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Functions of the Modern Techniques and their Influence on Analyses in Reconstruction of Historic Buildings

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ABSTRACT: The new computer techniques provide new ability in designing and reconstruction of historic buildings. Historic form of building is reproduced on the base of remaining documents and photographs and all process of architectural and structural design is adapted to that model. Presented in the paper historic buildings were constructed of brick and masonry units used in the structures were individually hand-made and manufactured sometime with specific pattern required by former architects. New materials specifically various composites actually used in reconstruction require different approach from the early stage of construction. Three-dimensional models of structure considered in process of design, geometrical imperfections and nonlinearity of materials parameters were recognized in process of reconstruction. Finite element analysis including long-term processes is a part of design.

1 INTRODUCTION

Stage of the reconstruction programme requires consideration of the new assignment and modern technologies.

- Different assignment in respect of exploitation and corresponding loading and actions differing from historic building shall be recognized in design procedure.
- Modern technologies and building materials require new methods of construction and designing.

The above problems are discussed on the examples of reconstruction of the gothic orthodoxy church in Suprasl (Malesza 1992) and the Comeldolite Monastery on Wigry lake island, the historic complexes located in the north-eastern part of Poland.

2 STAGE OF ANALYSE AND DESIGN

2.1 The orthodoxy church in Suprasl

The orthodoxy church reconstructed within last twenty years belongs to the most interesting monument of the late Gothic style along the eastern border-land of Poland. Suprasl orthodoxy monastery has been creating essential part in evolution of spiritual culture of polish orthodoxy. The former construction of the fortified gothic church begun in 1504 of XVIth century. The church was built on Byzantine form in plane with the Gothic citadel structure including some details adopted from wooden eastern orthodoxy sanctuaries widely spread along the Polish eastern border-land.

All building was originally constructed as the masonry structure with four central columns where two of them were single supports of high Gothic arches and two the others where built-in to the internal walls. The thick masonry outer brick walls with built-in system of ventilation and four round masonry corner towers create the main church structure. 46 m high the main tower was supported on the Gothic masonry arches. Several different masonry gothic vaults – the main stellar, the side cross vaults and one the crystal-vault forms the structural interiors of the church. All details outside and inside similar to those usually used in wooden orthodoxy churches were formatted with specially moulded brick elements and than built in the structure. Fig. 1 presents general view of the church before the World War Two and actual form after reconstruction.

(a) (b)

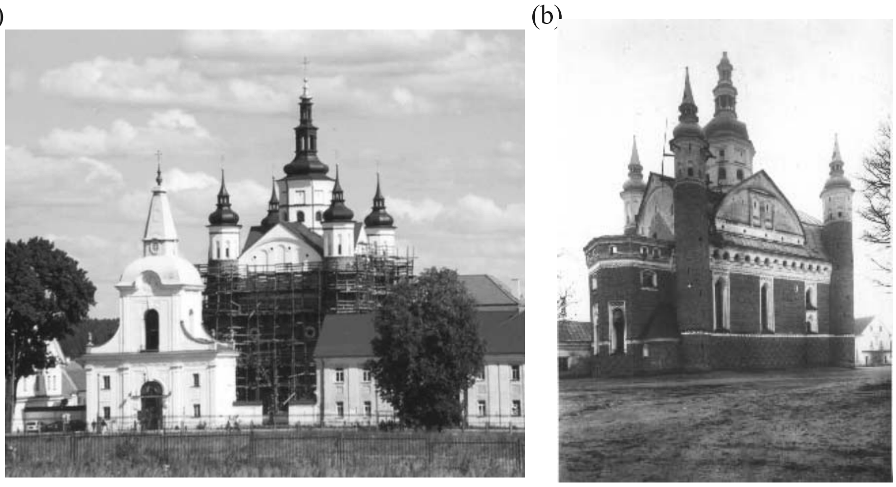

Figure 1 : General view of the church, (a) actual state, (b) historic photo.

The sanctuary was completely destroyed during the World War Two in 1944 by German army occupying 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 Pokryshkin's as-built drawings elaborated in 1911. Special attention were dedicated to the Gothic vaults and their reconstruction in the original architectural form, however this forms were to be detected from remaining sources.

Limited historic sources displayed some indications referring to construction of the main structural building elements. The foundations and all underground part were built 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 built as masonry structures with specially shaped and moulded clay bricks. High slightly arched roof was constructed as a timber structure.

(a) (b)

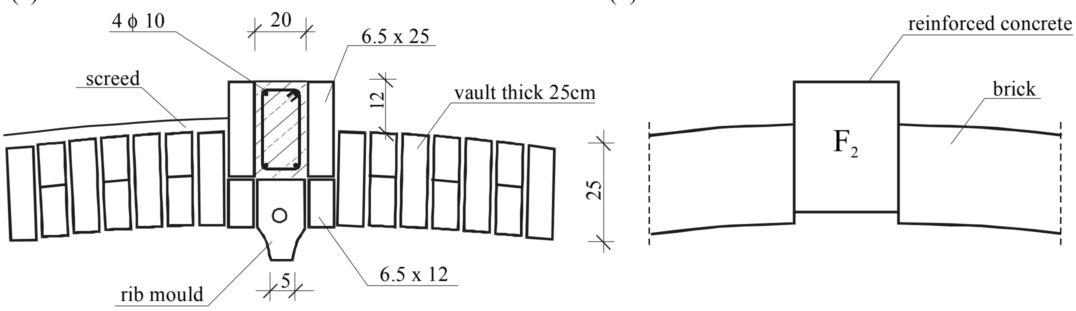

Figure 2 : The composite form of the reconstructed ribs of vault, (a) construction, (b) equivalent section.

Reconstructed building is actually used as the orthodoxy church according to its primary assignment. The modern materials and technologies were used during the reconstruction. Architecture details of the column capital, ornamental cornices, curved gothic vaults required some specially shaped and moulded masonry units. These units were to be built-in to the exterior and interior elements and actually they are not manufactured in industrial production. Composites were used replacing the specially shaped bricks.

Design and formation of the gothic vaults and construction of the central tower required structural modification preserving the old architecture form. In order to obtain required form of the gothic stellar vault the composite ribs instead of shaped moulded bricks were inserted according to the form presented in Fig. 3.

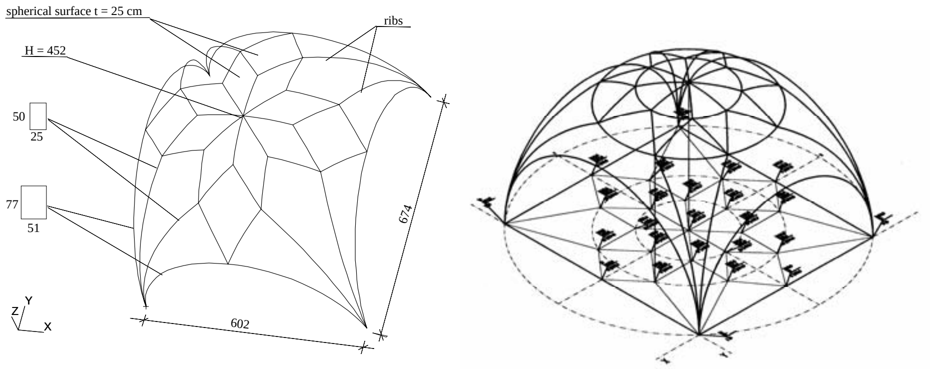

Figure 3 : Numerical modelling of the gothic stellar vault and its reproduced geometry.

The equivalent sections according to the principle of materials average strain and compression stresses were taken in analysis

$$\varepsilon_1 = \varepsilon_2 \tag{1}$$

where ε_1 = average strain of the composite section and

$$\varepsilon_2 = \frac{\sigma_2}{E_2} \text{ the average strain of the equivalent section} \tag{2}$$

$$F_2 = \frac{P_2}{E_2 \cdot \varepsilon_1} \tag{3}$$

The vault was modelled adapting the following static scheme presented in Fig. 3.

Most difficulties in respect of structural and analytical calculation of the vault appeared during the modelling of composite bricks and reinforced concrete arched ribs with masonry infilling shells. Complexity and the brittle behaviour of the vault three - dimensional masonry structure required compression action in the cross - section of the spatially curved beams interacting with stabilizing the infilling brick shells (Molins and Roca 1998)

A curved spatial beam-rib has the following generalized internal forces in the cross-section presented in Fig. 4.

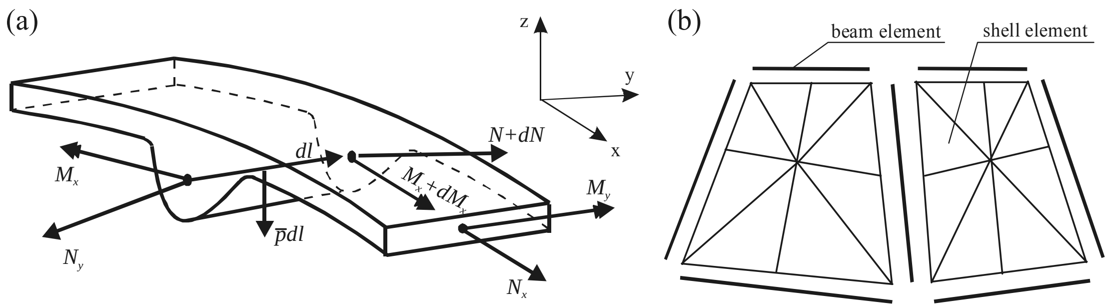

Figure 4 : Internal forces in the cross-section of a curved beam with shells.

Generalized equilibrium of the finite element method can be described in the form

$$\mathbf{W} = \{N_x, M_y, M_x, M_y, M_{xy}, Q_z, Q_{xy}\}^T \tag{4}$$

$$\mathbf{W} = \overline{\mathbf{D}} \cdot \varepsilon \tag{5}$$

$$\varepsilon = \{\varepsilon_x, \varepsilon_y, K_y, K_{xy}, \gamma_z, \gamma_{xy}\}^T \tag{6}$$

Two methods were applied to solve the internal forces in the combined shell - beams system

(Malesza and Miedzialowski 2004). The first way assumed the three dimensional structure as a system of arched spatial beams loaded with infilling surrounding masonry shells. Fig. 5 presents this structural system.

(a) (b)

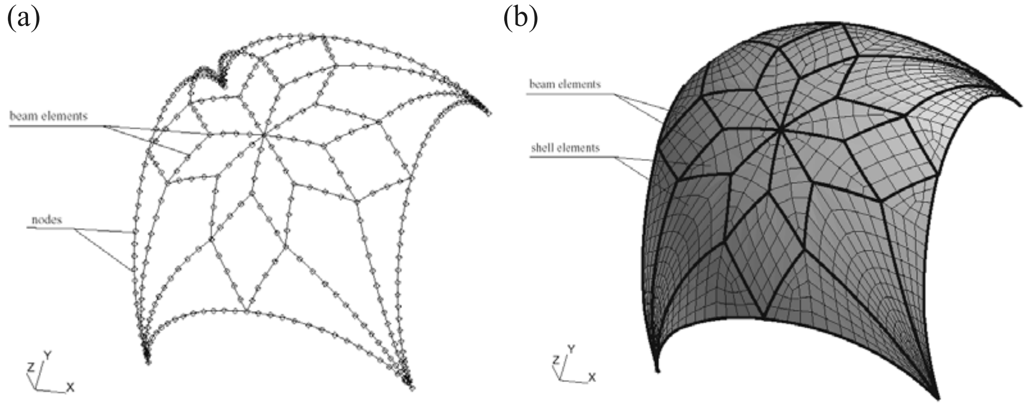

Figure 5 : Three-dimensional beam system of the structure and three-dimensional system of the arched beams with infilling shells.

Analytical model has been obtained in result of discretization of the structure curved ribs applying the finite beam elements. System of equilibrium equations is described in the form

$$\mathbf{Kd} = \mathbf{P} \tag{7}$$

where $\mathbf{K}$ = stiffness matrix of the system, $\mathbf{d}$ = displacement vector and $\mathbf{P}$ = loading vector.

The second method considered the spatial ribs system with interacting shells like a combined three - dimensional structure and all system is presented in Fig. 5.

The analytical model was obtained in results of discretization of the ribs applying the beam finite elements and infilling shells which were described designating the plane quad4 finite elements.

System of equations has been completed with stiffness matrix and vectors of displacement and loading adequate the infilling shells.

$$\mathbf{K} = \mathbf{K}_b + \mathbf{K}_P \tag{8}$$

where $\mathbf{K}_b$ = beam elements stiffness matrix and $\mathbf{K}_P$ = stiffness matrix corresponding the plane element.

The interface $\mathbf{K}$ matrix of the transition provides conformity of the degrees of freedom and plane elements. Fig. 6 presents modelling of transition elements.

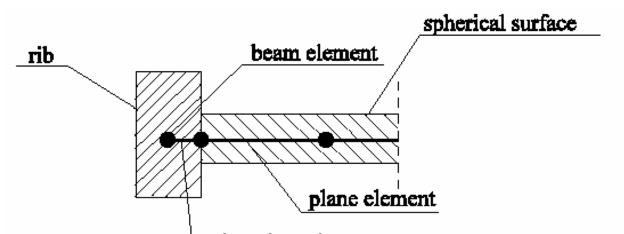

Figure 6 : Coupling of the beam and plane elements.

Procedure of designing incorporates:

- system identification its dimensioning, material properties and phases 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,

– for ribs $\gamma_r = 20$ 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 of the internal forces in both considered models, 3D beam system and 3D and incorporated shell under dead load.

Table 1 : Internal forces.

Models	Axial loading N [kN]	
	at the crown	at the supports
Beam	23.6	35.8
beam-shell	11.2	20.9

The other problem appeared when high on 46 m the central tower supported originally on the gothic arches and system of masonry interior walls requires firm and stable supports. Former load bearing system was replaced introducing three-dimensional model requiring new static approach.

In the process of reconstruction design the tower was supported on the horizontal RC raft structure based on masonry bottom. Introduction of new bearing system unloaded the arches reducing the thrust action of the arches without reducing the vertical load of the sporting structures.

The original historic masonry structure did not satisfy the design limit state and serviceability limit state conditions of building elements using adequate material solution. Also in result of the thrust actions obtained from 3D analysis the former structural system did not satisfy both limit state conditions especially the masonry supporting arches.

The reconstructed tower was designed as the 3D reinforced concrete frame built-in traditional masonry structure with geometry and configuration fitted to the originally shaped the church. The diagram of the base-raft was adapted to geometry resulting from historic form of supporting walls maintaining the asymmetry in plane as a result of the real mapping of original XVIth century masonry gothic orthodoxy church.

The structure and static diagram of the base-raft bearing the central tower is presented in Fig. 8.

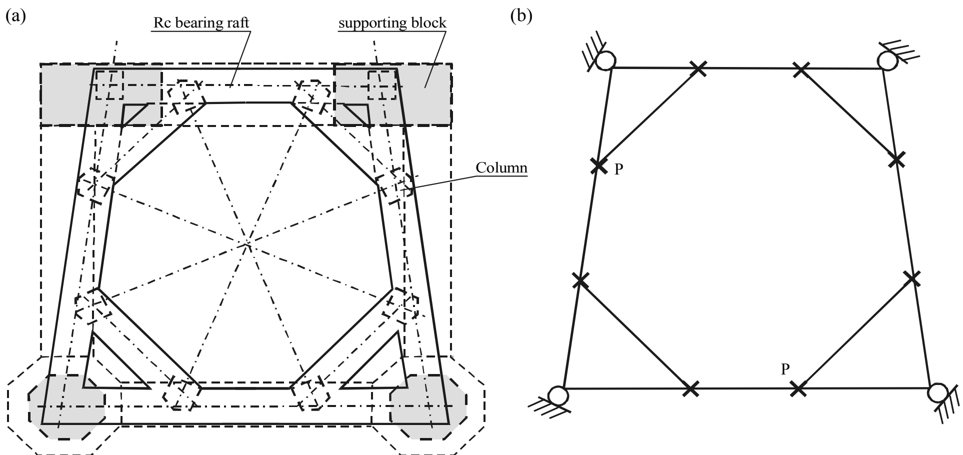

Figure 8 : The RC base-raft bearing the tower, (a) structure, (b) static diagram.

2.2 Buildings of the Wigry Comeldolite Monastery

Historic sources from XV century informs that the hunting manor-house existed in this place. Roman Catholic church as the first masonry building on the hill was constructed within period of 1694 to 1745 according to Italian architect Peter Putini's design. After settling the monks the chancellor's chapel and monk's erems with the auxiliary buildings were constructed on the island. During the World War One within the period of 1914 to 1918 some buildings were destroyed and demolished. Within the inter-war period some buildings and church were reconstructed, but within the World War Two 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 XXth 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 Vth century giving evidence on early settling in the region.

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

Fig. 9 presents historic and actual general view of Wigry comeldolite-hill monastery.

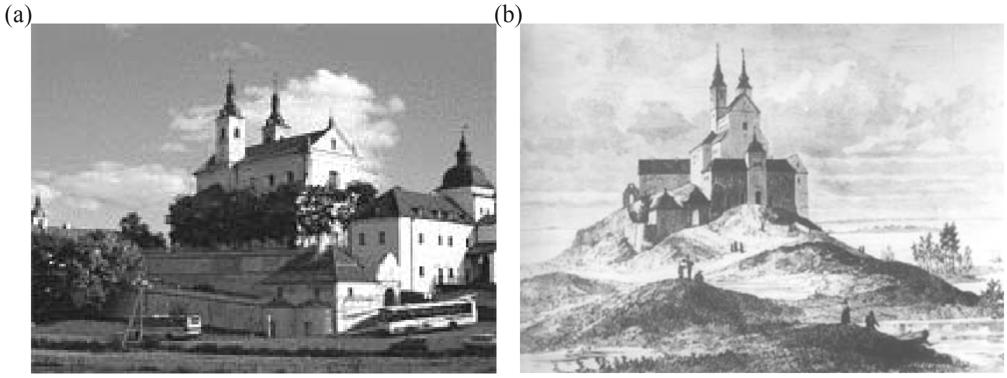

Figure 9 : The comeldolite monastery – (a) actual general view, (b) historic drawing.

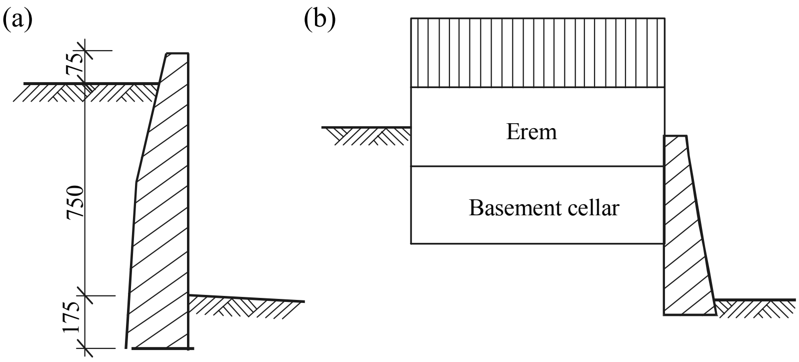

Figure 10 : The cross-section of the retaining wall with erems, (a) the retaining wall, (b) erems behind the wall.

All post-monastery complex on the island of Wigry lake is actually used as recreation centre and the former monk erems are used as the hotel apartments. New material and technologies were applied within the period of the monastery complex reconstruction. Main changes were introduced in the range of securing the retaining wall stability and erems foundations. The static scheme of the former retaining walls with unloading vaults reducing the lateral load from earth pressure and ground water hydrostatic pressure presents Fig. 11a.

The basement under vaults was used in the monastery for stores, bath and cellars. After reconstruction the vaults were demolished increasing the lateral load in result of ground pressure to the retaining walls. The unloading chambers according to Fig. 11b were used in reconstruction for stabilization of the overloaded retaining walls.

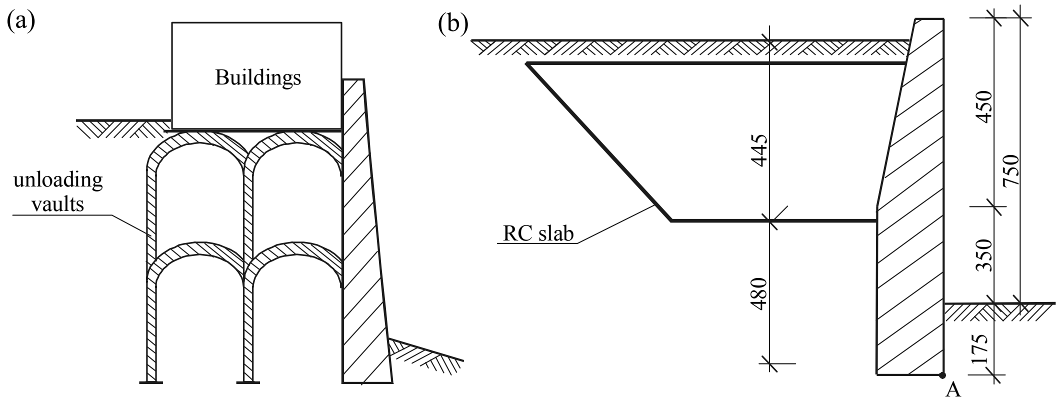

Figure 11 : Schemes of unloading vaults, (a) in the building cellars, (b) scheme of unloading chamber.

3 STAGE OF CONSTRUCTION

3.1 The orthodoxy church in Suprasl

The external and internal bearing walls were reconstructed in their original form maintaining all details coming from historic available sources and architecture requirements. In case of historic gothic vaults they were reconstructed protecting old form providing additional structural composite rib elements. The central tower was constructed as the RC 3D frame (Malesza and Miedzialowski 2004) with masonry elevating cladding due to historic requirements and form. Dome heading the top of tower was designed and constructed as the fine aggregate shotcrete concrete.
Some constructing details are presented in Figs.12-13.

Figure 12 : Central tower construction and reinforcement of the tower base-raft structure.

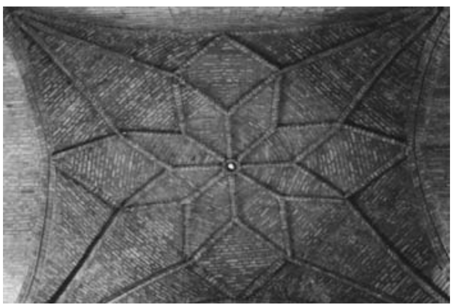

Figure 13 : Details of stellar gothic vault after reconstruction.

3.2 The monastery on Wigry island

High massive retaining walls and erems exhibit structural failures and degradations more evident than any other buildings in monastery. Horizontal displacements of the retaining walls exceede serviceability limit state and became hazardous for stability of the wall and slopes of the hill.

The first stage of revalorization and emergency repair work referred to strengthening of wall with additional temporary supporting timber angle bracing according to the scheme in Fig.14a.

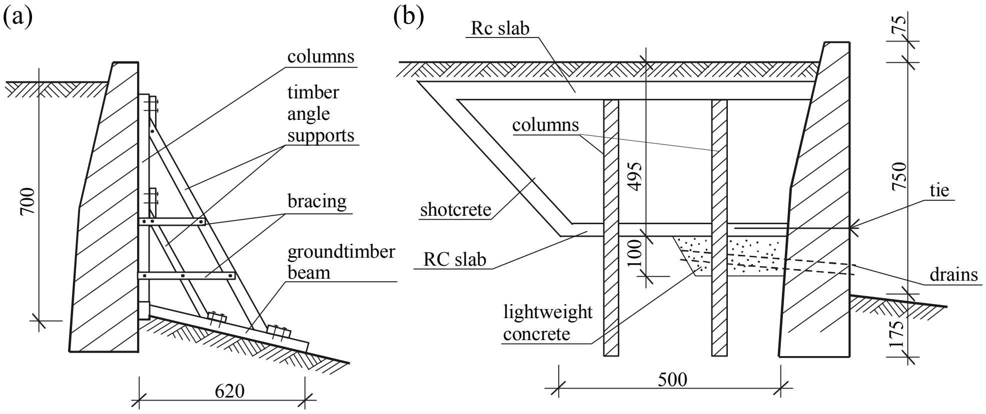

Figure 14 : Temporary supports of the retaining wall and the cross section through the unloading chamber.

Due to unload the retaining walls from the backfill side the empty chambers were constructed as indicated in Fig. 14b.

Underground chambers dimensions of 880x5000x445 cm instead of historic cellar vaults were designed and constructed with RC walls and RC floor slabs covered with soil layer. In addition in the bottom floor RC slab the steel bracing ties were provided to carry out conditions of the retaining wall stability. Draining system was constructed to avoid percolation of ground water behind the renewed retaining walls.

4 CONCLUSIONS

Conducted analyses display the necessity of including and considering the modern technologies, new materials, methods of analysis and new assignment of the historic building at the stage of its reconstruction.

New assignment and technical state can change the scheme of structure, its loading as it was in case of the retaining walls unloading chambers presented in the paper. New materials and technologies are determining and conditioning structural elements varying in their structure scheme as presented in case of stellar gothic vaults.

The modern numerical methods of analyses and computer techniques precisely and more complex evaluate the state of stress and displacements as presented in examples of the stellar vault and base-raft of tower structures.

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