 1 mm. For overall re-laying the value of displacement amounts to 3 mm, while the partial re-lying gave the effect of 6 mm. The historical value should be taken into account, when strengthening of historic buildings are design. The best solution in this case is the implementation of I-beams, because historical value of masonry preserves with a great extent (almost the entire wall will be saved in their original form).

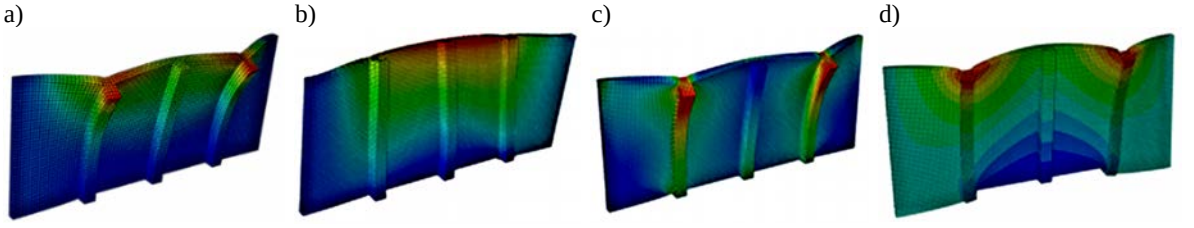

Fig. 6. Numerical analysis assuming different methods of strengthening:(a) without strengthening, (b) use of steel I-beams, (c) overall re-laying, (d) partial re-laying.

6. Conclusions

Work by the strengthening of historic buildings is one of the most difficult fields in monuments protection. Interference in the structure of the historic building is connected with the implementation of a wide range of preliminary work in order to select the appropriate method. Design, diagnostic and inventory work can be included to this group. The example of perimeter wall of former garrison arrest in Olsztyn has shown as wide experience and knowledge about work by historical buildings is required. There is not one method that is appropriate for all objects. For each of them an individual approach is needed. Choice of brick wall strengthening method depends on the considered case and could not be generalized nor established as a uniform procedure. Numerical method is usually complicated, but often it is necessary to plan work in such buildings. Numerical analysis, based on the finite element method, seem to be a powerful tool to complete a thorough analysis.

Problems discussed in this paper is intended to indicate the future direction of research in the field of analysis of the historic brick walls. The presented methods could be a good way to understand the basics of strengthening of historical masonry.

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