Analysis of retaining wall stability in areas specified in register of objects of cultural heritage

Ryszard Chmielewski[*]

Faculty of Civil Engineering and Geodesy, Military University of Technology, Warsaw, Poland

Abstract. The case study of the assurance of retaining wall stability in densely urbanized conservation and cultural heritage areas are described in this paper. During The Second World War many of these historic buildings in Warsaw were completely or partially destroyed and until these days their remains constitute elements of the existing building development of the capital of Poland. This may be connected with a change in the nature of applied loads as well as current functions of these buildings. The results of expert opinions and investigations are presented, regarding the operational and technical state of two retaining walls submitted to an expert before the repair works. When designing the design concept, both the historic character of structures, the technical feasibility of performing construction works in the densely urbanized area, as well as determined water and ground conditions were considered. The first of the analysed cases concerns the retaining wall localised in the vicinity of the Ordynacka Street and the Tamka street. After analysing the historical aerial photographs, it was found that the retaining wall constitutes an underground part of the apartment house destroyed during the warfare. The second case study refers to Warsaw Old Town – the retaining wall ensuring the stability of the Vistula escarpment along Brzozowa Street in Warsaw.

1 Introduction

The formation of scratches and cracks in masonry load-bearing elements of the construction is one of the main challenge of operation and maintenance of historic building structures [1,2]. Damage to brick retaining walls generally arises as a result of the lack of effective foundation waterproofing and natural aging of built-in materials [3]. The methodology for determining the type and the scope of renovation works necessary to ensure the safety of the load-carrying structure for two selected retaining walls are presented in this paper. Moreover the aspect of ensuring the safety of use and operation of these building objects is included in the study [3,4,5]. The proposed methodology, consistent in both analyzed cases, should include the following steps [6, 7, 8]:

- The analysis of the current technical state of retaining walls structure,
- The structural and geometric inventory,

[*] Corresponding author: ryszard.chmielewski@wat.edu.pl

- The analysis of the technical conditions, including the surrounding area (vicinity of other buildings and structures), as well as the groundwater and the rainwater impact on designed object,
- The determination of the scope and the technology for protecting and reinforcing the existing retaining wall structure or its reconstruction.

Both analysed cases regard very similar retaining wall constructions, however the design process of their effective repair solution required an individual approach due to different technical conditions and their locations [6].

2 Description of the technical condition of the structure

2.1 Retaining wall at Ordynacka Street

The analysed retaining wall is a masonry structure made of full ceramic brick. The thickness of the wall varies with height and ranges from 50 cm to 100 cm. At the time of site inspection, the age of the retaining wall was about 150 years, which means a wear level of over 70% for this type of construction. As a consequence, its technical condition had to be described as “an emergency” [6].

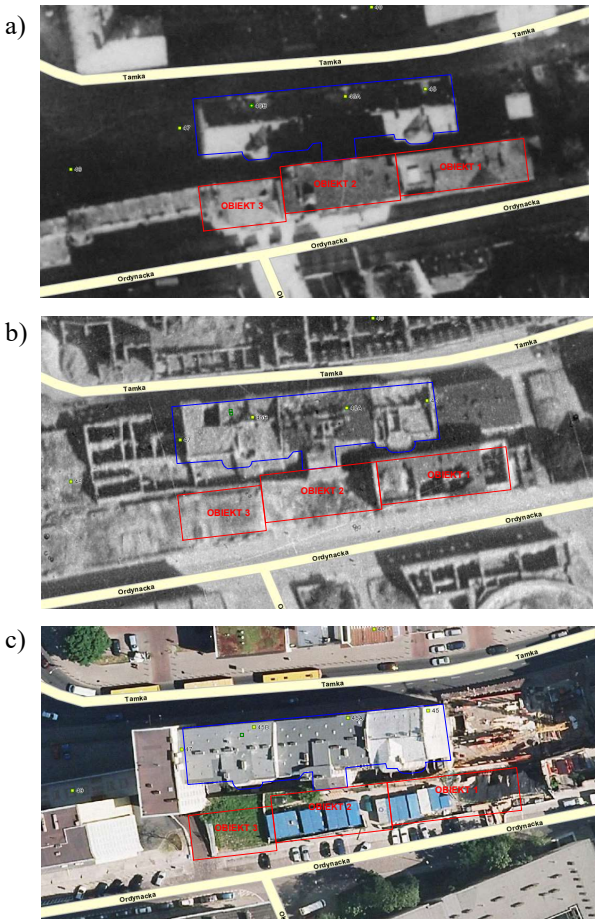

Fig. 1. Land development at the location of the analysed retaining wall: a) aerial photograph from 1935, b) aerial photograph from 1945 c) aerial photograph taken in 2008 [9].

The analysis of archival documentation, the assessment of the technical condition of the wall and inventory measurements allowed to conclude that the analysed object was a part of three tenement houses debris destroyed during The World War II - Fig. 1. The aerial photographs and diagrams show that there were three tenement houses in the area adjacent to the retaining wall – building objects marked with number 1 ÷ 3. Only one house remained in this location in 1945 - object 1. Presently, there are no facilities or buildings in this area. The remains of apartment house marked with No. 1 could be observed during conducting earthworks for the Chopin Centre built in 2009 - Fig. 2.

Fig. 2. The debris of the basement walls of facility No. 1 taken in 2009 during earthworks.

During the WWII The Nazi Germans destroyed almost 80%-90% of the buildings in Warsaw while an immense part of the cultural heritage was deliberately demolished or burned to the ground. Ashes, debris and the remains of buildings, most often in the form of parts of foundations or basements were covered with mixed brick rubble and sand during post-war reconstruction. For this reason, two levels had to be distinguished in the analysis and the technical assessment of that retaining wall. The first of determined levels was aforementioned basements stiffened with walls and filled with mixture of sand and rubble. The second one referred to the classic retaining wall structure with height about 2,0 ÷ 2,5 m. This structural arrangement was also evidenced by the observed deformations of the wall, whose buckling occurred only in the upper part up to the height of 2.0 m - Fig. 3.

Fig. 3. Buckled and secured eastern part of the retaining wall.

The technical condition of the retaining wall should be specified as “an emergency”. Diagnosed and observed damages as well as measured deformations had posed a direct hazard to the safety of use and the safety of the load-bearing structure. In order to protect the damaged wall structure and prevent from further propagation of damages, wooden struts were used. Their basic task was to support the buckled and damaged part of the wall. These struts were left until the total completion of construction works related with refurbishment of the retaining wall. It should be stressed that due to the historic character of the structure, it was necessary to ensure that the retaining wall was reconstructed with the least possible interference in this object.

2.2 Retaining wall at Brzozowa Street

Similarly to the case described above the retaining wall at Brzozowa Street is also the masonry structure made of full ceramic brick. The age of the retaining wall was determined to be about 150 years, which means for this type of construction the degree of technical wear is above 70%. The technical condition was also determined as “an emergency”, which means that the analysed retaining wall was suitable for demolition [6]. The engineering structure is a fragment of the brick wall of the apartment house which was located in the place of the Brzozowa 10 between 19th and 20th centuries - Fig. 4a).

This conclusion resulted from a detailed analysis of archival documentation, assessment of the technical condition of the retaining wall and inventory measurements of the facility. Analysing aerial photographs, which present different stage of land development of this area in years 1891 - 2010 (Fig. 4), it can be concluded that building located at Brzozowa Street No.10 had been rebuilt and separated into two independent buildings. Currently undeveloped area between houses at Brzozowa 6/8 and 10 consisted with one compact tenement house in the past.

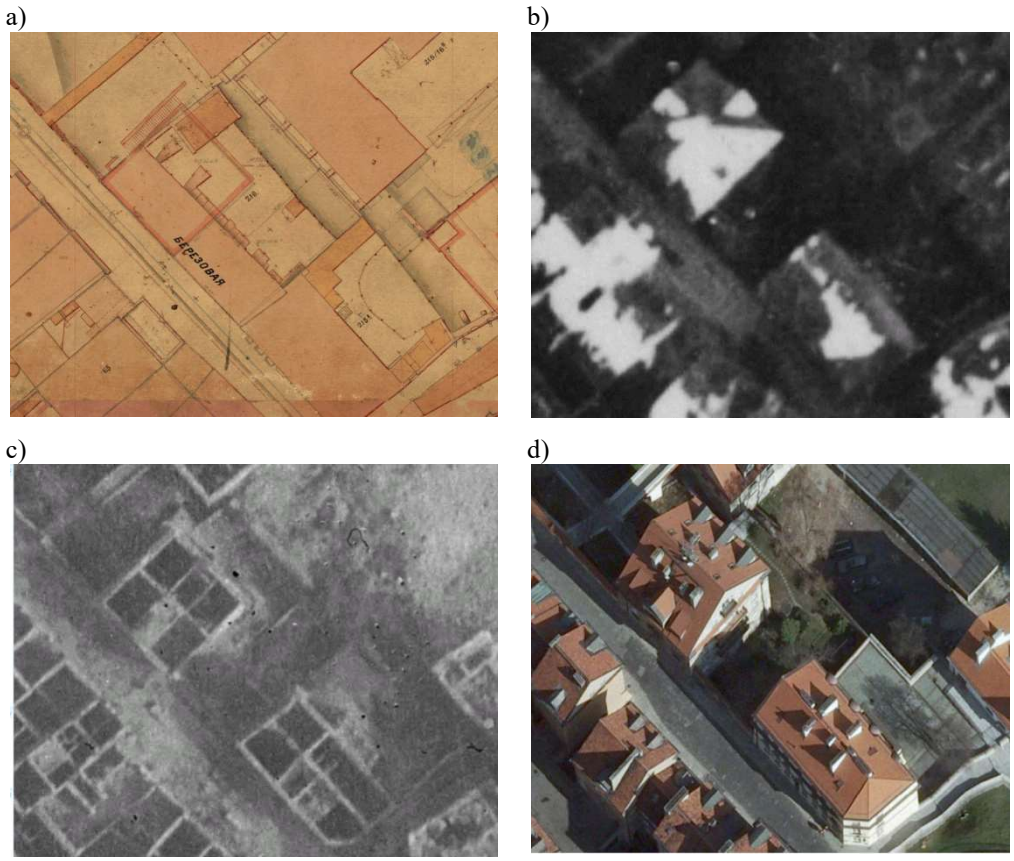

Fig. 4. Building development in the location at Brzozowa St.: a) years 1891-1908, b) year 1935, c) year 1945, d) year 2010 [2].

During the post-war reconstruction of the city, this wall was rebuilt with the use of solid brick and cement-lime mortar. The wall is topped with a fragment of a fence wall with two hemispherical openings and covered with ceramic tiles. The technical condition of the built-in materials was determined as “bad”. Chipped elements of bricks could be seen in the cross-section. Moreover lime mortar was completely corroded and did not ensure binding of bricks - Fig. 5. The poor quality of the construction works for reconstruction of the retaining wall is also evidenced by the clear delamination and bulging of the wall - Fig. 6.

Fig. 5. View of the retaining wall from Brzozowa street.

Fig. 6. Observed delamination and buckling of the wall.

In order to protect the damaged wall structure, it was recommended to make temporary wooden struts, whose task was to support the buckled and damaged part of the wall. These struts were used until the entire wall was renovated.

3 Proposed repair work programme

3.1 Retaining wall at Ordynacka Street

The basic design assumption was to repair the damaged retaining wall in such a way as to leave as much of the historic masonry structure as possible. For this reason, a solution was proposed which aimed on the construction of a new unloading structure in the form of a reinforced concrete retaining wall supported on a pile bent – Fig. 7.

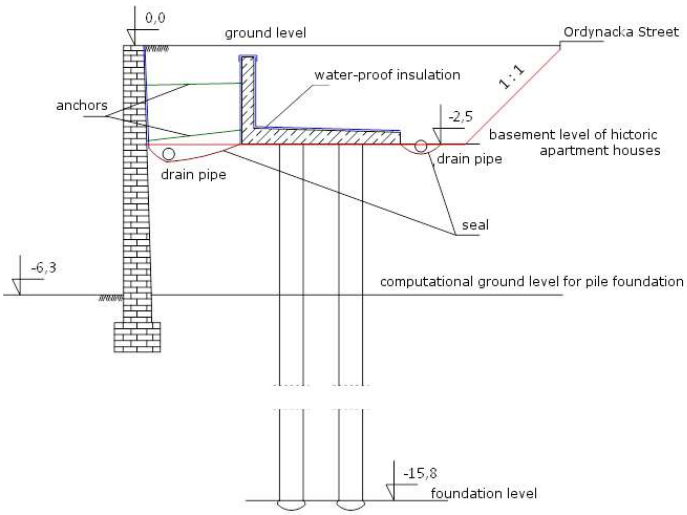

Fig. 7. Design solution for increasing retaining wall stability and reinforcement at Ordyncka St. [6].

The ground conditions were good - there were layers of soil with high load-bearing capacity under the embankment. In order to determine the dimensions of the designed unloading structure, the values of pressure acting on the retaining construction were considered first, taking also into account the surcharge load. The design value of the resultant pressure is calculated using formula:

$$E = \frac{1}{2} e_2 \left(h + h_z\right) = 265{,}25 \ [kN/mb] \tag{1}$$

The position of the resultant pressure was calculated using formula:

$$h_E = \frac{1}{3}\left(h + h_z\right) = 2{,}20 \ [m] \tag{2}$$

As the foundation solution the deep foundation was proposed in the form of piles arranged in two rows spaced every 1,5 m, with the 1,5 m distance between the rows. Hence the spacing of piles was r = 2,12 m. The sketch of the arrangement of the piles is shown in Fig. 8. The stress zones around the piles did not overlap. In this way over two times the load capacity of the foundation framework for vertical load was obtained. With regard to the lateral load capacity of foundation piles, the safety margin was just over 1%.

Fig. 8. The location of a retaining structure and the arrangement of piles in proposed foundation solution. [3].

The proposed repair technology required creating a proper repair programme. In the first step, the soil layer was removed to a depth of ~ 2,5 m in order to reveal the upper surface of the basement rooms. At this stage, demolition of the upper part of the damaged retaining wall was also carried out with soil removal. After making the pile bent and new retaining construction, the wall was restored with its anchoring. New foundation waterproofing in the form of waterproof membrane insulation was performed on a brick retaining wall, as well as on a new reinforced concrete structure. Moreover a new drainage system was carried out.

3.2 Retaining wall at Brzozowa Street

Firstly two test bore-holes under the road surface of Brzozowa Street were made in order to determine the current soil and water conditions. The first of the test holes (No. 1) was located in the corner of the building at 8 Brzozowa Street, adjacent to the wall. The test well was made at the opposite edge of the road due to the existing utilities network. As a result of the examination, under the layer of sand being part and parcel of the building embankment, the presence of organic embankments with skeleton and interbedding from sandy dust to a depth of 4,80 m were found. This soil was defined as anthropogenic aggradate mud in the medium plastic state [3]. Due to its state and the content of organic parts in the calculation of pressure induced by this layer of soil, cohesion values as well as the angle of internal friction should be equal to zero. Under the layer of organic embankment, there is a subsoil in the form of fine, semi-compacted sand with $I_D = 0,50$ (according to standard PN-EN-ISO 14688-2:2006). In the second test hole (No. 2), the soil layers arrangement was analogous, with the thickness of the anthropogenic top-layer of the organic embankment being 7.70 m. Anthropogenic soil found were not suitable for use as a subsoil in the form of a building embankment.

The technical condition of the retaining wall was defined as "emergency". For this reason, temporary support construction was carried out using solid concrete blocks connected with steel struts. Moreover a timber wall supporting structure was performed – Fig. 9.

a) b)

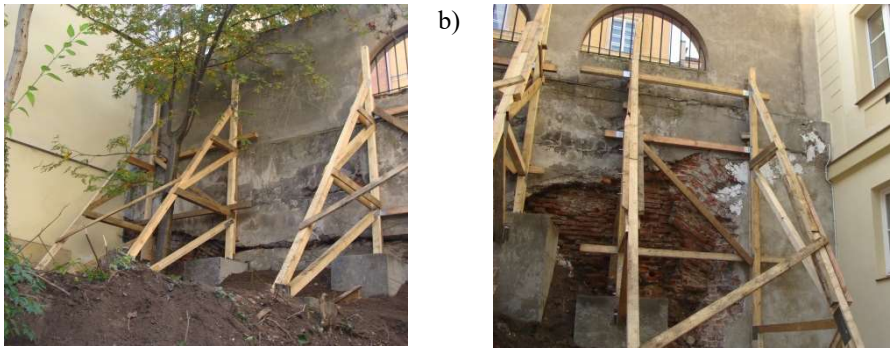

Fig. 9. Temporary construction supporting the retaining wall.

A dense network of underground installations was without any doubt additional difficulty during conducting the repair works. Over thirteen different types of utility installations and urban network services on the width of 7,0 m were identified underneath the adjacent Brzozowa St. Poor technical condition of the retaining wall as well as built-in building materials implied the necessity of immediate proposal a repair technology. In the first stage, the a protective structure in the form of a "Berlin" type wall was designed. The structure had to be anchored in the subsoil - the estimated length of the anchors was at least 20 m. The next step proposed was the removal of the soil between the existing retaining wall and the Berlin wall as well as the gradual demolition of the damaged the retaining wall. Drilled or screwed piles arranged into two rows were proposed - the first row between the Berlin wall and the damaged retaining wall, the second one at a distance of ~ 1,0 m from the face of the damaged retaining wall. The pile bent was topped with a pile cap in the form of a reinforced concrete block ~ 1,0 m thick (the width of the pile was 4,2 m). At the final stage, the dismantled brick retaining wall was reconstructed, water-proof insulation and drainage system was designed, as well as the space between the existing retaining wall and the Berlin was filled with light weight aggregate (eg. expanded clay aggregate). The scheme of the proposed technical solution is shown in Figure 10.

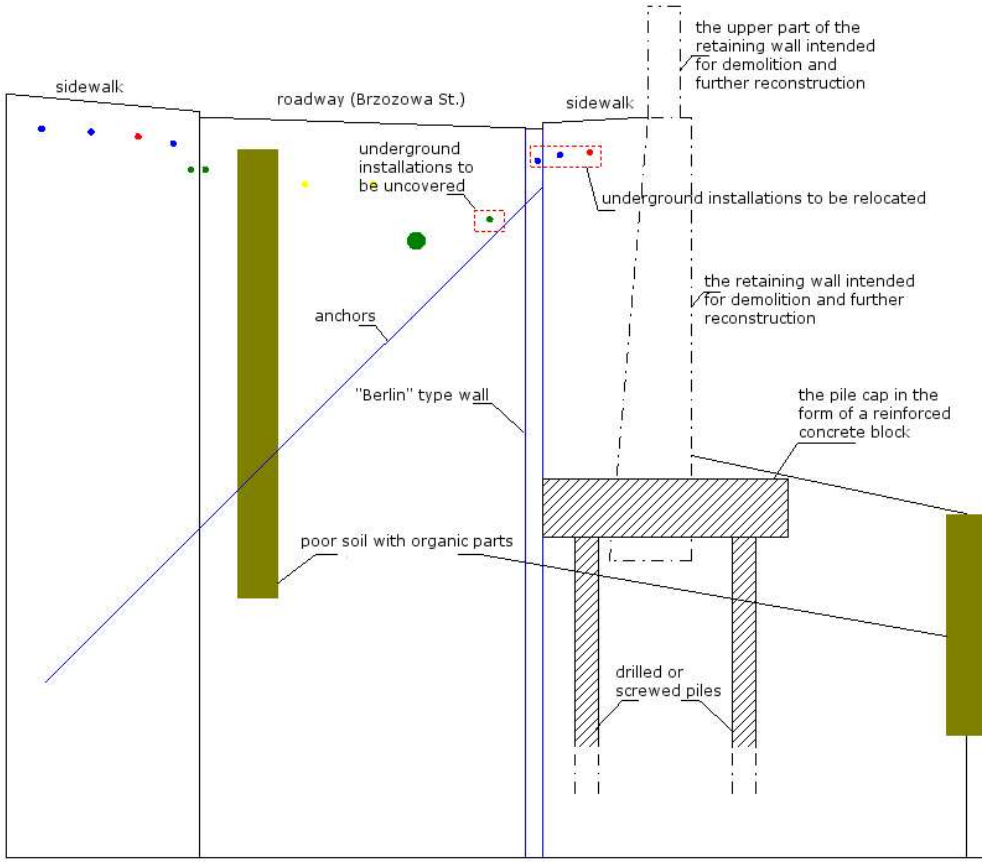

Fig. 10. The proposed solution for repairing the retaining wall.

4 Summary and conclusions

The methods of ensuring safety and stability of the retaining walls presented in this paper required a detailed assessment and analysis of the structures themselves as well as location conditions. Obtained results of tests and measurements were used to develop proposals and technical solutions for effective reinforcement and renovation process of the selected retaining walls [6].

The engineering solution specified for construction of the retaining wall for Ordynacka Street has been applied and verified in practice. It was also proved to be a very effective solution. It was based on the assumption of the most unfavourable conditions of local parameters and conditions. The engineering works were carried out in two stages. The first stage consisted in making a new retaining wall along the buildings at Tamka 45 Street and at Tamka 45A Street. The remaining retaining wall section was carried out in the second stage. This partition of the construction process into two steps was conditioned with the necessity of finding adequate space for excavated excess soil during earthworks.

In the case of a retaining wall along Brzozowa Street, the determined soil and water conditions and a dense network of underground installations hampered construction works. This implied the possibility of performing civil engineering works only from the side of Brzozowa Street. Taking into account abovementioned facts a solution based on demolition of existing retaining wall and its further reconstruction using anchored “Berlin” type wall

was applied. This design solution was also based on the assumption of the most unfavourable local conditions variant, i.e. at the lowest point near the retaining wall near the building at the Brzozowa Street No. 10. Unfortunately, due to high costs, the proposed design solution is awaiting a practical application, which is to take place by 2020.

This work was supported by the Grant No. PBS 662/2017

References

1. R. Chmielewski, L. Kruszka, Case Studies in Construction Materials, **3** (2015), pp. 92-101. (https://doi.org/10.1016/j.cscm.2015.08.001)
2. V. Turco, S. Secondin, A. Morbin, M.R. Valluzzi, C. Modena, Compos Sci Technol, **66**, Issue 2 (2006), pp. 289-296.
3. B. Villemus, J.C. Morel, C.Boutin, Engineering Structures, **29** (2007), pp.2124-2132 (https://doi.org/10.1016/j.engstruct.2006.11.007).
4. Qian Xu, Shock and Vibration, Vol.**2017**, (2017), (https://doi.org/10.1155/2017/4691947).
5. S. Vijayakumer, A. B. Subhash, T. P. Sumant, M. B. Venkatesh, and L. K. Yallappa, International Journal of Innovative Research in Science, Engineering and Technology, vol. **4** (2015), pp. 2319–8753.
6. R. Chmielewski, L. Kruszka, *Expertises and technical opinions in the area of building construction*, (WAT, 2005-2017), *in Polish*.
7. B. Szmygin, ed. *How to assess built heritage? Assumptions, methodologies, examples of heritage assessment systems* (Lublin University of Technology, Florence–Lublin 2015).
8. G. Gigli, W. Frodella, F. Mugnai, D. Tapete, F. Cigna, R. Fanti, E. Intrieri, L. Lombardi, Nat. Hazards Earth Syst. Sci., **12** (2012).
9. www.mapa.um.warszawa.pl – *historic Warsaw map*