

## MONITORING OF INTERACTIONS OF A MONUMENTAL HISTORICAL COMPLEX LOCATED ON AN EARTH EMBANKMENT

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**Abstract.** The Camaldolese Monastery was built in the seventeenth-century on a man-made hill raised on a Wigry lake island in the north-eastern part of Poland. Over the following two hundred years, the Monastery buildings were subjected to destructive weathering processes and underwent significant demolition during the two World Wars. Subsequently, the complex was reconstructed and renewed. All the Monastery buildings were raised on two earth terraces varying in height from 6 to 8 m. The terraces were formed of crushed bricks and stone debris that filled up the underground structures built earlier. The hill is composed of different geotechnical layers and their influence on the stability of the whole hill, displacement and deformation of the buildings have been monitored. The results of the monitoring are presented in the paper. The thickness of backfilled soil layers varies from 1 to 5 m and an assessment of layer parameters is influencing the actual state and future renovation of the Monastery buildings. In 2004, the Monastery buildings were affected by dynamic forces of an earthquake that measured 5.3 on the Richter scale despite the fact that this region had never been subjected to any seismic hazards. As a result, larger than expected deformations of the sub-base caused excessive cracking of the buildings and destruction of existing water and sewage system.

**Keywords:** Wigry Hill, buildings and structures of the Hill, destruction and degradations, technical state, displacement monitoring, investigations and protection.

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### Introduction

To preserve historic structures for future generations, the engineer often needs to disregard the inflexibility of contemporary standards and norms imposed by law and must travel back in time to fully understand the context in which the structure was conceived, designed, constructed and maintained (Izqueredo-Encarnacion 2012; Pfeifer, Cankurtaran 2013; Pérez Gálvez *et al.* 2013). New technologies applied within an engineering project including meticulous investigations, model analysis and execution process required to create large underground spaces and involving geotechnical survey, consolidation and strengthening of the substratum are presented in Mahmood (2012), Goepfert and Haspel (2013).

In the course of time, partitions of historic masonry structures crack forming macro-elements, which makes it impossible to produce a numerical model of the structure and simulate its behaviour. A numerical model can only show the results based on real data. On the other hand, each historic masonry structure must be examined using extensive historic studies. Instead of virtual analytical modelling methods, historic masonry reconstructions require deep historic knowledge of the subject (Blasi, Ottoni 2012; Bednarz *et al.* 2011; Šliaupa 2013).

Some cracked masonry structures can be repaired using low segregation grouts with hydraulic lime to improve the rheological parameters through reduction of plastic viscosity and yield stress, as proposed in Baltazar *et al.* (2012), Bochen and Labus (2013). The impact of environmental conditions on the durability of brick masonry and the necessary measures of masonry repair to be undertaken are discussed in Hamid and Orphy (2012), Silva *et al.* (2013). Changing environmental conditions such as wetting/drying and salt crystallization resulting from the rise and fall of ground water as well as relative humidity play a destructive role in the deterioration of the quality leading to excessive destruction of masonry walls. According to Roca (2012), on the one hand, structural modelling enables computer simulation of the effects of technological interventions on the structural response thus verifying and comparing their efficiency. Besides, monitoring carried out during and after the intervention verifies adequate performance of strengthening.

In the study of historic constructions, three different phases should be considered, i.e. diagnosis, safety evaluation and design of intervention (Roca 2006; Quist *et al.* 2013). They provide concepts and methodological guidelines to be observed in order to obtain scientifically deri-

ved conclusions on the true conditions, safety and needs of repair or strengthening. Diversified vertical settlements require accurate techniques for displacement monitoring. A monitoring system based on the principles of communicating vessels, emphasizing the relation with the structural behaviour of buildings is presented in Scherenmans and Van Balen (2006).

The papers (i.e. Ramos *et al.* 2006) present a way of assessing damages in masonry structures at early stages of degradation, finding adequate correspondence between dynamic behaviour and internal crack growth.

Limit analysis of historic massive masonry structures with rigid block models was successfully used in the works (Orduna *et al.* 2006; Korkanc 2013; Lott 2013), and the results obtained were comparable to those of micro-models. According to Basu (2006), systematic analysis and modern investigative techniques are of great help ascertaining the extent and cause of damages. In a historic building, diagnostic analysis is of utmost importance to protect structures from further deterioration or ultimate damage. In some cases of monumental buildings, structural aspects and safety factors take precedence over sentiments and myths linked with cultural aspects.

Damage of masonry structures mainly relates to cracks, foundation settlements, material degradation and displacements (Tarque *et al.* 2013). Localized cracks usually split structures into macro-blocks. Damage methods (Ramos, Lourenço 2008; Silva *et al.* 2014) were applied to experimental models, in which progressive and controlled damage scenarios were induced by controlled loads.

An acoustic emission technique was used (Carpinteri *et al.* 2008) to evaluate the time dependence of damage because cracking, in fact, is accompanied by the emission of elastic waves which propagate inside the body of material.

As can be seen from the presented review of the literature on the subject, the discussed problems are very significant in practice but, at the same time, they pose some technical difficulties due to historical, structural and technological complexity of renovating and strengthening activities. Besides, some other aspects of the problems specifically concerning the foundation and location of large historic complexes on man backfilled hills have not been fully described in literature sources.

Underground constructions always produce settlements that may affect the architectural heritage (Camos *et al.* 2012). The prediction of damage to buildings induced by ground movements is an essential task when designing underground elements. Diversified settlements of historic buildings are caused by various subsoil factors influencing correct decisions about remedial measures (Meli, Sanchez-Ramirez 2006). Excessive settlement of the structure creates problems to building operation despite of small structural harm.

The present paper is devoted to the technical history of one of the oldest historic complexes. It emphasizes how hasty and inconsiderate decisions from a technical point of view produce undesired effects in the form of accelerated degradation of structure and buildings. Wigry

Hill is located in Suwalki region in the north eastern part of Poland. The Hill is located on the peninsula of the Wigry Lake, the former island of the lake. Twenty-eight buildings and engineering structures constitute the former Monastery and remains one of the most precious historic heritage sites in this part of Poland (Wigry 1959). Figure 1 shows an aerial view of the Hill with its buildings at present (Miedzialowski, Malesza 2006). Constructions on the Hill began in 1667, when King of Poland John Casimir granted an extra fund and permission to establish a church and monastery following the Camaldolese Rule. The building site was chosen according to the principles of the eremite rules that require a location far away from urban centres and transport routes, a place surrounded by water and forests. Made of timber, first monastery buildings were destroyed by fire in 1671. A few years later, in 1678, a new masonry church was erected following the design of Italian architect Peter Putinni. Camaldolese monks extended their possessions until the end of their monastic activities in the year 1800. The Royal House was the last large investment and construction and was used after its completion as a bishop's residence. Later, in the following time periods, the Monastery buildings were used for parish functions; and during the World War I, they were partly adapted for use as a hospital and in part, as a war camp for prisoners. World War I brought almost all buildings to ruin, as seen in Figure 2. Only the church, foundations and the underground structures remained.



Fig. 1. Aerial view of the Monastery with the Church, Royal House and Chancellor Chapel at the front and hermitages at the back (photo by W. Wolkow, 2005)



Fig. 2. Camaldolese Wigry Hill after the World War I

In the interwar period, the Roman-Catholic Church building and hermitages were reconstructed. The Chancellor Chapel and Royal House cannot be seen at the

main entrance to the church as they had been destroyed during the war.

During the World War II, the reconstructed church building was destroyed again by artillery fire, which can be seen in Figure 3.

After the World War II in 1949, the reconstruction process of the Wigry Hill buildings was resumed starting from the church and presbytery while the remaining buildings were brought back to life later, starting 1958. They were rebuilt on the old foundations and underground structures with no detailed inventory or assessment of their technical state. Likewise, the processes of remedial and reconstruction works began without any archival and historic sources and documents. The south western view of the reconstructed church is shown in Figure 4. As can be seen, there are no buildings at the front of the church and no hermitages behind.



Fig. 3. The Church destroyed during the Second World War



Fig. 4. The reconstructed Church and southwestern view of the retaining walls in 1967

During the two World Wars, the buildings were undergoing destructions and disassembling and were finally brought to ultimate devastation.

At present, some reconstructed buildings of the Wigry Hill are used for religious purposes of the Roman-Catholic Church while some other parts of the complex are used as a Training and Recreation Centre. All the construction works realized on the Wigry Hill required raising the level of the ground adjoining the existing buildings as well as the surrounding terraces using main and intermediary massive retaining walls. The upper and the bottom terraces with the difference of ground levels of 6–8 m were constructed in that way.

## 1. Monitoring and analysis of backfilled earth sub-base under the Monastery buildings

### 1.1. Sub-base monitoring

Analysis of geologically multilayered substratum of the Hill was carried out by digging boreholes in accordance with a planned grid of holes and sections shown in Figure 5. According to the geotechnical reports, the upper substratum is formed by a backfill of low compaction especially in the top layers of the Hill.

Some chosen sections of the substratum illustrating its laminated composite geology are illustrated in Figure 6.

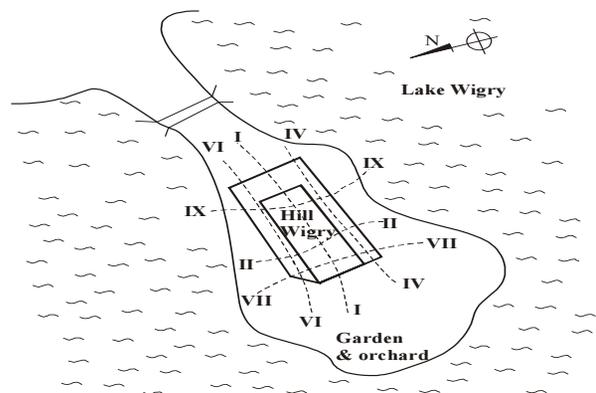


Fig. 5. Arrangement of sub-base investigation bore holes

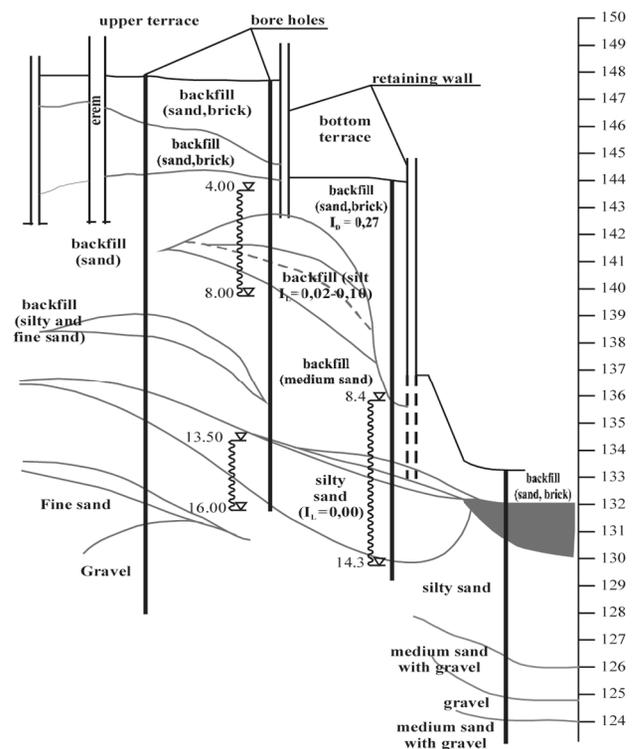


Fig. 6. Geological sections of the Hill

Soil analysis, investigations and tests made it possible to conclude that the multi-layered substratum considered to have been a backfill was primarily composed of natural mineral sandy soil. Thus, it appears that the older, originally erected Monastery buildings were found

ded on non-backfilled soil sub-base. Three basic layers were determined within the hill laminated soil structure:

- upper layer of mineral non-cohesive and low-cohesive soil with brick and stone backfill 0.5 to 6.0 m thick with degree of compaction 0.05 to 0.20;
- middle layer composed of older backfill containing mineral non-cohesive  $I_D = 0.2$  to 0.7 and cohesive soil  $I_L = 0.2$  to 0.55. This layer is considered as the bearing stratum;
- finally, the bottom layer composed of medium and coarse sands of varying compaction laminated with cohesive soil in the form of clay, i.e. a layer of natural mineral soil.

In the reconstruction process, the existing old foundations supplemented with new segments were used as required by the user. Unfortunately, the underground works, foundations, tunnels and retaining massive walls were reconstructed without required design and inventory works, which was discovered as a result of later investigations where all former underground structures were filled with crushed bricks and debris. Cross-section of the Wigry Hill and existing buildings are shown in Figure 7a, while the underground galleries are shown in Figure 7b.

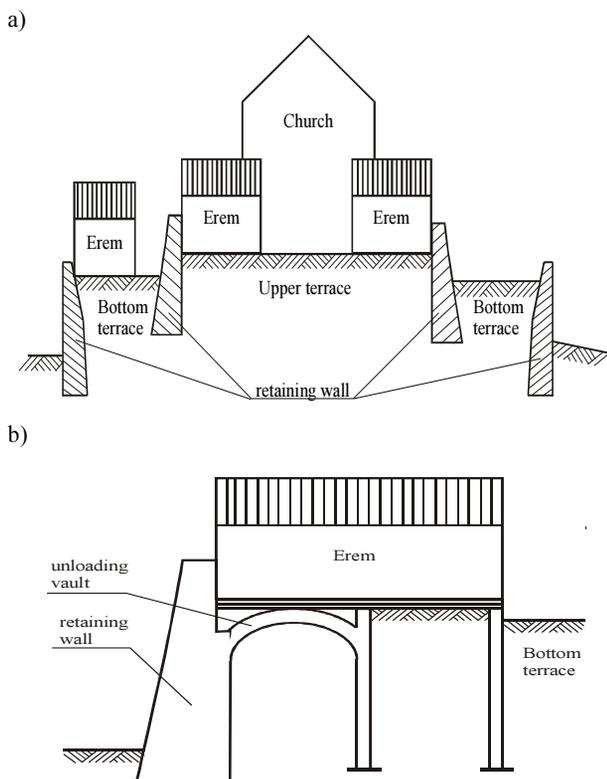


Fig. 7. Cross-sectional diagram of the Hill: a) section for terraces with massive retaining walls; b) unloading sub-structures

The Wigry Hill soil lacking adequate formation and levelling of the surrounding terrain as well as proper water and sewage disposal system was penetrated with precipitation and snowmelt water. In a note made in the Church inventory in 1800 when some buildings were disassembled, we can read the following: “retaining walls supporting the hill backfill are in a poor state particularly

those of the west and south sides where in the result of destroyed drain pipes, rain water percolate through holes in the walls” (Malesza, Miedzialowski 2006).

The hermitages at the bottom terraces were constructed partly on the retaining walls and partly on basements filled with crushed bricks and debris. As a result of non-uniform settlement, the hermitage buildings were subjected to cracking and were virtually excluded from use. Destruction and degradation processes are currently observed in all monastery buildings. The mid-part of the eastern retaining wall underwent destruction in 1987 (Miedzialowski, Malesza 2008). Some parts of the walls collapsed while others were displaced due to sewage and water pressure. Poorly backfilled former drifts and tunnels behind the retaining walls would collect water and sewage from leaky septic tanks resulting in increased pressure to the walls. The retaining wall became displaced outwards. In addition in 1999, greater displacements were caused by the damaged sewage network running along the retaining walls. Furthermore, the earthquake that measured 5.3 on the Richter scale strongly deteriorated cracking and failure state of buildings in 2004.

Initially, main processes of degradation and destruction were observed in the region of hermitages situated on bottom terraces. The water and sewage system became leaky and started cracking, which commenced a process of considerable destruction of the hermitages. The other buildings and structures also underwent cracking and large displacements especially around window sills and in corners as well as in contact zones of adjoined buildings compelling the user to conduct renewal and repair works on the basis of developed concepts and strategy of improvement and renovation (Miedzialowski, Malesza 2008).

Reconstruction of the Hill buildings/infrastructure required raising the ground level of terraces with surrounding main and subsidiary retaining walls. In that way, the upper and the lower terraces with the difference of ground levels of 6–8 m were constructed.

Incomplete archival building documentation in possession during the reconstruction resulted in some irregularities in the static work of newly reconstructed building structures resting on earlier old foundations and remaining elements of structures buried in the ground.

Whole post-monastery complex on the island of Wigry lake is presently used as a recreation centre and the former monk hermitages are used as hotel apartments. New materials and technologies were applied within the period of the Monastery complex reconstruction. Main changes involved securing the stability of the retaining walls and foundations of hermitages. A static diagram of the former retaining walls with unloading vaults over gallery reducing the lateral load from earth pressure and hydrostatic pressure of ground water is shown in Figure 7b. The basements under the vaults were used in the monastery for stores, baths and cellars. After the reconstruction, the vaults were demolished increasing the lateral load due to ground pressure against the retaining walls. The unloading chambers were used in the reconstruction to stabilize the overloaded retaining walls, returning to the former idea of the structures.

### 1.2. Selected results of stability assessment-measurement report

Five stages of surveying were specified to assess vertical and horizontal displacements within the Hill. In the first stage of measurements, twenty-eight bench-marks and datum points and ten feeler gauges were installed to monitor displacements and cracks in the structures. Significant vertical displacements from 0.3 to 5.6 mm within two-years were surveyed from points 1001 to 1039 in the control grid. The largest displacements in value, i.e. 7.6 mm, were observed at point 1007 of the southern retaining wall and 3.6 mm in the corner of the northeastern wall.

Inspection and assessment of displacements are shown in Table 1 of the Garden Tower – 1.5 mm, the Royal House – 2.0 mm, and the Gate Keeper’s House – 1.0 mm pointed towards destructive activities of water penetrating from leaking water and sewage systems rather than dynamic influence of earthquakes. The last fifth report was produced using measurements and surveys after the modernization of the water and sewage networks, which eliminated the negative influence of the leaking system that softened and washed-out the sub-base, especially the backfilled substratum. As many as 143 height and vertical displacement measurement points including 22 benchmarks and 94 points marked on buildings and structures with additional 16 stabilized traverse ground points were spaced across the Hill. Precise levelling electronic instrument DiNi-11 of 0.3 mm accuracy was used in surveying. The grid used for measurements of horizontal displacements was composed of 11 polygonal points, 28 feeler gauges and 92 deflection control points of the retaining walls, out of which 30 points were installed on the eastern wall, 33 along the southern wall, 23 points marked on the northern wall and finally 6 gauges – on the Garden Tower. The benchmarks and some selected surveying points on the lower hermitage terrace are presented in Figure 8.

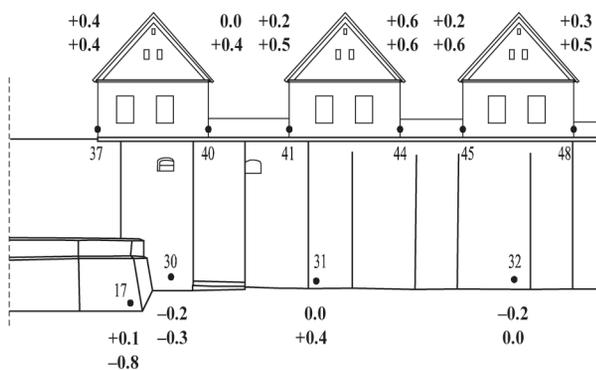


Fig. 8. Benchmarks on the hermitages

Displacements were measured applying:

- precise levelling method for vertical surveying datum points and control benchmarks;
- deflection measurements of the southern wall and the hermitages of the lower terrace applying side levelling method;
- deflection of the northern and the eastern wall applying the side levelling method;

- horizontal displacements were measured using feeler gauges.

Table 1 presents some selected deflections of the northern retaining wall.

The relative benchmark stability indicates displacements of –4.5 mm at points 11 of the Garden Tower and points 19 of the Boiler House. Hermitages of the lower terraces and the southern wall showed displacements from +0.9 to –1.3 mm. Cracks in the hermitages were widened by +0.7 mm. Also, cracks in the wall of the Boiler House widened from +0.5 to +1.3 mm. The northern retaining wall exposed an increase of vertical displacements from –0.6 to –1.1 mm and the northern part of the wall displaced from –0.7 to –1.7 mm. Vertical displacements of the NE of the corner of the eastern wall achieved –13 mm.

Table 1. Selected horizontal displacements of the northern wall

Marked points	X mm 09.2007	X mm 07.2006	X mm 06.2005	dx 07.2006	dx 06.2005
<b>Base points</b>					
<b>1011</b>	<b>0.0</b>	0.0	0.0	0.0	0.0
<b>1012</b>	<b>0.0</b>	0.0	0.0	0.0	0.0
<b>400</b>	<b>–0.5</b>	–0.5	0.0	0.0	<b>–0.5</b>
<b>413</b>	<b>0.0</b>	0.0	0.0	0.0	0.0
<b>The ground level</b>					
<b>401</b>	<b>589.5</b>	589.5	590.0	0.0	<b>–0.5</b>
<b>402</b>	<b>516.5</b>	516.5	516.5	0.0	0.0
<b>403</b>	<b>533.0</b>	533.5	533.5	<b>–0.5</b>	<b>–0.5</b>
<b>404</b>	<b>536.0</b>	536.5	537.0	<b>–0.5</b>	<b>–1.0</b>
<b>405</b>	<b>563.5</b>	563.0	563.5	0.5	0.0
<b>406</b>	<b>603.5</b>	603.0	603.5	0.5	0.0
<b>407</b>	<b>590.5</b>	590.0	590.5	0.5	0.0
<b>The top of the wall</b>					
<b>500</b>	<b>849.0</b>	848.5	849.0	0.5	0.0
<b>501</b>	<b>869.5</b>	870.0	871.0	<b>–0.5</b>	<b>–1.5</b>
<b>502</b>	<b>917.0</b>	916.5	917.5	0.5	<b>–0.5</b>
<b>503</b>	<b>919.0</b>	919.0	920.0	0.0	<b>–1.0</b>
<b>504</b>	<b>921.5</b>	921.5	922.0	0.0	<b>–0.5</b>
<b>505</b>	<b>942.5</b>	942.5	943.0	0.0	<b>–0.5</b>
<b>506</b>	<b>955.5</b>	956.0	957.0	<b>–0.5</b>	<b>–1.5</b>
<b>507</b>	<b>990.0</b>	989.5	990.5	0.5	<b>–0.5</b>
<b>508</b>	<b>1028.5</b>	1028.0	1030.0	0.5	<b>–1.5</b>

1. Minus means wall deflection outside (toward north)

Horizontal deflections and the widths of cracks remain the main method of horizontal deformation measurements. Significant increase of the crack widths amounting +0.7 mm was measured in the walls of the lower hermitages. The northern retaining wall exposed an increase of the crack widths from +0.2 to +1.7 mm. The southern retaining wall does not indicate horizontal displacements, while the eastern corner indicates the displacement of –3 mm in the outward direction. The eastern retaining wall shows displacements from +3 to +6 mm.

Four years of monitoring have shown that the structures of the eastern and southern retaining walls and lower terrace hermitages considered as hazardous in behaviour are generally stable and do not display any dangerous displacements. Water percolation and infiltration

into soil caused some noticeable vertical displacements of the Garden Tower, the Boiler Room and horizontal deflection in the northern corner of the eastern wall only.

## 2. Analysis and assessment of masonry and concrete structures constructed on the backfilled earth embankment

All the Monastery buildings have been already reconstructed except for some auxiliary ones. This can be seen in Figures 1 and 2. At the same time, a progressive process of degradation and damage has been observed. The mid-part of the eastern retaining wall underwent damage in 1987. A part of the wall was pushed out while another part was subjected to a considerable displacement under the pressure of water and outflowing wastes from the damaged sewage system. Previously unknown old galleries were revealed behind the retaining walls collecting rainwater and leaks from the sewage and water systems and increasing the damage. Figure 9 presents the actual state and displacements of the eastern retaining wall.



Fig. 9. Delamination of the eastern retaining wall lining

In 1999, another part of the retaining structure underwent large displacements forcing the owner to conduct some remedial work to improve the water sewage system and construct a chamber to reduce pressure on the wall. Some main processes of degradation and destruction were observed in the region of the hermitages located on the lower terraces. The water sewage system underwent unsealing and cracking, which started a process of large destruction of the hermitages as shown in Figure 10.



Fig. 10. Cracked wall in a hermitage

Cracks and element failure particularly in the lintels, at the element contacts and edges of openings were noticed in almost all buildings and structures.

Apart from the presented destruction processes, some other unfavourable factors have been observed to cause degradation and failure of all buildings on the Wigry Hill.

These factors include very low degree of compaction and backfilled character of soil forming the Hill. Others come from water infiltrating the soil of the Hill and negatively affecting and damping the masonry walls of all structures.

Incomplete archival building documentation used for the reconstruction caused faults in the static work of newly reconstructed building structures laid on older previously existing foundations and former parts of the structures buried in the ground. In addition, severe climate of the north eastern part of Poland intensifies the degradation of buildings and engineering structures with their outer finishes. These negative effects on the retaining wall are presented in Figure 11.

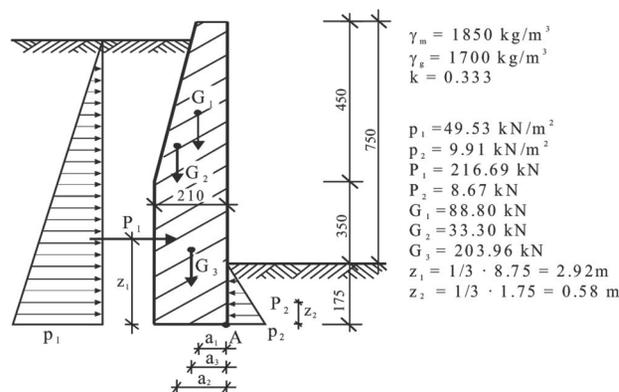


Fig. 11. Diagram of the loading to the eastern retaining wall

## 3. Pilot analysis and protections

The destructive factors presented above forced the authorities administering/in charge of the Wigry complex to commence the current protecting and repair works in parallel with development of an adequate strategy and concept of revalorization activity concerning the Monastery complex. Within the framework of repair and protection works, pilot studies of the retaining walls including their static and strength analysis have been carried out. Preliminary exposures of both sides of the wall including their geometry are presented in Figure 12a. The safety factor of wall stability against overturning is defined as the ratio between the sum of resisting moments ( $M_w$ ) and the sum of overturning moments ( $M_w$ ). In evaluating these moments, the vertical component of the active thrust on the wall may be considered in two different ways: as decreasing the overturning moment, or increasing the resisting one. Wall stability against overturning can be assessed using the position of the resultant force on the base, which is unaffected by the assumed thrust surface. Contrary to overturning, safety factors against sliding and bearing capacity are unaffected by the assumed thrust surface. The overturning moment was computed using the following equation:

$$M_w = P_1 \cdot z_1, \quad (1)$$

where:  $P_1$  – active lateral earth pressure resultant acting on the pressure surface at back of wall;  $z_1$  – vertical distance from the bottom of footing and level of applied

horizontal force. The resisting moment was obtained using the formula below:

$$M_u = \sum_{i=1}^n G_i \cdot a_i + P_2 \cdot z_2, \quad (2)$$

where:  $G_i$  – vertical dead loads of the wall;  $a_i$  – distances from the vertical loads to the front face of the wall;  $P_2$  – resultant of the lateral passive pressure acting on the pressure surface at front of wall;  $z_2$  – corresponding vertical distance from the bottom of footing and level of applied horizontal passive resultant.

It follows from the analysis of loadings shown in Figure 11 that the retaining wall fails to fulfil the required conditions of the overturning stability of the structure:

$$M_w = 216.69 \cdot 2.92 = 632.74 \text{ [kNm]}; \quad (3)$$

$$M_u = 88.80 \cdot 0.6 + 33.30 \cdot 1.5 + 203.96 \cdot 1.05 + 8.68 \cdot 0.58 = 322.42 \text{ [kNm]}; \quad (4)$$

$$M_u = 322.42 \text{ [kNm]} < M_w = 632.74 \text{ [kNm]}. \quad (5)$$

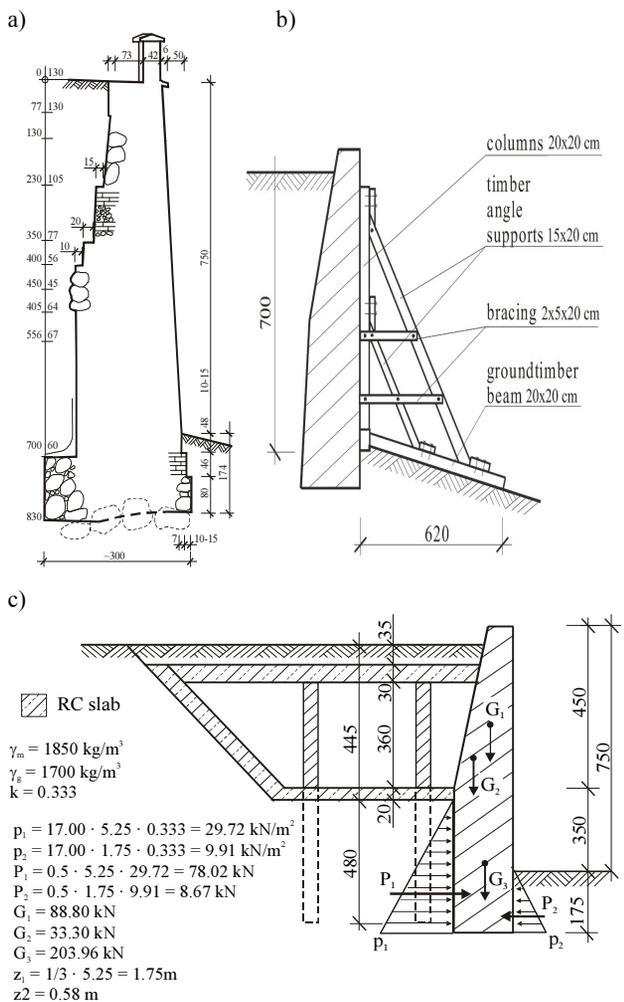


Fig. 12. Protection of the retaining walls: a) retaining wall diagram; b) timber bracings for temporary support; c) diagram of the unloading chamber behind the eastern retaining wall

The massive retaining wall in Figure 12a subjected to increased horizontal soil pressure and environmental destructions was temporarily protected using timber bracings and supports, which is shown in Figure 12b.

The unloading structure in the form of a chamber in the upper part of the wall securing its stability is presented in Figure 12c.

$$M_w = 78.02 \cdot 1.75 = 136.56 \text{ [kNm]}; \quad (6)$$

$$M_u = 409.43 \text{ [kNm]} > M_w = 136.56 \text{ [kNm]}. \quad (7)$$

Instead of timber bracing presented in Figure 12b, the stability of the wall can be protected applying an anchoring system of the wall. The tieback ground anchor system was considered but the final cost eliminated this method of wall protection.

Some immediate sources of water and sewage leakage were eliminated. New concept of elimination of the old leaking sewage septic tanks and replacing them to the Hill outside is shown in Figure 13.

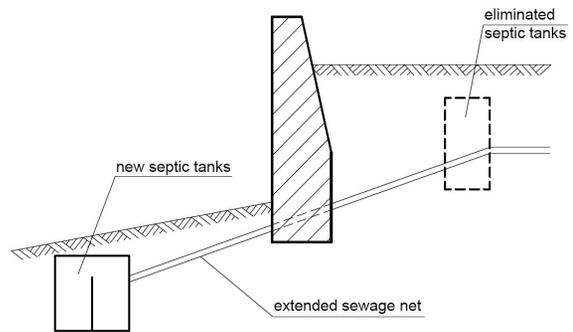


Fig. 13. New concept of the sewage system improvement

Incomplete archival building documentation during the reconstruction caused some incorrectness in the static work of the newly reconstructed building structure with the old existing foundations and the earlier parts of the structures remaining in the ground. Severe climate of the north eastern part of Poland has also intensified or sped up the degradation of the buildings and engineering structures with their outer finishes.

In addition, the earthquake measuring 5.3 on the Richter scale deteriorated the cracking and failure state of the buildings in 2004, which was discovered as a result of monitoring the structures.

Supplementary initial investigations of dynamic effects were analysed and some of the selected results are presented in the form of displacements in Figure 14 (Malusza, Miedzialowski 2008).

### Conclusions

The problems presented in the paper such as excessive settlements, cracking of structural elements, structural failure and other defects clearly indicate incorrect former reconstruction and repair works of the Monastery buildings. The works were undertaken and conducted without prior investigations of sub-base soil conditions and previously built structures remaining in the Hill from the earlier stages of construction.

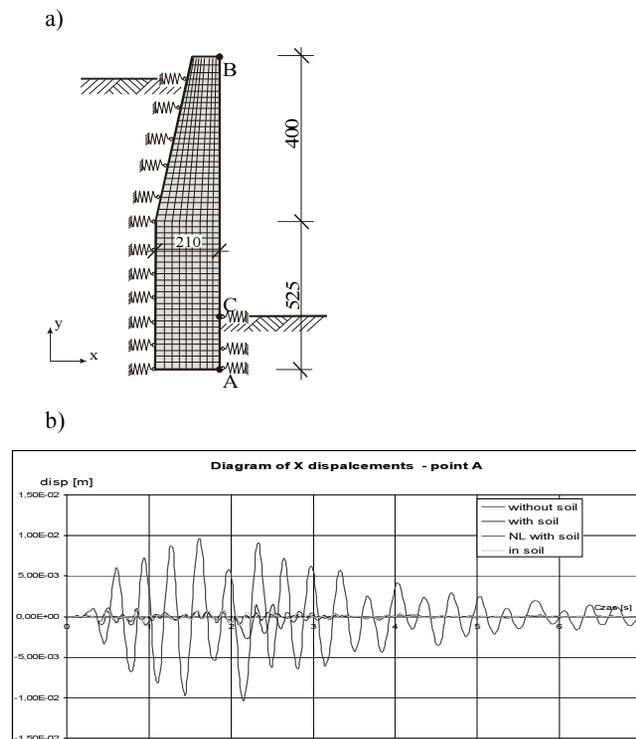


Fig. 14. Model of dynamic response of soil-retaining wall (a); displacement diagram (b)

Furthermore, larger than expected deformations of the sub-base due to its low degree of compaction caused excessive cracking of buildings as well as destruction of the existing water and sewage system. The paper underlines how reconstruction decisions based on incomplete technical data produce undesired effects in the form of accelerated degradation of structure and buildings including:

- insufficient identification and diagnosis of the technical state of buildings and soil sub-base conditions before making decisions on reconstruction;
- improper identification of areas or parts of back-filled ground soil or covered with rubble from damaged buildings;
- unsatisfactory static and strength analyses of structural elements;
- leaking water and sewage system;
- use of building materials and technologies for reconstruction, which are incompatible with the ones used in the historic structures.

Water and sewage system was improvidently planned in the past. The stability of massive retaining walls was insufficiently accounted for and, at present, they fail to fulfil the required structural standards. This necessitates construction of unloading chambers. According to historic sources, the unloading chambers behind the retaining walls existed during the Camaldolese time and use of the Monastery. Different buildings were set in varying soil conditions; i.e. hermitage foundations were laid partly on backfilled soil and partly on the retaining walls. As a result, excessive settlement and displacements caused cracking and failure in structural elements.

Present day technical state of historic Monastery buildings require more precise and systematic repair and renovation of existing buildings. Proposed strategy and conception of renovation require the following steps except to ensure immediate protection:

- Soil deep investigations to identify the stability of the Hill;
- Improvement of the water and sewage system;
- Supplementary inventory of buildings and structures;
- Design and expertise works concerning the stabilization of earth embankment and repairs of water and sewage system and buildings;
- Professional construction works.

## References

- Baltazar, L. G.; Henriques, F. M. A.; Jorne, F. 2012. Hydraulic lime grouts for masonry injection – effects of admixtures on the fresh grout properties, in *The Conference of Structural Analysis of Historic Constructions (SAHC 2012)*, 2012, DWE, Wroclaw, Poland, 1763–1770.
- Basu, S. 2006. Investigations of historical structures – a study of rational and irrational forces, in *The Conference of Structural Analysis of Historic Constructions (SAHC 2006)*, 2006, New Delhi, India, 1487–1494.
- Bednarz, L.; Gorski, A.; Jasienko, J. 2011. Simulations and analyses of arched brick structures, *Automation in Construction* 20(7): 741–754.  
<http://dx.doi.org/10.1016/j.autcon.2011.01.005>
- Blasi, C.; Ottoni, F. 2012. The role of structural monitoring in historical building conservation, in *The Conference of Structural Analysis of Historic Constructions (SAHC 2012)*, 2012, DWE, Wroclaw, Poland, 166–182.
- Bochen, J.; Labus, M. 2013. Study on physical and chemical properties of external lime-sand plasters of some historical buildings, *Construction and Building Materials* 45: 11–19. <http://dx.doi.org/10.1016/j.conbuildmat.2013.03.086>
- Camos, C.; Molins, C.; Arnau, O.; Galvec, J. 2012. Numerical simulation of the structural behaviour of buildings under tunnelling induced settlements, in *The Conference of Structural Analysis of Historic Constructions (SAHC 2012)*, 2012, DWE, Wroclaw, Poland, 432–440.
- Carpinteri, A.; Lacidogena, G.; Manuello, A.; Binda, L. 2008. The Ancient Athena Temple in Syracuse (Sicily): an investigation on structural stability, in *RILEM Symposium “On Site Assessment of Concrete, Masonry and Timber Structures” (SACoMaTiS 2008)*, 2008, Varenna, Italy, 727–736.
- Goepfert, K.; Haspel, L. 2013. National Stadium Warsaw, Poland, *Structural Engineering International* 23(3): 311–316. <http://dx.doi.org/10.2749/101686613X13439149157713>
- Hamid, A. A.; Orphy, M. 2012. Durability of historic brick masonry, in *The Conference of Structural Analysis of Historic Constructions (SAHC 2012)*, 2012, DWE, Wroclaw, Poland, 1836–1843.
- Izquiere-Encarnacion, J. M. 2012. Codes, policies and earthquakes as applied to historic preservation projects, in *The Conference of Structural Analysis of Historic Constructions (SAHC 2012)*, 2012, DWE, Wroclaw, Poland, 94–104.
- Korkanc, M. 2013. Deterioration of different stones used in historical buildings within Nigde province, Cappadocia, *Construction and Building Materials* 48: 789–803. <http://dx.doi.org/10.1016/j.conbuildmat.2013.07.033>

- Lott, G. 2013. Sourcing stone for the conservation and repair of historical buildings in Britain, *Quarterly Journal of Engineering Geology and Hydrogeology* 46(4): 405–420. <http://dx.doi.org/10.1144/qjegh2013-004>
- Mahmood, G. 2012. Conservation, repair and extension of Imam Reza Holy Shrine, in *The Conference of Structural Analysis of Historic Constructions (SAHC 2012)*, 2012, DWE, Wrocław, Poland, 141–149.
- Malesza, M.; Miedzialowski, C. 2008. Monitoring of interaction of monumental historic complex located on Earth Embankment, in *RILEM Symposium "On Site Assessment of Concrete, Masonry and Timber Structures" (SACoMaTiS 2008)*, 2008, Varenna, Italy, 1239–1246.
- Malesza, M.; Miedzialowski, C. 2006. The modern methods of analysis in reconstruction of historical buildings, in *The Conference of Structural Analysis of Historic Constructions (SAHC 2006)*, 2006, New Delhi, India, 1231–1238.
- Meli, R.; Sanchez-Ramirez, A. R. 2006. Structural rehabilitation historical buildings affected by subsidence in Mexico City, in *The Conference of Structural Analysis of Historic Constructions (SAHC 2006)*, 2006, New Delhi, India, 1503–1510.
- Miedzialowski, C.; Malesza, M. 2006. *Catalogue of historical and technical elaborations of Comeldoli Monastery*. Bialystok, Poland. 56 p.
- Miedzialowski, C.; Malesza, M. 2008. *Principles of renovation of Wigry Hill*. Report. Bialystok, Poland. 12 p.
- Orduna, A.; Roeder, G.; Arisa, J. C. 2006. Development of macro-block models for masonry walls subject to lateral loading, in *The Conference of Structural Analysis of Historic Constructions (SAHC 2006)*, 2006, New Delhi, India, 1075–1082.
- Pérez Gálvez, F.; Rubio de Hita, P.; Ordóñez Martín, M. J.; Morales Conde, M. J.; Rodríguez Liñán, C. 2013. Sustainable restoration of traditional building systems in the historical centre of Sevilla (Spain), *Energy and Buildings* 62: 648–659. <http://dx.doi.org/10.1016/j.enbuild.2012.05.009>
- Pfeifer, M.; Cankurtaran, U. 2013. "New old" calculation methods on the example of the historical Bergheimer Bath in Heidelberg, *Beton- und Stahlbetonbau* 108(8): 570–579. <http://dx.doi.org/10.1002/best.201300043>
- Quist, W.; Nijland, T.; van Hees, R. P. 2013. Replacement of Eocene white sandy limestone in historical buildings: over 100 years of practice in the Netherlands, *Quarterly Journal of Engineering Geology and Hydrogeology* 46(4): 431–438. <http://dx.doi.org/10.1144/qjegh2013-023>
- Ramos, L. F.; Lourenço, P. B. 2008. Post-accident damage investigation based on vibration measurements applied to masonry structures, in *RILEM Symposium "On Site Assessment of Concrete, Masonry and Timber Structures" (SACoMaTiS 2008)*, 2008, Varenna, Italy, 453–462.
- Ramos, F. L.; de Roeck, G.; Lourenço, P. B.; Campos-Costa, A. 2006. Vibration based identification of masonry structures, in *The Conference of Structural Analysis of Historic Constructions (SAHC 2006)*, 2006, New Delhi, India, 641–650.
- Roca, P. 2012. Knowledge – based seismic assessment of architectural heritage, in *The Conference of Structural Analysis of Historic Constructions (SAHC 2012)*, 2012, DWE, Wrocław, Poland, 2906–2913.
- Roca, P. 2006. The study and restoration of historical structures: from principles to practice, in *The Conference of Structural Analysis of Historic Constructions (SAHC 2006)*, 2006, New Delhi, India, 9–16.
- Scherenmans, L.; Van Balen, K. 2006. Hydrostatic levelling system: monitoring of historical structures, in *The Conference of Structural Analysis of Historic Constructions (SAHC 2006)*, 2006, New Delhi, India, 529–536.
- Silva, R.; Oliveira, D.; Miranda, T. 2013. Rammed earth construction with granitic residual soils: the case study of northern Portugal, *Construction and Building Materials* 47: 181–191. <http://dx.doi.org/10.1016/j.conbuildmat.2013.05.047>
- Silva, B.; Dalla, B.; da Porto, F. 2014. Compression and sonic tests to assess effectiveness of grout injection on three-leaf stone masonry walls, *International Journal of Architectural Heritage* 8(3): 408–435. <http://dx.doi.org/10.1080/15583058.2013.826300>
- Šliaupa, S. 2013. Modelling of the ground motion of the maximum probable earthquake and its impact on buildings, Vilnius city, *Journal of Vibroengineering* 15(2): 532–543.
- Tarque, N.; Lai, C. G.; Bozzoni, F. 2013. Expected ground motion at the historical site of Poggio Picense, Central Italy, with reference to current Italian building code, *Engineering Geology* 166: 100–115. <http://dx.doi.org/10.1016/j.enggeo.2013.09.003>
- Wigry Initial historic documents*. 1959. Collective work. Historical Buildings Preservation Atelier in Bialystok, Poland.

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