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The Modern Methods of Analysis in Reconstruction of the Historical Buildings

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ABSTRACT: Presented paper is based on reconstruction of the orthodoxy gothic church in Suprasl and comeldolite Wigry Lake Monastery. On the base of remaining documents and photographs historical form of building is restored and all process of architectural and structural design is adopted to that model. The stellar gothic vaults are the main part of structure supported on high masonry arches. The vault is modelled as 3D shell with system of curved ribs and filling thin masonry barrels. Numerical model of the three-dimensional structure consisting of varying cross-section curved members is adopted in design of the masonry Gothic vaults. The macro-modelling of the masonry vaults as a composite material structure is adopted in description of the shell.

1 INTRODUCTION

Performance complexity and application of the efficient and verified modern techniques marks the new approach to the problem of reconstruction of historical buildings. The following stages can be distinguished in the process of reconstruction:
- parameters identification,
- computational and design analysis,
- realization and construction.

The first stage very often decides on progressing of the sequence activity. This stage is determined by the following work:
- archeological investigations,
- geological tests,
- geodesy surveying,
- architecture and drawing up inventory,
- evaluation of materials and structure condition.

These problems are examined on the examples of reconstruction and maintenance of the Cameldolite Monastery on the Island of Wigry Lake and the gothic orthodoxy church in Suprasl, two historic buildings located in the north-eastern part of Poland.

Configuration of loading and actions on the building structure is also important considering the past and the time being. The examined monastery building on the Island of Wigry Lake in 2004 was in addition loaded with the dynamic forces in result of earthquake intensity of 5.3 degree in the Richter scale; however this region was never recognized as the subjected to the earthquake hazard.

2 PARAMETERS IDENTIFICATION STAGE

2.1 *Buildings of the Comeldolite Monastery*

The post-Comeldolite Monastery complex contains 20 buildings with centrally situated Roman-

Catholic church, adjacent the priest house with administrative and auxiliary buildings, the presentable building so-called Chancellor's Chapel, hotel building, the clock tower and the erems – the monk's cell houses actually used as the hotel apartments. The monastery was created on the island and than within the time of few centuries linked with the stable land creating the peninsula and extending the area of monastery.

The hill with the church and the monastery buildings creates the spatial dominant over the area on the lake background. Historic view of the hill on the base of nineteenth century drawing is presented in Fig. 1a, and the actual view is shown in Fig. 1b.

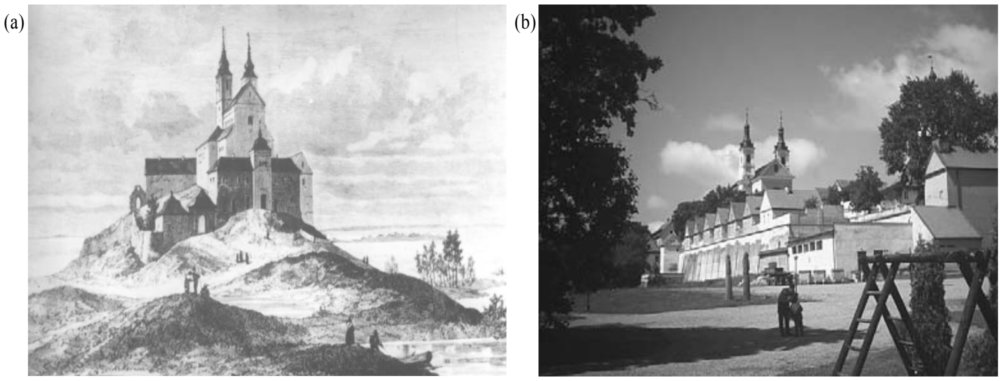

Figure 1 : The Comeldolite Monastery (a) historic drawing, (b) the actual state.

According to the historic sources in the fifteenth century the hunting manor-house existed in this place. The first masonry building on the hill – the church was constructed within period of 1694 to 1745 according to Italian architect Peter Putini's design. Next the auxiliary buildings, the chancellor's chapel and monk's erems were constructed in the island. Within the period of the World War One from 1914 to 1918 some buildings were destroyed and demolished. Within the interwar period some buildings and church were reconstructed, but within the World War Two from 1939 to 1945 the hill was again devastating and buildings were destroyed. After the War the monastery buildings were again reconstructed and completed in the eighties of the twentieth century. Excavations and archaeological investigations indicate that the monastery hill covered ceramic bowls and cups as well as the ornamented decorations from the period of fifth century giving evidence on early settling in the region.

The geological investigations demonstrate that actually existing on the lake peninsula land in the past created island where the first monastery buildings were founded. Within few centenaries time the island was enlarged through the backfill and connected with the stable land.

Geological investigation and in-situ tests proved that the hill is mostly built as the non-bearing backfill composing the upper layers with a brick-stone debris and fine sand. The thickness of this layer is varying from 1.0 to over 5.0 m. Layer of clayey sand with fraction of boulder has the plasticity index $I_L = 0.2 – 0.5$ and degree of compaction adequately $I_D = 0.5 – 0.6$. In order to investigate soil condition and evaluate the parameters the net of the bore-holes was set up as it is presented in Fig.2.

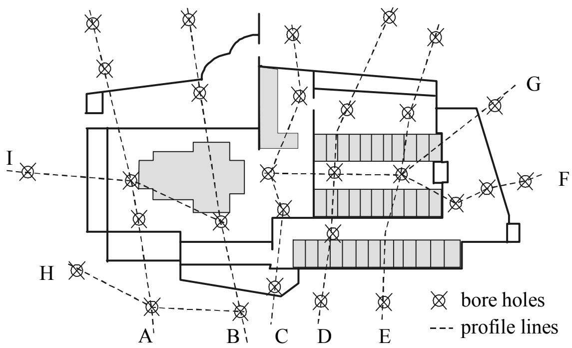

Figure 2 : The network of the geologic bore-holes.

Selected geologic sections are presented in Fig.3.

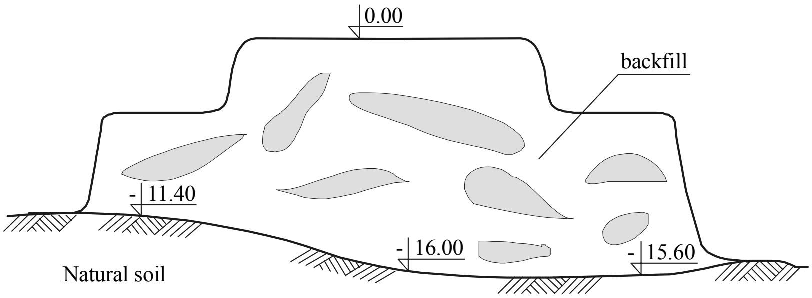

Figure 3 : Geologic section E-E across the hill.

The technical state of the structures and material parameters were investigated and evaluated parallel to the architecture analyses and drawing-up inventory. These investigations proved that not only within the two wars time but also during the exploitation in the XX century some monastery buildings underwent destroying. Constructed underground and existed from the beginning the brick vaults reducing the earth pressure and hydrostatic underground water pressure acting to the retaining walls were demolished and destroyed. Fig. 4 presents the static scheme of the structure and unloading vaults.

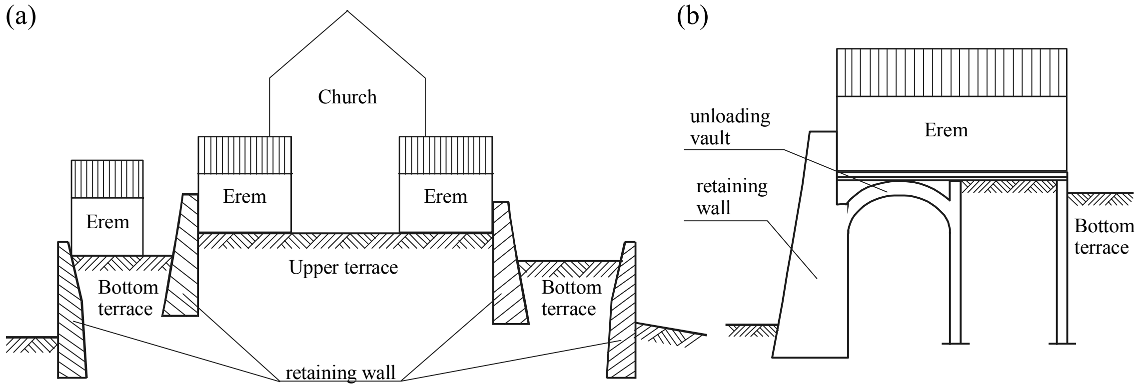

Figure 4 : The section of the hill and unloading vaults

After the World War Two all buildings were reconstructed neglecting some important structural details. The unloading vaults and underground passages were completely backfilled. Also only partly rebuilt the water and sewage network system caused saturation of the backfill structure of the hill.

Evacuation of snowfall and rainwater requires adequate shaping and configuration of the ground surface, because inadequate water run-off leads to percolation of surface water into ground consolidating backfill of the hill.

Inspection of structural elements and retaining walls displayed cracks and failures on the masonry and concrete walls. Fig. 5 presents cracks and failures on the retaining walls.

Cracks and failures appeared despite the periodic routine repairs of buildings particularly in results of the earthquake. There were recognized two kinds of cracks. The first one above the ground level appeared in result of the earth motion and cracks in the upper parts of buildings as a result of thermal, shrinkage and seismic actions on structural elements

(a) (b)

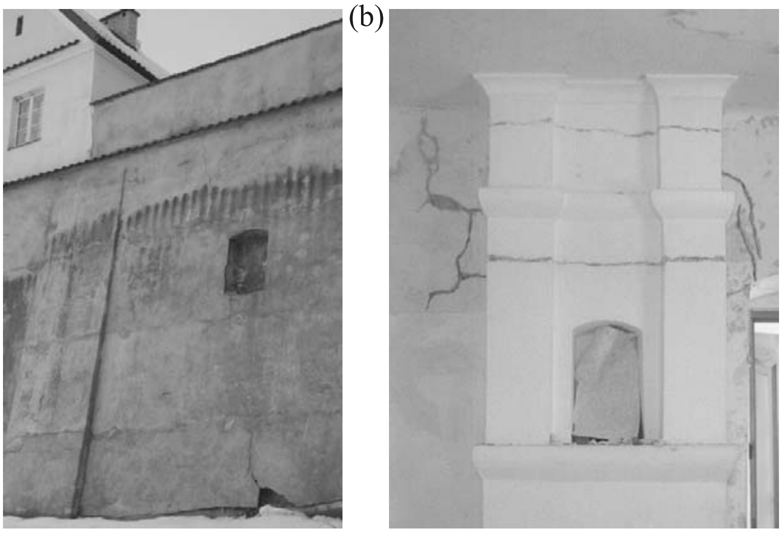

Figure 5 : Visible cracks on the retaining wall.

2.2 The orthodox church in Suprasl

The orthodoxy church reconstructed within last ten years belongs to the most interesting monument of the late Gothic style on the eastern border-land of Poland. Suprasl orthodoxy monastery has been creating essential part in evolution of spiritual culture of polish orthodoxy. The fortified orthodoxy church constructed originally in early of XVI century was built on Byzantine form in plane with gothic citadel structure when some details were adopted from wooden eastern orthodoxy sanctuaries.

All building was originally constructed as the masonry structure with four central columns, thick masonry brick walls with built-in system of ventilation and four round corner towers. Central tower high on 46 m was supported on high gothic masonry arches supported on central columns. All inside area was covered by several different masonry gothic vaults. All details outside and inside similar to those used in wooden orthodoxy churches were formatted with specially moulded brick elements and built-in the structure. Fig. 6 presents general view of the church before the WWT and actual form after reconstruction

During the World War Two in 1944 the sanctuary was totally destroyed by German army leaving Poland. The reconstruction was initiated by the Synod of Bishops of Polish orthodoxy church in 1984. Design and reconstruction were based on the limited available sources, remaining photos and the unique as-built drawings worked out by Pokrishkin in 1911. Special attention was dedicated to the Gothic vaults and their reconstruction in the original architecture form.

Limited historic sources displayed some indications referring to construction of the main structural building elements. The foundations and all underground part with kind of basement catacomb were build in stone on lime mortar. External and internal walls were constructed as masonry structures also main central columns were constructed as the masonry. Gothic vaults were build as masonry structures with specially shaped and moulded clay bricks. High slightly arched roof was constructed as a timber structure.

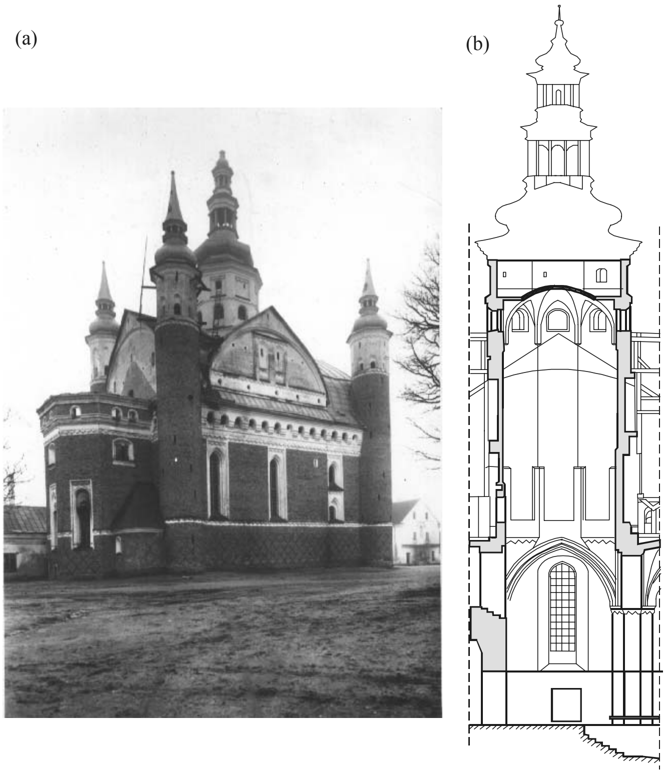

Figure 6 : General view of the church, details of the cross-section.

3 COMPUTATIONAL ANALYSES AND DESIGN

3.1 Monastery buildings on the Wigry island

The high retaining eastern wall displaying the widest symptoms of degradation and destructions was subjected to computational analysis and numerical modelling.

The following structural scheme was adopted in analysis of the retaining wall. Fig. 7 presents the scheme of wall and its loading.

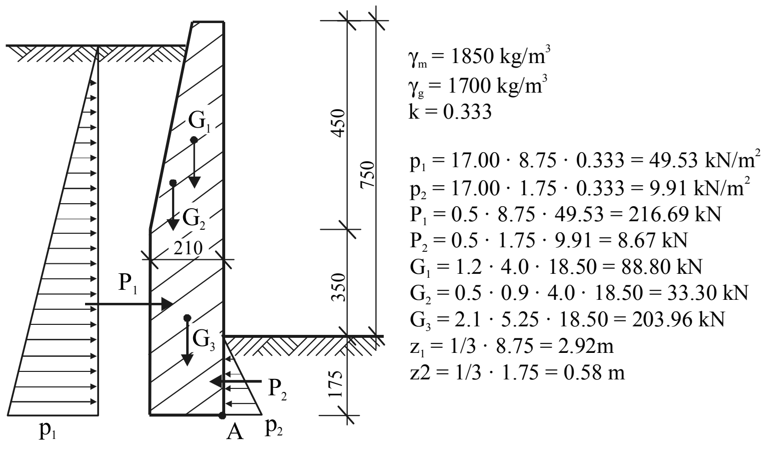

Figure 7 : Retaining wall and its loading.

$$M_w = 216.69 \bullet 2.92 = 632.74 \; [kNm] \tag{1}$$

$$M_u = 88.80 \bullet 0.6 + 33.30 \bullet 1.5 + 203.96 \bullet 1.05 + 8.67 \bullet 0.58 = 322.42 \; [kNm] < M_w \tag{2}$$

The stability condition is not satisfied

Stability of the retaining wall under lateral loading resulted from backfilling behind the wall creates hazardous conditions for structure and in order to unload the wall the reinforced concrete chamber was constructed according to the scheme

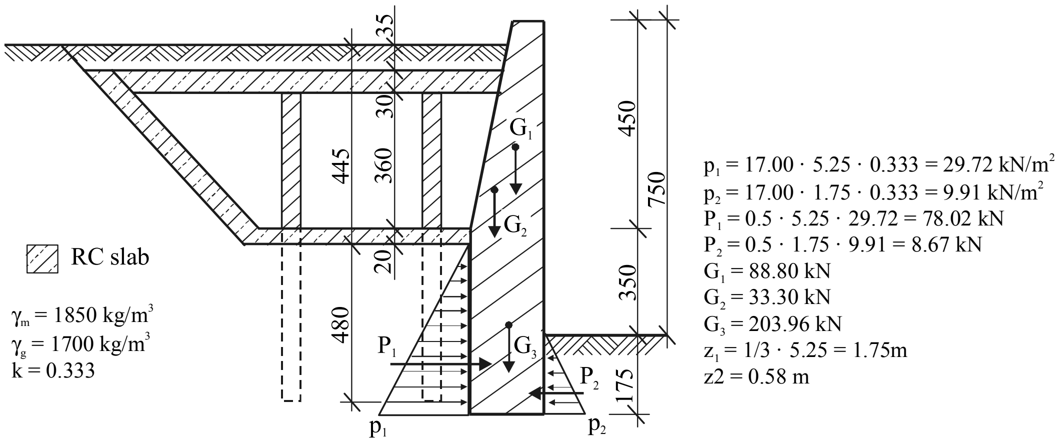

Figure 8 : Diagram of the unloading chamber structure.

$$M_w = 78.02 \cdot 1.75 = 136.54\ [kNm] \tag{3}$$

$$M_u = 322.42\ kNm > M_w \tag{4}$$

The stability condition is fulfilled.

The influence of 2004 earthquake with intensity 5.3 degree in the Richter's scale induced lateral loading applied to the wall. Influence of this phenomenon on retaining walls was analysed considering the interaction with backfilling soil according to the scheme.

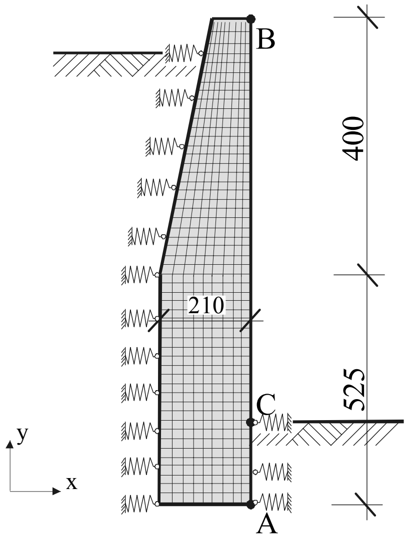

Figure 9 : Static scheme of the retaining wall including interaction of backfilling soil.

The problem was analyzed applying the finite element method including the above interactive model. The diagram of model shock applied to the retaining wall foundation and displacement of point A under different interactive alternatives presents Fig. 10.

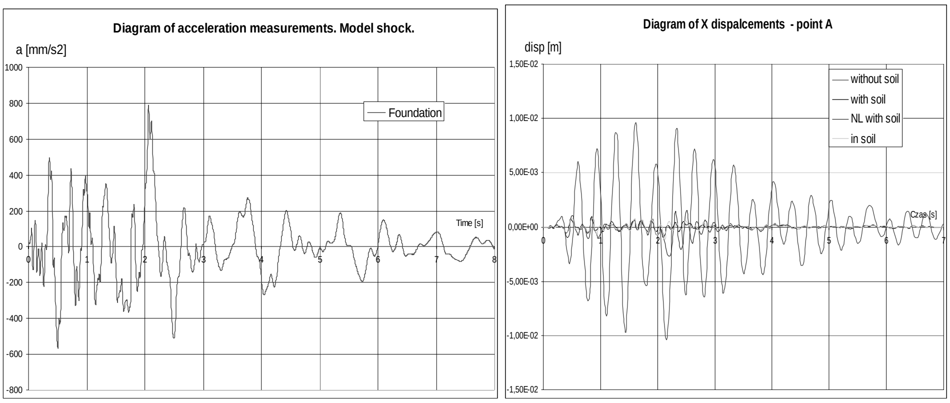

Figure 10 : Diagram of model shock and diagram of displacement of A point.

According to Polish National Building Low Regulations building structure does not need to be designed for seismic loading. Displacments of massive retaining walls under dynamic earthquake loading were examined in respect of accidental action. Except displacements the local cracks in result of earthquake loading were examined and they are presented in Fig.5.

3.2 The orthodoxy church in Suprasl

Structural analysis was conducted for selected masonry vault the most sensitive structural element in building. The vaults with supporting columns are shown in Fig. 11a. Geometry and analytical model presents Fig.11b. The numerical model has been described applying the Finite Element Method, taking into account three-dimensional beam system in the first case and beams with filling shells in the second case. The equation describing problems have the form.

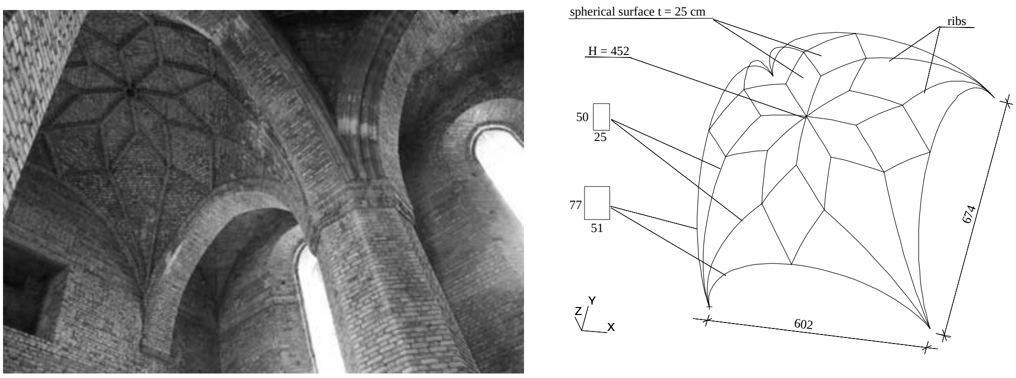

Figure 11 : Reconstructed stellar vault.

$$\mathbf{Kd} = \mathbf{P} \tag{5}$$

where **K** = stiffness matrix of the system, **d** = displacement vector and **P** = loading vector.

Procedure of designing of the structure has been consisted in identification of the system (i.e. dimensioning, material properties, phase of loading), recognizing of internal forces and verification of the limit state conditions. There were recognized and taken into account the following phases of the ribbed shell loading.

- dead loads,
- dead load with stabilizing infilling in the spandrel of the vault,
- supports displacements.

Material properties of the ribs and infilling shells were determined using homogenization technique and evaluating the average material parameters.

Calculating parameters of the structure were the following ribs infilling shells

– for ribs $\gamma_r = 18 kN/m^3$, $E_r = 10000 MPa$, $\nu_r = 0.1$,
– for infilling shells $\gamma_s = 18 kN/m^3$, $E_s = 4000 MPa$, $\nu_s = 0.1$.

Table 1 presents the example internal forces in both considered models under dead load.

Table 1 : Internal forces.

Models	Axial loading N [kN]	
	at the crown	at the supports
3D beam structure	23.6	35.8
beam and shell structure	11.2	20.9

4 CONCLUSIONS

Conducted analyses proved that in reconstruction of historic buildings the following stages are influencing the final results:

– the archeology investigations,
– geological tests of soil
– parameters of materials,
– component structures.

Geological and geotechnical investigations permit to evaluate proper interaction of structure with subbase soil.

Tests of material parameters give the data necessary in analyses, design and application of adequate methods in repairing and renovation.

The stage of analyses and design requires application of adequate analytical model considering 3D structural model and interaction with the soil subbase or surrounding ground. The modern numerical methods and computer techniques are giving these possibilities what is shown in presented examples in the paper. The interaction of the wall structure with surrounding backfill under seismic loading recalls damping of vibrations.

Shells considered in analysis of vaults decrease the internal forces in the ribs.

The same results are obtained introducing the chamber behind the retaining walls.

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