THE RECONSTRUCTION OF THE "BIRTH OF THE BLESSED VIRGIN MARY" CATHEDRAL AT THE CURCHI MONASTERY

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BRIEF HISTORICAL BACKGROUND

According to the legend, the monastery was founded in 1765. The construction of the "Birth of the Blessed Virgin Mary" Cathedral has begun in 1810 and concluded in 1872 (Golubi 2000). This is the only building - the representative of pure baroque style, built on the territory of the Republic of Moldova (fig. 1).

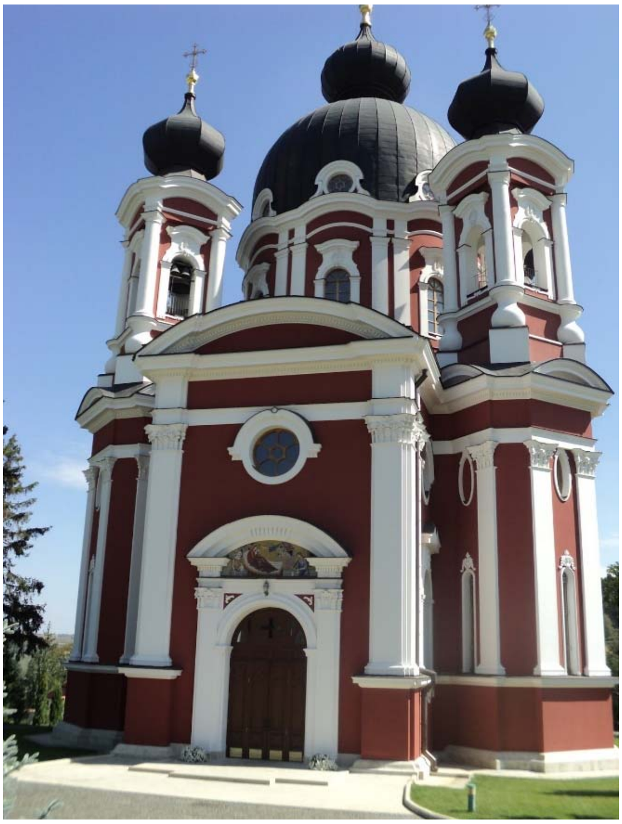

Figure 1. The main facade of the Cathedral.

The fate of the monastery is tragic: it has been closed several times and has faced fire and earthquakes. Only since 1995, it again became an active friary and was opened to the public.

1. STATUS OF THE ISSUE AND FORMULATION OF THE RESEARCH PURPOSE

The opening of the monastery has required the reconstruction of the buildings and structures, and at first instance – of the Cathedral.

For a period of over 150 years, the Cathedral has endured various environmental impacts, including seismic. Because of these effects, damages reducing the overall strength and stability of the building appeared in the structures. In the north and south facade lateral walls, full-height through cracks were observed: from the foundation up to the bottom of the dome cylinder;

Cracks were also located on the axes of the apertures of the windows, with their maximum openings in Northern and Southern part (respectively 1,5 and 2,0 cm).

In the Eastern and Western walls, slight disappearing throughout the height splits were observed.

All over all the types of apertures, on the bottom side of the Cathedral and dome drum, in V-shape breastplates splits and shifts of its organizing stones existed.

In the outer layer of the bottom ring of the drum, built of stones, the weakening of the mortar and the fall of the masonry stones were observed.

From the four designed belfries, two were dismantled. The rest came to the state of failure.

The plaster decoration, paintings were all over damaged.

The main goal of this work was development of the structural conception with a view to ensure the required strength and stability of the Cathedral.

To clarify the causes of the observed deformations the following tasks were set:

- to perform a detailed geological and hydro geological study of the monastery grounds and the adjacent slope;
- to assess the status of the bases and the carrying capacity of a base;
- to assess the stability of the slope;

- to determine the composition and strength of the load-bearing walls.

2. THE RESULTS OF THE CARRIED RESEARCH

Analysis of specific sources and archive materials (Polcanov 2006, Osadcenco & Dombrovan, 2006) and the conducted measurements of the building revealed:

Cathedral is presented in the plan as an octagonal shape with a round projecting altar. The central part is covered with a dome on a high drum cupola (fig.2).

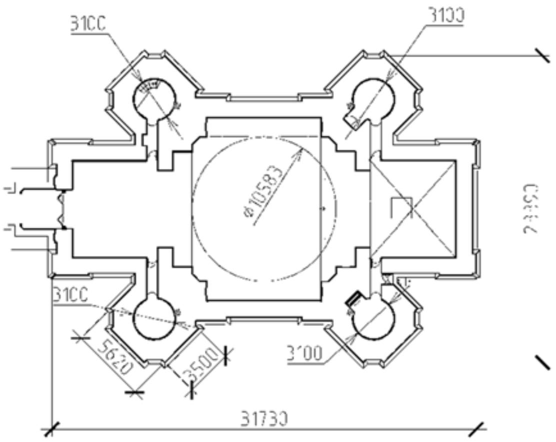

Figure 2. *Plan of the Cathedral at level 0.000*

At the level 0.00, constructively, the building is determined by four 5.62 x 7.08 m pillars. The pillars –
hollow, cavity diameter 3.1 m.

The outdoor maximum building dimensions 31.73×23.39 m, the height to the top of the dome - 40.34 m, the height of the Cathedral with the cross - 42.84 meters.

The foundations of the building walls with the width of 33.0 m and depth of – 2.6 m are made of sandstone masonry on mortar.

Walls - multilayered masonry. The inside of the walls and outside corner areas - of rectangular limestone ashlar; intermediate part of the layered horizontally laid sandstone rocks on a sand-lime mortar.

Domed drum - from sandy limestone rocks; dome – of red brick; outside at the level of the dome, in 1977 was made a reinforced-concrete band with a section of 40×40 cm.

Weight of aboveground parts – 5824 t; foundations – 1285 t.

In order to solve these tasks, 4 prospecting shafts were laid on the perimeter of the building at characteristic points, with the depth exceeding the depth of the location of the foundations base. Probing was carried out manually. Using a hand drill, from the depth of the prospect holes 4 wells were drilled (fig. 2), with the depth from 2.2 to 5.5 m. The depth of the explored strata is from 4.7 m to 8.5 m.

On the geological structure of the site, at a drilling depth up to 8,5m, from the surface the following are involved: filled soil (layer No.1), with a capacity of 0,5 to 1,2 m; soil-plant layer (layer No.2) with a capacity of 0,7m; the sediments of the Quaternary age, presented with sand clays (layer No.3), with a capacity of 1,5 to 3,0m, clayey sands (layer No.4) with a capacity of 1,2 to 1,5m; clay (layer No.5) with the explored capacity of 1,7 to 4,2m.

Manner of occurrence of the selected layers is presented in the Fig. 4-7.

Groundwater was discovered by the wells 1 and 4 at depths of 4,0 and 3,6m accordingly. The depth of occurrence of the water table in the storing well, located below the Cathedral on the territory of the Monastery, was 6,8m in June 2006.

At the depth of the foundation base samples of ground were taken from each prospect hole. In the laboratory, on samples of the natural structure, according to standard procedures, values of the basic physical strength and deformation characteristics have been determined.

The strength properties (the strength parameters C and φ) were studied in box shear apparatus with one given slide plane, under the conditions of the unconsolidated shift with a vertical pressure of 100, 200 and 300 kPa. The results of the shearing tests were corrected after making a connection $\tau = f(\lambda)$, where λ – the deformation value of the sample under the shear.

Strain characteristics (module of the structural strains E) – in consolidometers. Altogether, 24 samples of natural structure were tested. The results of the tests are summarized in Table 1.

Table 1. Physico- mechanical characteristics of the analyzed soils.

Name of soil	ρ_n, g/cm^3	C_n, кPa	φ_n, grad	I_p	I_L	w_e	E, MPa
Low-plasticity loam	1.84	42	19	0,14	0,28	0,26	13
Semisolid clay	2.05	54	22	0,19	0,02	0,25	22
Semisolid loam	1.93	30	28	0,16	0,12	0,23	14
Plastic sandy loam	1.81	40	26	0,17	0,17	0,19	10

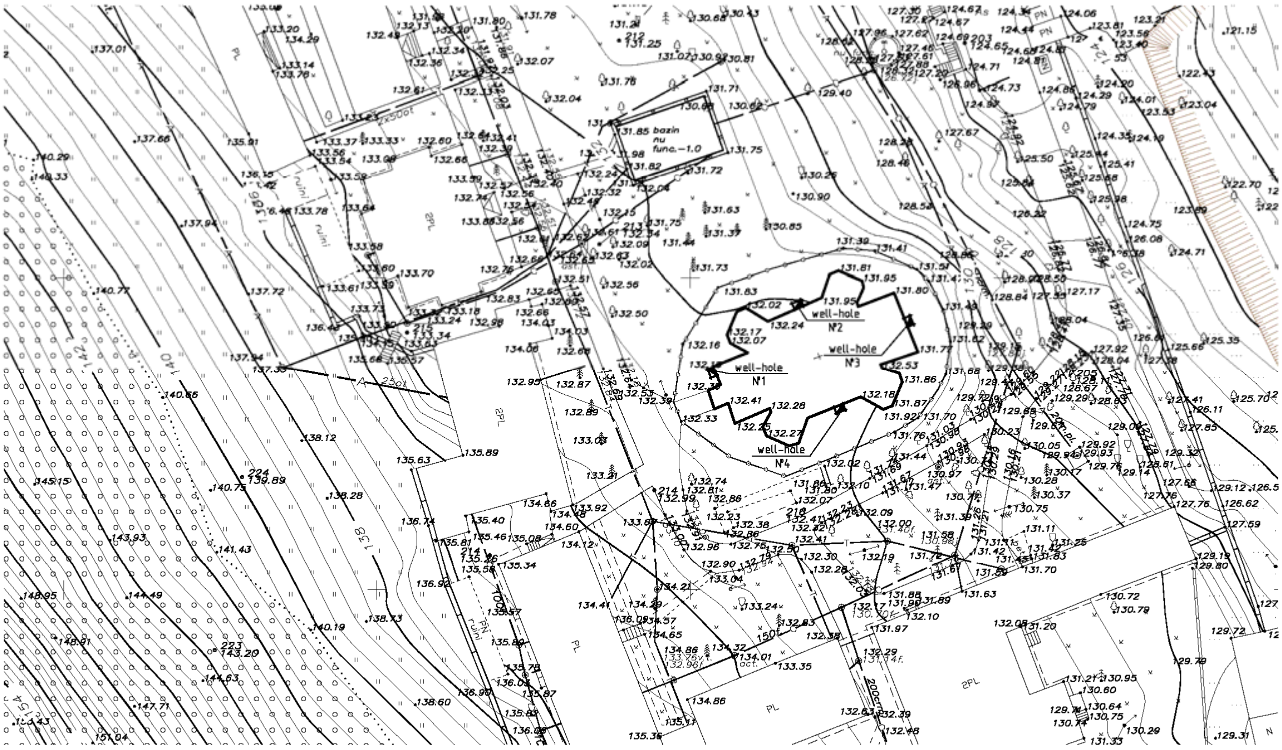

Figure 3. Schema of placement for the well-holes.

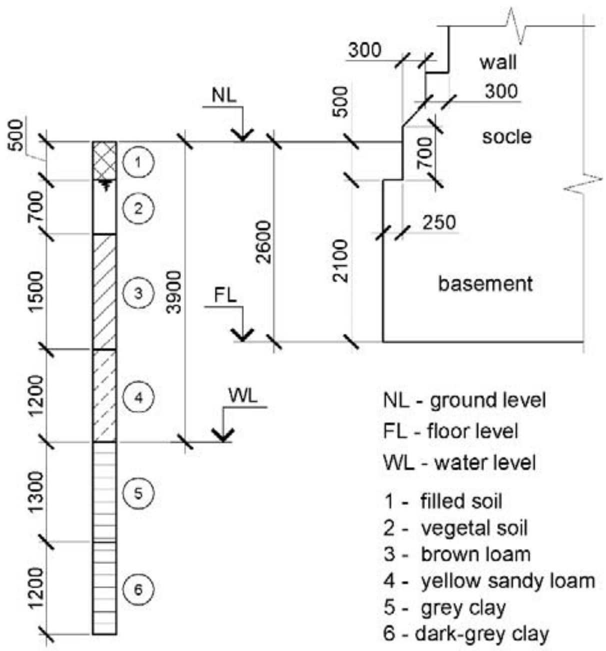

Figure 4. The scheme of the foundation and the geologic column for well-hole 1.

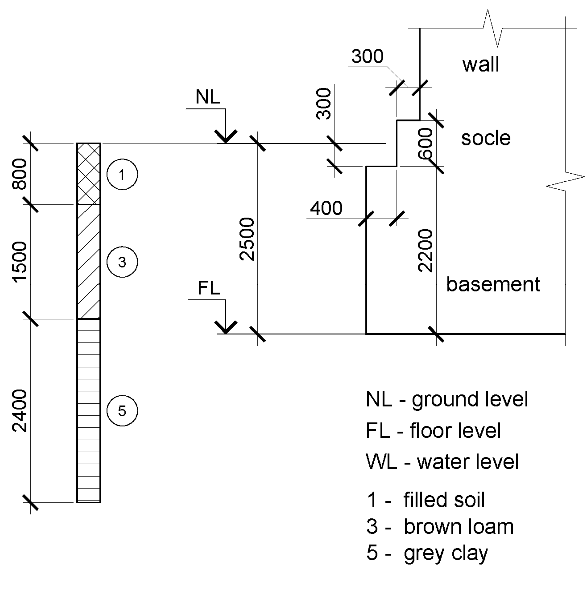

Figure 5. The scheme of the foundation and the geologic column for well-hole 2.

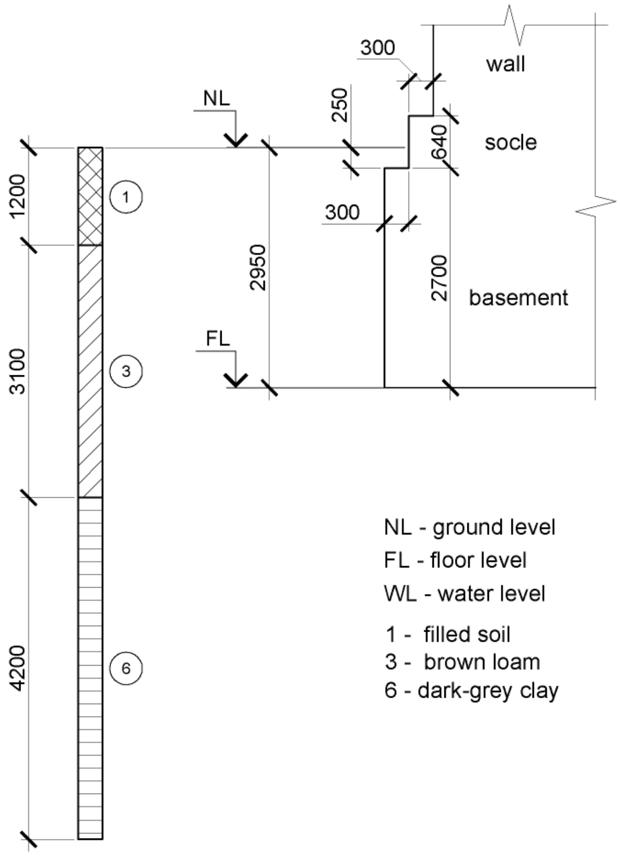

Figure 6. The scheme of the foundation and the geologic column for well-hole 3.

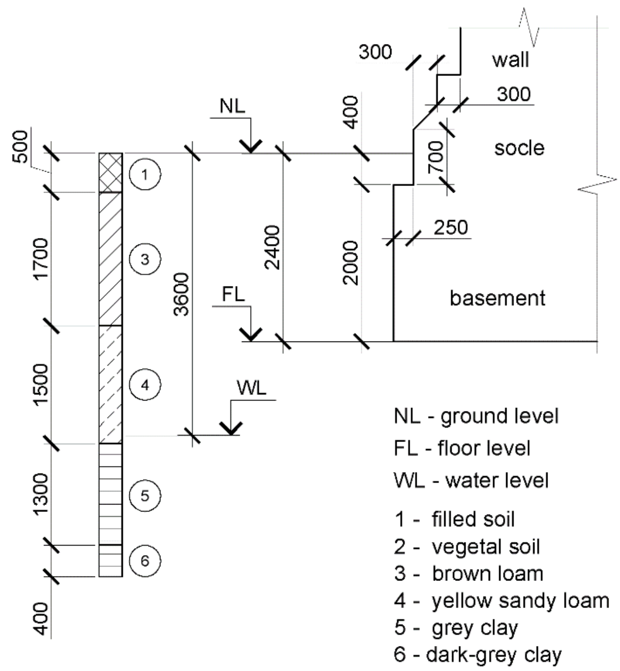

Figure 7. The scheme of the foundation and the geologic column for well-hole 4.

The received data have shown that the Cathedral foundations on four sides on a relatively small site are placed on mixed grounds with different properties.

The average ground strength (S), that is lying directly under the bottom of foundation was determined by the well-known Couloumb's expression:

$$S = \sigma \cdot tg\varphi + C \qquad (1)$$

where σ – vertical stress, кPa;
φ – angle of internal friction, grad;
C – specific cohesion, кPa.

With respect to the open prospecting shafts 1-4, its values were, respectively: for brown semisolid sand clay (prospecting shaft hole 1) - S_1=76 kPa; for pale grey semisolid clay (prospecting shaft hole 2) - S_2 = 94 kPa, for dark-brown semisolid sand clay with carbonate inclusions (prospecting shaft hole 3) - S_3 = 83 kPa, for soft sandy loam (prospecting shaft hole 4) - S_4 = 97 kPa. A little higher values of soft sandy loam strength in comparison with semisolid sand clay and clay, are explained by the presence of carbonate inclusions in the displacement zone.

In view of the discovered geological structure of the strata of the base and the considerable mass of the Cathedral, it can be assumed that, as in the construction process and also in the subsequent years, because of non-uniform deformations of the base in the walls of the building primary stress was accumulated.

In conjunction with occurred earthquakes, determining seismic fault, formation and development of the splits have occurred in weaken places of the Cathedral structures.

The calculations have shown, that a negative factor which was contributing to ruptural deformation of the Cathedral walls, could serve rheological processes, which are taking place in adjacent old landslide slope.

Taking into consideration the uniqueness for Moldova of the restored Cathedral, geomorphological complexity, geological and hydro-geological conditions, researches were continued on the monastery's territory and the adjacent slope. On the basis of the performed land survey and prospect boring an outline of the existing profile of the slope was received and an assessment of its stability was conducted. The calculations were made on the basis of N.N. Maslov's provisions of physical-technical creep theory and were based, inter alia, on the results of numerous studies of potentially dangerous slopes.

In the Northern and Central parts of Moldova slopes are composed of hidden layers with Quarternary Neogene clay mineral. Thus, their long-term resistance is determined to a large extent by the regional features of these solids, suggesting the presence in them of natural micro and macro zones of weakness, including also inclined mirrors of slip. The presence of these zones has an effect on the nature and speed of percolation in time of rheological processes and determines the calculated values of parameters of lasting properties with a comprehensive assessment of developed slopes sustainability. The main indicators which characterize the process of reducing the strength in time under projecting the stableness, according to Professor N.N. Maslov's physico-technical creep theory, as well as the views of Professor M.N. Goldstein and their learners, are: residual strength (S_{lim}), structural cohesion (C_c), *"threshold creep"* (τ_{lim}) and viscosity grade (η).

According to main provisions of the physic-technical creep theory (N. Maslov, 1984) development in the clay rock formation on the slopes of sliding surfaces is associated with the fall of strength as a result of several primary deformations, resulting in surface discontinuity of the solid and their additional moisture in the shear zone.

The forecast of long-term resistance is based on a well-known expression, given by Professor N.N. Maslov, for the description of the clayey soil (N. Maslov, 1941).

$$S_{pw} = P_n \cdot tg\varphi_w + C_w, \qquad (2)$$

where: $C_w = C_c + \sum_w$

P_n - normal stress, kPa;

φ_w – true angle of internal friction, grad

C_c - rigid structural cohesion of irreversible character;

$\sum_w$ – coupling connection of water-based – colloidal nature of reversible behavior (cohesion bond);

The appearance of crawling is possible with the simultaneous observance of conditions

$$\left.\begin{matrix} \tau_{max} < P_n \cdot tg\varphi_w + \sum_w + C_c \\ \tau_{max} > P_n \cdot tg\varphi_w + C_c \end{matrix}\right\} \qquad (3)$$

where τ_{max} - maximum shear stress at a point of foundation, kPa.

In other words, deformation of crawling is possible under mobilization of cohesive property of soil ($\sum_w$) in conditions of a secured general stability of the slope under the condition:

$$\tau_{max} > \tau_{lim} = P_n \cdot tg\varphi_w + C_c, \qquad (4)$$

where τ_{lim} - "*threshold creep*", kPa.

In other words, when

$$\left.\begin{matrix} K_{\varphi_w C_w} > 1.0 \\ K_{\varphi_w C_c} > 1.0 \end{matrix}\right\} \qquad (5)$$

threshold creep is impossible and the general stability of the slope is ensured.

Provided that

$$\left.\begin{matrix} K_{\varphi_w C_w} > 1.0 \\ K_{\varphi_w C_c} < 1.0 \end{matrix}\right\} \qquad (6)$$

the insurance of overall stability is carried-out under the conditions of appearance of threshold creep and, therefore, disbonding of the firm structural strength ($C_c \to 0$).

Under circumstances where

$$\left.\begin{matrix} K_{\varphi_w} < 1.0 \\ K_{\Sigma_w} > 1.0 \end{matrix}\right\} \qquad (7)$$

The slope is also stable, but is experiencing the threshold creep.

And finally, under

$$K_{\varphi_w \Sigma_w} < 1.0 \qquad (8)$$

the harsh breakdown of the stability of the slope occurs.

In terms of 5-8 indexes with assurance coefficients correspond to strength properties, included in the calculation.

During the evaluation of the stability of the considered slope horizontal forces method was used, also known as "*Maslov-Berer*" method (fig.8). Main formula is presented below.

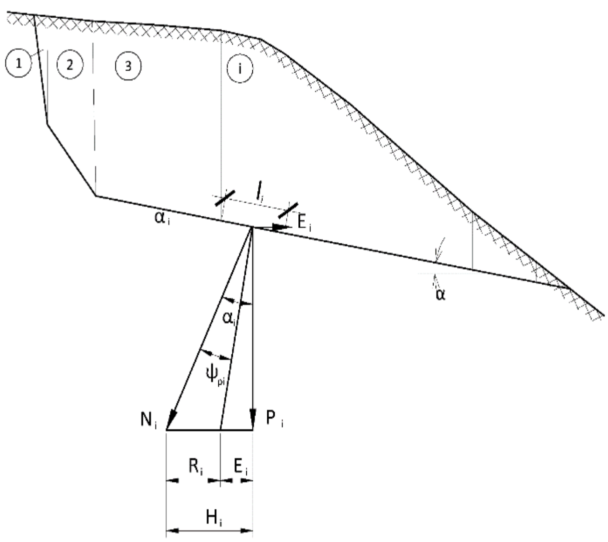

Figure 8. Calculation's scheme for "*Maslov-Berer*" method.

$$K = \Sigma R_i / \Sigma H_i \quad (9)$$

with

$$\begin{cases} H = P \cdot \mathrm{tg}\alpha \\ E = P \cdot \mathrm{tg}(\alpha - \psi_p) \\ R = H - E = P \cdot \left(\mathrm{tg}\alpha - \mathrm{tg}(\alpha - \psi_p)\right) \end{cases} \quad (10)$$

where $\psi_p = \mathrm{arctg} F_p$,

$$F_p = \mathrm{tg}\,\varphi + c / \sigma_n \quad (11)$$

F_p – angle of shear resistance;

P_i – weight of the selected block;

α_i – inclination to the horizon of the selected block;

In view of the foregoing, for determination of factor safety the following functions were use

$$K_{\varphi wCw} = \frac{\sum_{i=1}^{n} P_i \left\{ tg\alpha_i - tg\left[\alpha_i - arctg\left(tg\varphi_{wi} + \frac{\Sigma_{wi} + C_{ci}}{p_{ni}} \right)\right]\right\}}{\sum_{i=1}^{n} (\pm P \cdot_i tg\alpha_i)}$$

and, at the same time

$$K_{\varphi wCc} = \frac{\sum_{i=1}^{n} P_i \left\{ tg\alpha_i - tg\left[\alpha_i - arctg\left(tg\varphi_{wi} + \frac{C_{ci}}{p_{ni}} \right)\right]\right\}}{\sum_{i=1}^{n} (\pm P \cdot_i tg\alpha_i)}$$

where $K\varphi_{wCw}$ – coefficient of resistance, corresponding to the total coupling C_w;

$K\varphi_{wCc}$ – coefficient of resistance for structural cohesion C_c;

Analysis of the calculations showed that the slope has some stability margin ($K\varphi_{wCw} = 1.6$), but also is exposed to creep deformation ($K\varphi_{wCc} = 0.98$), with offset on the slope with a velocity of v_0.

Unfortunately, for some reasons, beyond the control of the authors of the work, detailed studies regarding the estimation of the speed of the deformation in time were not held.

However, taking into account early conducted researches (Polcanov et al. 2012), it was proved that, rheological processes, laying on the slopes of the republic have a very negative impact on operating conditions of the buildings and constructions.

In the majority of cases in the walls of the buildings even with rigid structural scheme, numerous splits can be observed. Destruction of separate buildings can be seen.

Given the nature of the observed deformations on the slope, for stabilization a suite of anti deformation measures were proposed. In developing of the suite was taken into consideration that the raise of soil dampness on the slope may affect the reduction of «threshold creep» and viscosity grade and thereby increase the speed of the massif downhill. Thus, in the suite of anti-deformation measures the drainage system was included in conjunction with the use of easy-to-hold construction bored piles. Along with this measures for improvement of natural conditions on the slope (partial redevelopment, planting of trees, bushes, perennial grass) were recommended.

CONCLUSIONS AND RECOMMENDATIONS

The performed studies have shown that the main load bearing structures of the Cathedral – groundwork, pillars, walls, etc. are, in general, in fair condition and can be restored.

In the restoration work has been included:

- preliminary stressed structure framing of the bottom stone ring of the drum;

- general concrete shell throughout floor structure, over the choirs and the altar, at the base of the belfries, harmonized with build-up preliminary-stressed bottom ring of the dome drum;

- the shell is designed to create a rigid disk to ensure the joint movement of the top of the pillars, separated by formed splits.

- the proposed solutions must ensure the joint work of the bottom and crestal area of the Cathedral (fragment of the proposed restoration is presented in figure 9).

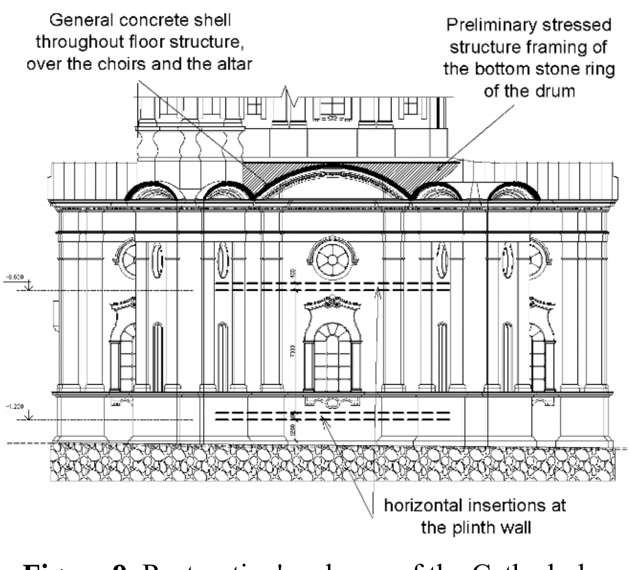

Figure 9. Restoration's schema of the Cathedral.

- the execution of the cast reinforced concrete preliminary-stressed horizontal insertions at the plinth wall levels, bottom and top windows, joists.

The screed coats should draw together the walls, existing through – wall splits;

- construction of the cast reinforced concrete horizontal insertions, harmonized with bottom and top rings of the dome drum;
- drafting of the map of splits with its further broaching cementation with polymer solutions.
- for stabilization of slowly developing creep deformations a suite of anti-deformation measures was proposed.
- taking into consideration the possible negative impact of the Cathedral construction of rheological processes, it is recommended to provide stationary geodetic observations of the adjacent slope behavior.

The proposed project was implemented. "*Birth of the Blessed Virgin Mary*" Cathedral is opened for service and visitors.

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