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The Importance of Field Tests and Monitoring Activity for the Remedial Measurements Coresponding to Some Old Buildings in Bucharest

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THE IMPORTANCE OF FIELD TESTS AND MONITORING ACTIVITY FOR THE REMEDIAL MEASUREMENTS CORESPONDING TO SOME OLD BUILDINGS IN BUCHAREST

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ABSTRACT

The present paper shows the way in which by field tests such as light and standard dynamic penetrations, the effects of a deep excavation on the nearby constructions could be quantified. The consolidation works could be design taking into account the interpretation of the test results

INTRODUCTION

The paper presents the history of a deep excavation supported by slurry walls in the historical centre of Bucharest. As shown in figures nr 1 and 2, the emplacement chosen for the construction of an 18 level building already finished, is found in the very proximity of some old constructions (the Armenian complex and a block of flats). The building is also placed at the crossing of two high traffic boulevards. According to the project on this difficult emplacement was built a complex structure consisting in 4 level basement a ground floor and 18 office levels. The design excavation was realized 16,15 m deep and sustained by walls cast in situ 60 cm thick and 21 m deep, which means 5 m under the excavation base.

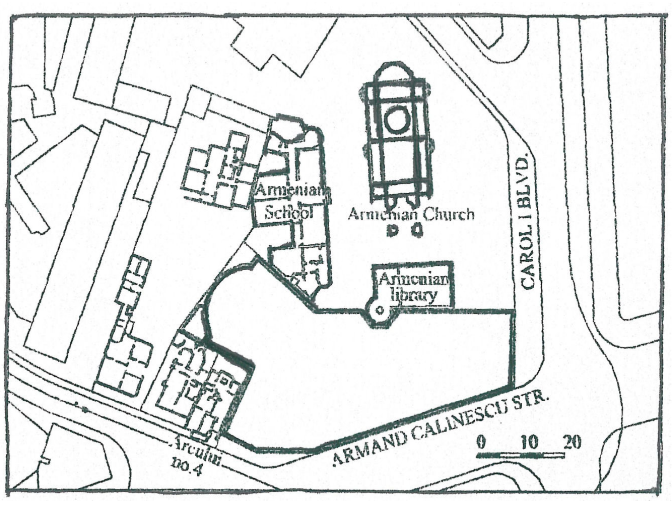

Fig.1. "Armenian complex" and the deep excavation contour

Photo 1. General view of the "Armenian complex" and of the deep excavation area

GENERAL DESIGN DATA

From a geotechnical point of view, the emplacement is characterized by the presented formation in fig.2 that is:
- "Bucharest" clay;
- "Colentina" sand an gravel complex;
- intermediary sand;
- intermediary clay and "Mostistea" complex

The excavation design took into consideration the possible loads due to the seismic conditions of the site location. The physical and mechanical characteristics for the geotechnical formations are shown in Table 1.

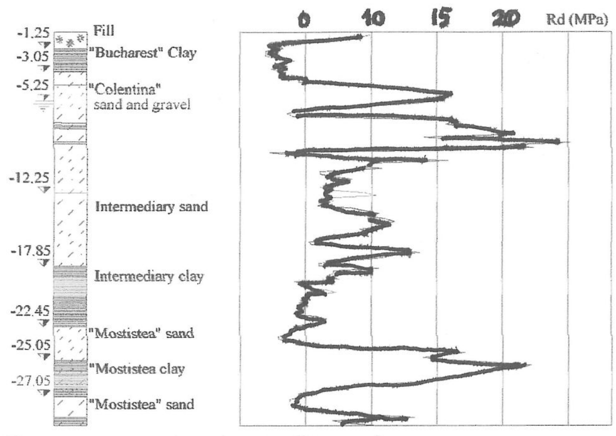

Fig.2 Litological colum and SPT results

Table 1 geotechnical characteristics:

Soil type	Physical characteristics					Mechanical characteristics		
	γ	n	Ic	Ip	Id	M_{2-3}	4	c
	(kN/mc)	(%)	(-)	(%)	(-)	kPa	(º)	(kPa)
Bucharest Clay	19	40	0.60	32	-	12500	18	30
"Colentina" Sand and gravel	22	33	-	-	0.7	-	36	-
Intermediary sand	19.5	30	-	-	0.5	16600	25	15
Intermediary clay	20	35	0.70	35	-	16600	14	70
"Mostistea" Sand	21	32	-	-	0.7	11100	30	20

TECHNOLOGICAL EVENTS AND THE INFLUENCE ON THE NEIGHBOURHOOD AREA

On photos 2 and 3 one can see the buildings situated in the vicinity of the excavation under slurry walls protection. It is about the "Armenian complex" with 3 main buildings (church, library and school) and an old multi-storey structure situated in Arcului 4 Street.

The slurry walls have been designed with a length of 21.00m, with 5.00m under the excavation bottom. Analyzing the lithological column it results that the excavation is protected against boiling, by the length of the slurry walls and by the presence of the intermediate clay of 5.00m in thickness.

Considering the irregular form and the dimensions in cross section of the excavation (Starting from 15.00m up to 28.00m) it was designed a retaining system using two solutions: five levels of prestressed anchors 20.00 to 28.00m long, with bulbs of 8.00 and 12.00m and four levels of steel struts made of pipes 600 mm in diameter. The calculated force in the anchors was 540kN. [Chirica et al, 2004]

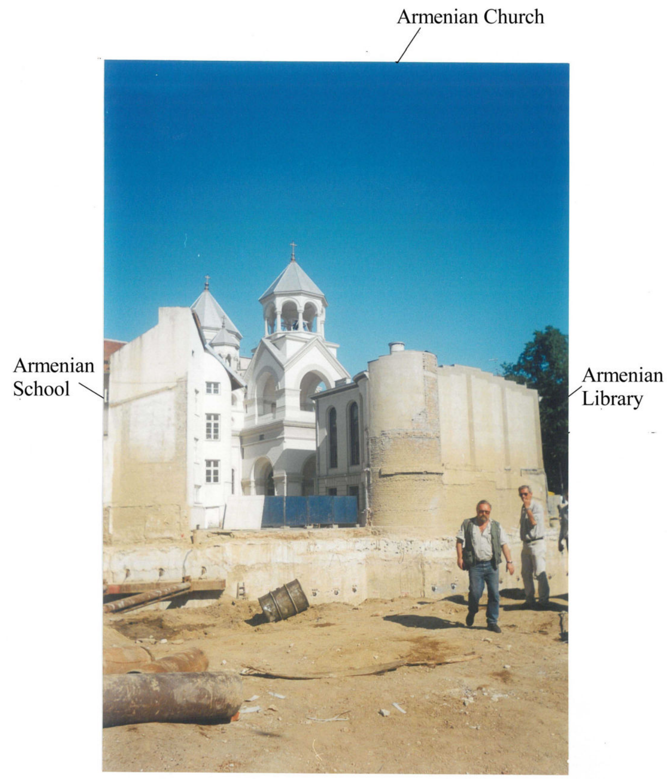

Photo 2. Armenian complex and the executed slurry wall

Analyzing the existing structure of he buildings in the close proximity of the site, it was decided to increase the safety of the old multi-storey building in Arcului 4 Street, by a screen of tangent micropiles of 180mm diameter drilled 8.00m deep (See photo 3).

The screen was made before the excavation for the slurry walls in that area, in order to protect the basement of the building. On photos 4,5 and 6 one can see the beginning of slurry wall execution adjacent with the old building and the micropiles screen position.On photo 7 a general view of the slurry walls and sustaining structure near the "Armanian Complex" is presented

The most important technological incidents were (see fig 3):

- the execution of the anchors (5 levels A1-A5) under the underground water level was done with important losses of water and granular material (fine sand) during the drilling; it was approximated that volumes between 0.5 to 1.0 m3 of lost material remained uncompensated for each anchor;

- defects in the slurry walls, located between 13.5 and 16.15m deep, consisting in openings (holes) 0.30m to 0.50m wide (D1, D2); because of the high hydraulic gradient and of the corresponding pressures of the saturated ground (about 100kPa) important volumes of water and soil material came into the excavation area; in photo 8 the D_1 defect location is presented.

Photo 3. The old multi - storey building in Arcului 4 street

Photo 4. The screen of tangent micropiles position and the beginning of slurry wall execution near the old building

Photo 5. The slurry wall execution - lateral image

Photo 6. The slurry wall execution - front image

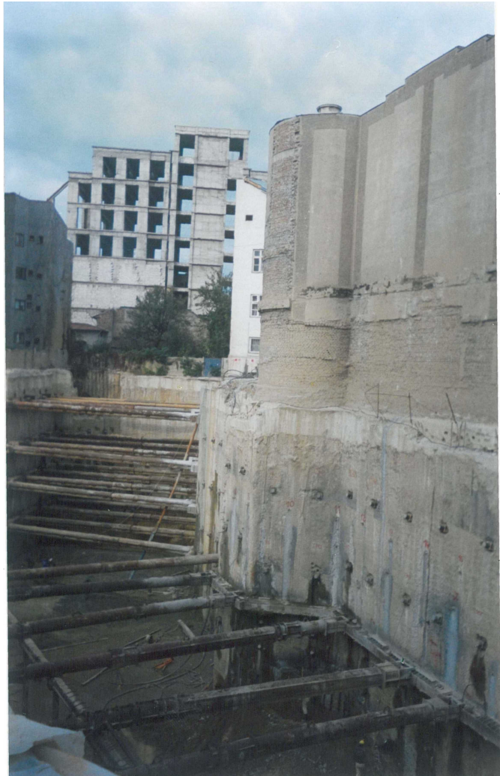

Photo 7. General view of the deep excavation near the "Armenian complex" location

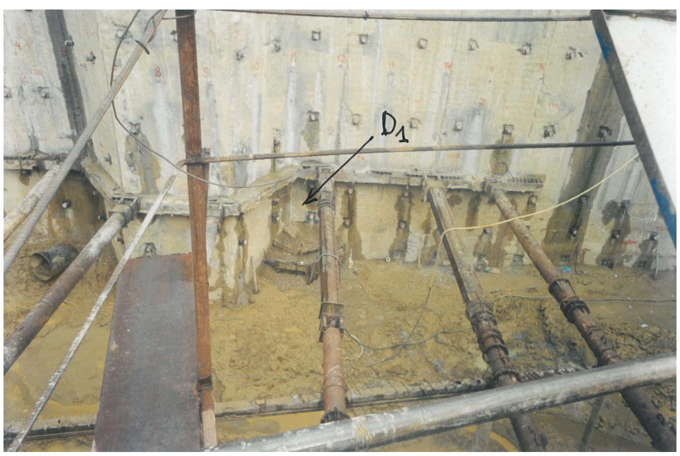

Photo 8. Slurry wall defect situated adjacent to Armenian library at 16 m deep (D1 on the figure no 3)

Analyzing the two types of technological incidents it results that the excavation surrounding area was influenced especially the foundation ground of the old buildings, with very sensitive structures.

MONITORING AND THE FIELD TEST RESULTS

The slurry walls performance begun in November 2000 and the excavation was realized during the period February–November 2001.

Taking into account the density of the buildings in the vicinity, their bad technical shape and the heavy traffic on the two main streets, a monitoring system made by settlement and cracks marks was installed in order to evaluate step by step the effects of the execution on these buildings.

Figure no. 3 shows the location of the principal settlement marks, installed on the most sensitive buildings. Also a lot of SPT tests by using a heavyweight hammer device were performed during four stages as below:

- stage I having 14 tests during January 2002 in order to identify the affected zones because the technical accidents;

- stage II having 10 tests;

- stage III with 39 tests; stage IV with 14 tests during the period April-July 2002 in order to quantify the effect of field consolidation by rejections.

- stage IV with 14 tests during the period April-July 2002 in order to quantify the effect of field consolidation by rejections.

In figures 4, 5 and 6 is represented the evolution of the settlements related with the mentioned technological incidents, leading to the following conclusions:

- for the Armenian Library, the execution of the 3rd level of anchors (-10.55m) and of the corresponding excavation lead to settlements increasing of 2.5 to 3 cm; it is important to observe the strong influence of the defect in the slurry wall (D1), leading to an increasing of the settlement from 3.0 to 3.5cm (see fig 4);

- for the Armenian School, starting with the execution of the 3rd and 4th level of anchors some increasing of settlements have been registered, from 1.0 to 1.5 cm ; the defect (D2) in the slurry wall had a strong influence , the settlement increased with 6cm (see fig 5);

- for the American Church, situated at about 20m distance from the excavation , the major defect D1 in the slurry wall had an important effect, with settlement increasing of 2.5cm (see fig 6); the anchors execution had less effect (settlements recorded of about 0.5cm).

For the processing and interpretation of the SPT test results, the correlations in table 2 were used. According to these correlations, for every geological formation were determined equal value Rd curves after the execution of slurry walls, anchoring and excavation.

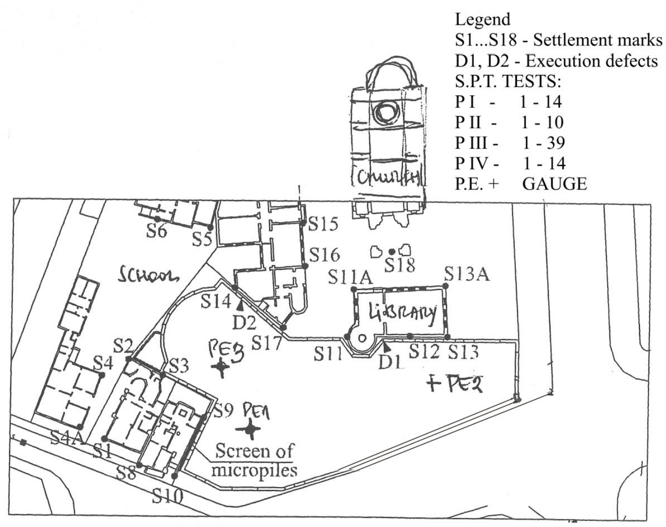

Fig.3. Surveying marks and S.P.T. location

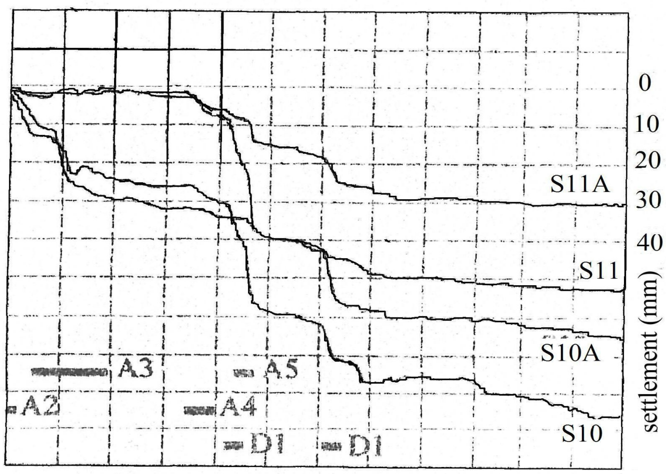

Fig. 4. Settlement evolution Armenian Library

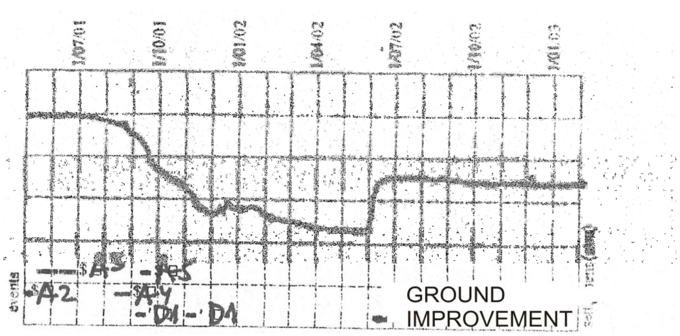

Fig.5. Settlement evolution, Armenian Church

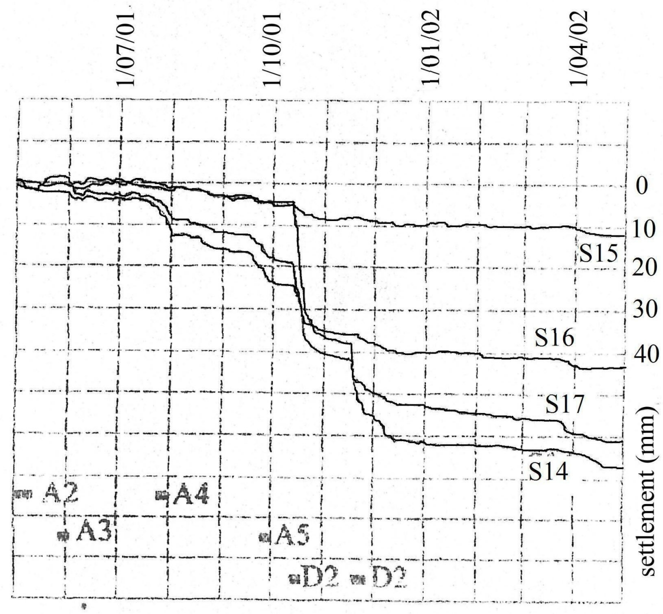

Fig. 6. Settlement evolution Armenian School

Table 2. Correlations between $N_{20,}$ values of Rd dynamic penetration resistance and physical state of soils

Soil type	N_{20}	R_{20}	Physical state
non cohesive	0 - 10	<50	loose
	10 -20	50 - 95	medium compacted
	>20	> 95	soft
cohesive	0 - 4	< 24	plastic consistent
	4 - 15	24 - 48	consistent
	15 - 40	48 - 120	stiff
	>40	>120	hard

After the processing of the SPT results, it could be determined the horizontal and vertical extension of the influenced area of the foundation ground as a consequence of the flaws in the slurry walls, and also of those of anchoring.

From the processing of the SPT results, the following conclusions were reached:

- - the result of the execution of the slurry walls was mainly the aeration of soil by ≈ Δn=4% on 8m deep and 4m behind the walls;
- - by execution of the anchoring with high losses of material, the extension of the weak area from the foundation ground was up to 12 m deep and another 4÷6m wide;
- - in the weak area the dynamic penetration resistance Rd has diminished from 200÷ 300 kPa to 50kPa. The above observations explain very well the increase in the settlements by 6cm (see figure 8) for the Armenian

Church and Library, and thus the spreading of structural flaws.

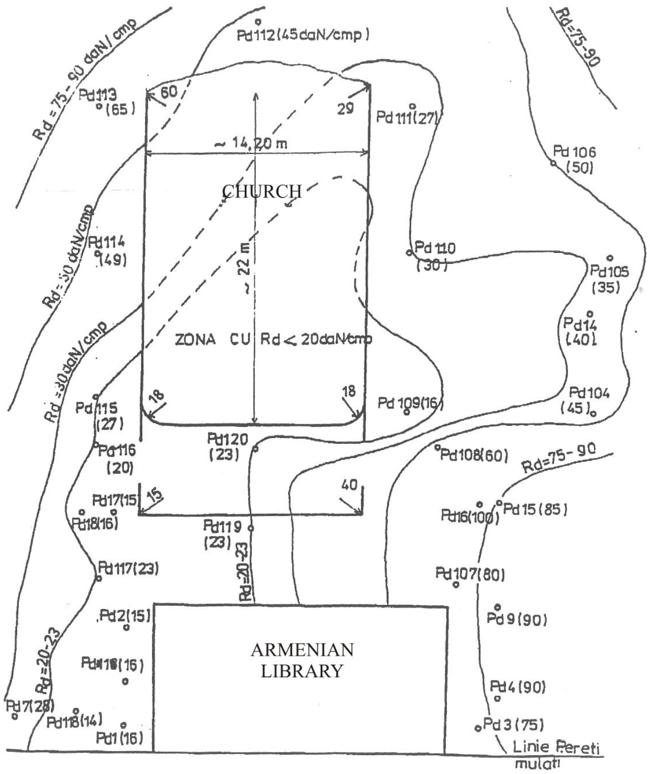

Fig. 7. Izocurves for dynamic penetration resistance of "Bucharest Clay" by processing S.P.T. results data

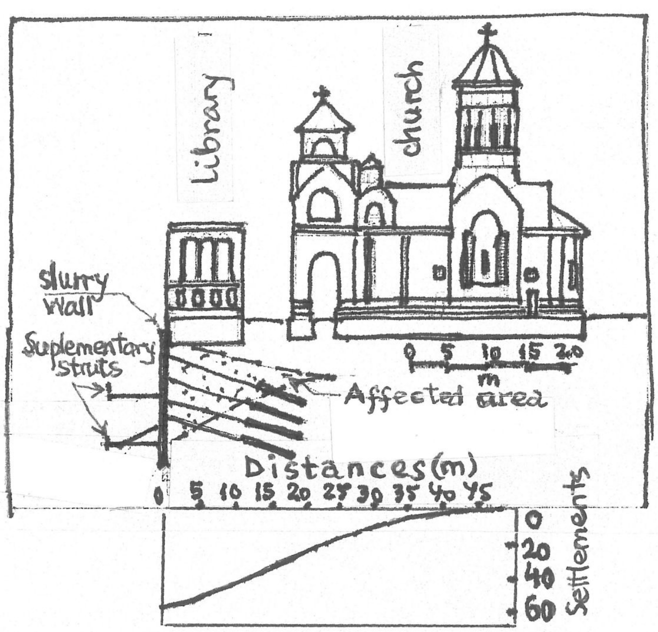

Fig.8. Settlements values and affected area extension

THE STRUCTURAL SYSTEM CONCEPT FOR ARMENIAN CHURCH CONSOLIDATION

The Armenian Church in Bucharest, with Holy Archangels Michael and Gabriel as patrons of the church, was built as it is following the project of architect Dimitrie Maimoroiu between 1911 - 1915.

The emplacement coincides with the location of an old church from the XVIII century which burned during a fire. In time, the church suffered important deformations caused by a series of earthquakes from which the major ones were in 1940 and 1977.

The church was partially repaired last time in 1988 – 2000 with the occasion of facade restoration when local reparations were also made for the superstructure. It should be mentioned that before the completing the slurry walls and the excavations, the church as the other buildings from the Armenian Complex had unmonitorised deformations, yet visible at foundations and at superstructure.

The execution flaws previously presented led to the reactivation of the settlement process and also to the apparition of new structural dameges, cracks in foundations beside the existing one.

This process was accelerated by the lack of waterproofing of a very old sewer system in which a large quantity of water (~200 m^3/day) was evicted to descend the ground water level from the excavation. Immediately, the settlement monitoring process started and a system for improving the ground foundations properties by injections was designed.

Tacking into account that Bucharest clay has a dampening sensitivity of 1.8 % the reactivation of settlement process has one more explanation beside the major flaws of slurry walls executions.

Figure 9 shows the distribution of injection drillings afferent to "Armenian Church" executed in three stages:

- stage I – injection drillings of 7÷10 m deep equally spaced of 1,85m on 2.4 m wide strip;
- stage II – injection drillings of 7÷10 m deep at 1.15÷1.85 distance following church contour on 0.6 m wide strip;
- stage III – injection drillings around bell tower foundation situated in the vicinity of cast in situ walls.

These drillings of ~ 18 m deep have the role to rehabilitate the ground structure in depth in the area which was mostly affected by executions flaws, which lead to sufozia toward excavation of dozens of m^3 of soil and water.

The drillings were rotary executed with bentonite mud circulation and cased with 133 mm diameter tubes and were equipped with 50 mm diameter sleeve pipes for 2 linear meters. Subsequently the pipe was built in a covering made of stabilized cement-bentonite suspension.

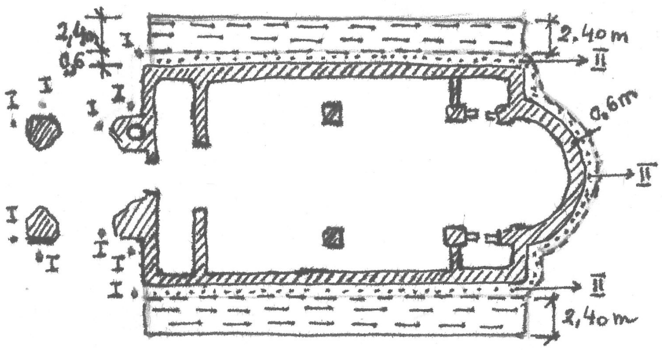

Fig. 9. Grouting boreholes location on the Armenian Church contour

The sleeve tubes were connected from a maximum depth to 2.0 m from ground surface. The injection was made upwards by hydraulic fracturing under maximum pressures of 4 atm.

The suspension used for one cubic meter was: 600 kg cement, 50 kg bentonite, 10 l sodium silicate, 730 l water. The injection suspension has a Marsh viscosity (at 15 º - 20 ºC) of 45-50 sec and a density of 1.38-1.40 t/m^3. The pressure of ground injections was checked to prevent a deformation of 1/100 mm for ground and building structure. In this case the injection drillings had the inclination of 10º and were executed symmetrically from longitudinal axis of church to prevent generating supplementary efforts.

After finishing all the injection phases, by using the monitoring process it was observed that the evolutions of settlement and fissures process had diminished in speed and intensity.

Eng. Viorica Ciugudean and Dr. Eng. Rene Jaques Bally from “Metroul” Bucuresti Company had a great contribution for the consolidation ground and control of the grounds injections effect.

Soon after completing the consolidation process by ground injections, the rehabilitation process started for the urbanistic network around church foundations.

The church is built on vertical plane (Fig.10), symmetrically to the longitudinal axis, apses included in nave and has a tower bell at the entrance, main stipple Pantocrator on nave and polygonal altar. [N. Gospodinov et al,2007]

The main stipple lies on four piles. The Church is painted at the interior. There are some important chambers situated at the corner of “the nave” with walls up to the attic level that form some tubes with high resistance and rigidity.

The bell tower (fig.9) has a ground floor and two square levels with 8 m side, the third level is octagonal and has a metal structure to sustain the bell.

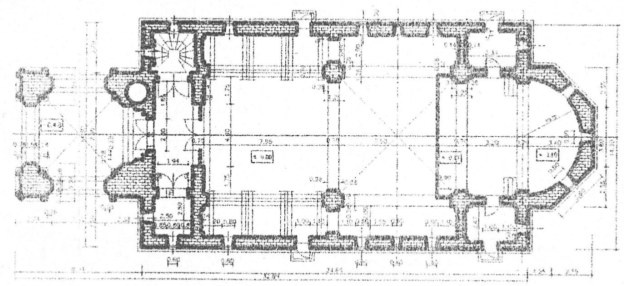

Fig.9 Ground level plan

The tower is symmetrical on both directions with a 2.5 : 2.9 ratio between height and base.

The church nave has at the entrance a choir located at approximately 5 m above the church porch and between the two chambers, one of which is the stair well that leads to the choir and the bell tower.

The choir has the cylindrical vault supported by the Western tympanum and the arch between the choir and the pronaos; next, the pronaos also has a cylindrical vault supported at East on the arch of the end of the choir, at West on the naos arch, and on the sides on the plates supported by the console that come out from the longitudinal walls.

The key of the cylindrical vault is approximately 12 m high.

The square plan of the naos with the distances between the axes of the pillars at 7,5 m, supports through pendentives, the main tower cylinder with a vault at about 25 m hight.

The altar has the same height regime as the pronaos and is situated between proscomedie and diaconicon which are at the Eastern corner of the nave, is continued by the polygonal area and is covered by a cylindrical vault continued with a semi vault.

As for the materials used for the construction, the studies have confirmed the good quality of the brick masonry, of the mortar and the concrete from the structure, while for the foundation were used poor materials as stabilized gravel (a mixture of gravel and lime).

For all vertical elements were used brick masonry, C75-100 with mortar M100, while for the elements of the vault type or arches, reinforced concrete with a low mark (120 - 150 daN/cm^2 compression in strength; in addition, the main tower cylinder is made of reinforced concrete with I metal profile and high resistance and rigidity.

In time, the church was subject of a great number of Vrancene earthquakes, 8 with a magnitude above 6 (on Richter scale), of which 2 major earthquakes: the first one in October 1940 (7,4), and the other in March 1977 (7,2).

Thus, in time the church has suffered a series of damages, therefore it was repaired several times, without being entirely consolidated.

The last consolidation in 1998-2000 (with the occasion of façade restoration) also included local consolidation works for the bell tower and the walls of the nave.

We also mention that the repaired areas ("ZIA" bow tie and reinforced masonry) have well lasted in time, the later cracks being smaller and uniformly distributed.

Mainly, the mechanism of failure can be described as characteristic for all cult monuments (orthodox or catholic), and is determined by geometrical, volumetric and structural ununiformities, that generate side rigidity and different dynamic characteristics.

During the earthquakes, the structures thus designed, act as a conglomerate of "blocks" with independent oscillations as well as for frequency and for amplitude.

The oscillations of these blocks change phases during the seismic excitations, which determines amplifications and diminutions that lead to effort concentrations in the 'contact' areas and also lead to specific degradations (crack and/or fractures).

As a rule, the mechanism of failure has two major components, one longitudinal and the other transversal, which go through the structural zone with smaller or weaker sections of the construction that is doors or windows.

In our case, the mechanism of failure of the Armenian Church was characterized by a dominant transversal component.

This particularity was determined by the fact that the reinforced concrete vaults have a smaller weight than the brick vaults, but the strength and the deformation modulus are significantly superior, which reduced the longitudinal degradation component to a continuous crack line from the west tympanum to the altar with openings of more than 1 - 2 mm.

On the other side, because of the airing of the foundation ground that lays on a longitudinal degradation gradient, the transversal component of the failure mechanism has developed more by the apparition of new cracks which by that time hadn't been damaged, and the old cracks and fractures reached approximately 2.5 - 3.5 cm from 4 - 5 mm.

As a consequence to the failure mechanism developed in time and amplified by the uneven settlement phenomenon, the monument has been divided in 7 separate blocks that, in case of a major earthquake, were subjected to structural greater damage and even some collapses (fig. 10).

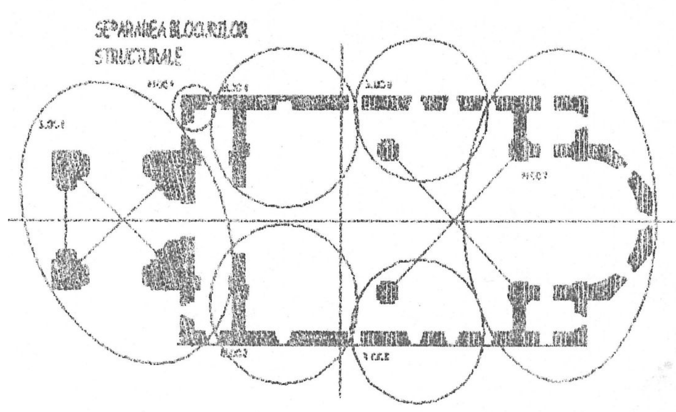

Fig.10. Structural blocks separation

Thus, the chosen consolidation solution was thought as a structural chain that could take over all the loadings that could have appeared in exceptional cases and passing them on to the foundation ground.

The problem was to design a rigid and powerful spatial system for the entire structure that could recover the continuity of the original material and to assure the binding and the stability of all the structural blocks.

In the same way, the consolidation system must meet the following structural demands:

- to assure the material compatibility, the adhesion and the mechanical astriction to the existing structure so that together to contribute to the taking over of the loadings in some exceptional cases.
- to have the necessary strength and rigidity that might be needed in case of a major earthquake.
- to be hidden to the interior and the exterior of the monument, not to harm what so ever the paintings and the original decorations; these are the compulsory requirements for any king of intervention on any historical monument.

In these conditions, for the foundation system we have chosen a set of Vierendeel spatial beams that links at the foundation level the tower bell and the walls of the nave (fig 11).

This foundation system recovered the structural continuity for the infrastructure which, because of the failure mechanism, was transformed from continuous foundations to isolated ones, each with different displacements and rotations.

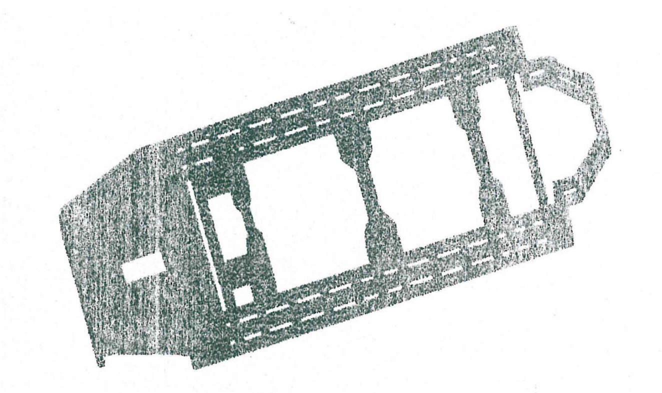

Fig. 11. The new foundation system

The consolidation system of the superstructure consisted of creating four towers at the corners of the nave inside the two lateral compartments of the church porch, as well as in the Eastern head of the nave inside the altar (fig.13).

These four towers have been the main structural elements for the concept of unitary structural consolidation of the superstructure and the infrastructure.

The project for the recovery of the church structure was elaborated in association with Eng. Nicola Gospodinov, and led to the assurance of foundation-superstructure binding by longitudinal and transversal links.

The restoration works were executed at the same time and for the recovery of the interior decorations, degraded in time as a consequence of settlements, the restoration of the paintings as well as the total recovery of the damaged mosaic.

The works were made by a number of restoration painters, stone masons and carpenters. The mosaic was restored under the supervision of the restoration architect by workers who also made the consolidation works.

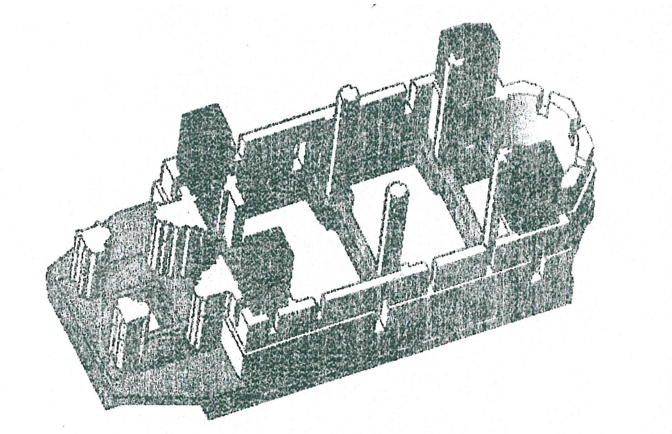

Fig. 13. Vertical structural elements

Photos 9 and 10 show details with the operation of reinforcement assembly for the supplementary foundations.

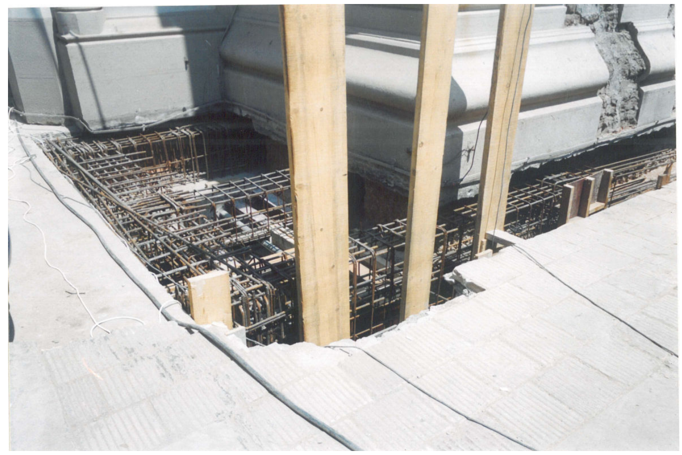

Photo 9 Supplementary foundations area near the church entrance

Photo 10 New foundation reinforcement inside the church

CONCLUSIONS

The main object of this paper is to underline the importance of field measurements during the execution of works such as deep excavation in the proximity of old buildings with very sensitive structures.

The SPT monitoring and settlements survey of the impact on surrounding areas of such technologies improperly executed was essential for designing the consolidation works. By using the same type of soil tests the effect of ground injection could be determined by improvement of mechanical properties and also by decreasing and stabilizing the settlements for the surrounding buildings.

Due to their great importance for the safety of some foundation works with advanced technologies in areas with old structures settlement sensible, the field tests and measurements should be included as part of the initial project.

The execution of a very difficult work such as the one presented in this paper in optimum conditions, requires a continuous collaboration between the designer and the contractor. A very good collaboration between the expert in Foundation Engineering and the expert in Structural Engineering is also needed. The level of this collaboration must be at the same level as the efficient unity between the foundation and the ground!

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