# THE ENVIRONMENTAL IMPACT OF THE UNDERGROUND CONSTRUCTIONS. CASE STUDY – "MILLENNIUM BUSINESS CENTRE"

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ABSTRACT
The article describes in detail the effects which could be generated by an inadequate technology in construction for the underground structures during excavations in precincts with diaphragm walls. As an example, Armenian Cultural Centre which was affected by the execution deficiency of the precincts with diaphragm walls from Millennium Business Centre. The role of the paper was to emphasize the following aspects: the importance of respecting the technical project because technical solution could be easily compromised by the constructor, the conforming of the technical solution with site conditions and the necessity of a monitoring programme during the constructions works.

RÉSUMÉ
Le contenu du présent article envisage de détailler les phénomènes qui peuvent être générés si on ne respecte pas exactement la technologie d'exécution des constructions souterraines par excavation en enceintes de parois moulés, et traite brièvement le cas du Centre Culturel Arménien, détérioré par les défauts d'exécution de l'enceinte de parois moulés du "Millennium Business Centre". Le rôle de l'ouvrage est de souligner: l'importance de respecter le projet technique dont la solution technologique peut être facilement compromise par le constructeur; la nécessité d'adapter la solution technologique aux conditions de terrain et la nécessité de monitoriser systématiquement l'exécution des travaux.

## 1 GENERAL ASPECTS

### 1.1 Location

The Millennium Commercial Centre – Bucharest building is under construction in the central area of the Bucharest city, nearby Armenian Centre (dated on 1911), on Armand Calinescu street, no 2-4, sector 2. (Figure 1).
Armenian Cultural Centre is represented by the Armenian Church, the Armenian Library and the Armenian School.
The Millennium Business Centre building was designed as a 4BASEMENT+GROUND FLOOR+18 FLOORS (3B+G+18F) construction but finally the building will have 3B+G+18F.


Figure 1. Works location

### 1.2 Constructive Characteristics of the Structure

Construction excavation is at 16m depth , 11m under phreatic aquifer. To assure the stability of the excavation and the tightness against infiltrations, it was designed a precincts with diaphragm walls but without a top beam for diaphragm walls interlocking.

Support elements are designed to perform step by step in the same time with the excavation using horizontal struts made by helicoidally welded pipe of 600mm in diameter or 3 pipes of 325mm in diameter, interlocked with plates and angle brackets which form one strut (4 levels-where it is possible) and prestressed anchors (length is 20-28m with bulbs of 8-12m) located on 5 layers.

Behind the diaphragm walls, supplementary joantive pillars were designed to assure stability of the excavation wall along Arcului 6-8 area and also micropiles with intensifier mud.

A dewatering system for phreatic and under pressure aquifer wasn't designed.

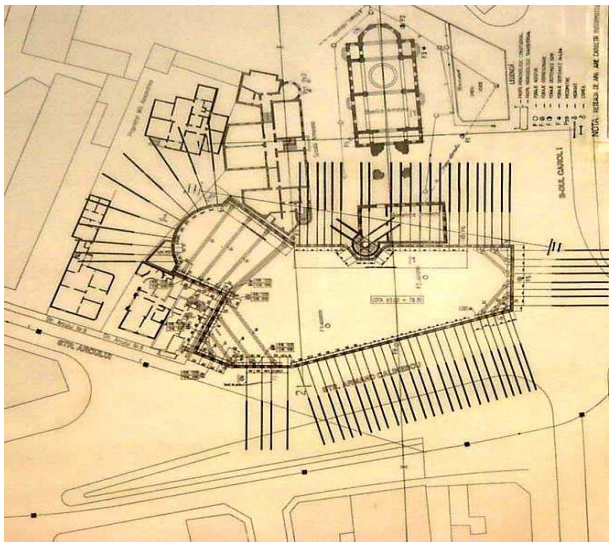

Figure 2. Plane-table sheet

## 2 TECHNICAL HISTORY

Technological errors during the performing of the diaphragm walls and anchors but also during the excavation execution for Millennium Business Centre (November 2000 - November 2001) determined degradations of the nearby buildings, located on Armenian Centre area. Degradations phenomena are: uneven/discontinuous settlements of the constructions and platforms, fractures of the ground and local collapses.

Technical errors and accidents revealed during the performing of infrastructure works appear at the beginning of the anchors under the underground water level when major displacements of noncohesive material occurred. After the anchors were finished, rush afflux of material with water produced along the rubber filling of the tie rods, almost 80%.

Rush afflux of sandy material with water (hundred of mc, estimated after consolidation of the ground at Armenian Centre) appeared at 13 - 16.5m depth during the performing of excavation as a consequence of gaps deficiency between panels ( 0.3 - 0.6m departure).

The dynamical penetration tests on the two longitudinal profiles, parallel with longitudinal axle of Armenian Church revealed:
- punctual, critical alteration areas, which extended max. 5m behind the diaphragm walls, near the old gaps, at max. 14m depth;
- semnificative alteration areas, from 0.4-4.0m to 8.4-10.2m depth, which extend to max 14m distance behind the diaphragm walls ( on the technical accidents direction when diaphragm walls panels were performing);
- the area of the Pronaus to the Armenian Church Altar, the diagrams of the penetration tests indicates the same aspect as the standard/natural one – unaffected by antropic works.

Figure 3. Fissures along Armenian Church wall.

Figure 4. Fissures inside the Armenian School.

Considering the high density of buildings nearby Millennium Business Centre, and their ages (built on 1910-1915) but also the intense traffic on both thoroughfares, a topometric marks system has been installed in the area since the beginning of the works. These were mensurated and revealed the settlements values of the structures (figure 6).

Uneven settlements were as follows (Figure 5):
- 2.5 - 3.0cm at the Armenian Library,
- 1.0 - 5.0cm at the Armenian School,
- 0.0 - 2.5cm at the Armenian Church.

The results of these settlements were:
- local collapse of the basement pavement, fissures in foundations and carrying brick walls at the Armenian School,
- fissures in the pavements and basement walls at the Armenian Library,
- increasing some of the old fissures and appearance some new cracks at the Armenian Church,
- fissures down to the pavements parallel with the long side of the precincts with diaphragm walls,
- settlements of the building from Arcului 4
- alterations (limited areas) of the ground stiffness condition from the precincts of buildings placed on Arcului 6, 8 and 10.

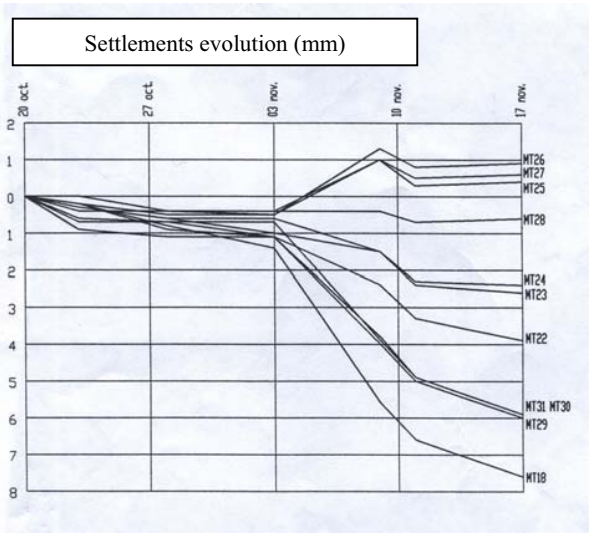


Figure 5. Settlement evolution diagram

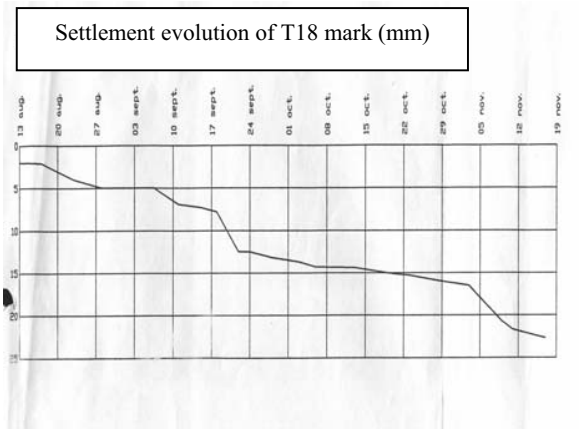


Figure 6. Settlements diagram

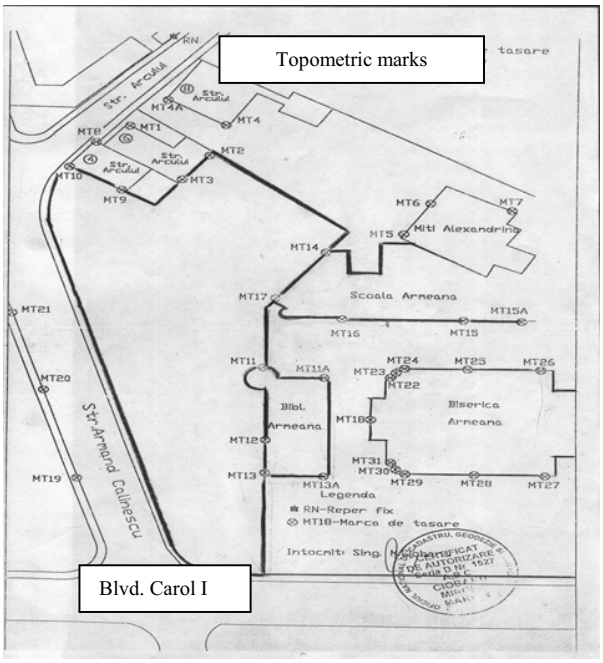


Figure 7. Topometric marks.

## 3 DATA REGARDING GEOMORFOLOGICAL, GEOTECHNICAL AND HYDROGEOLOGICAL CONDITIONS AT THE MILLENNIUM BUSINESS CENTRE AND ARMENIAN CENTRE AREA, BEFORE AND AFTER THE CONSTRUCTION OF THE EXCAVATIONS IN PRECINCTS WITH DIAPHRAGM WALLS.

The areas are placed on interfluvium field Dambovita – Colentina, on an almost plane surface (figure 8).

Maximum level of field area which is the limits for our site, University Square and Iancului Square, is between 79 and 81m.

The lithological succession (resulted from hydrogeological and geotechnical investigations) is lenticular, is non-homogeneous, in both vertical and horizontal plane, with cohesive and non-cohesive discontinuous layers alternating dispositions, as follows:

- Type 1 stratum: recent surface sediments, made up of vegetal soil and clayey sediments, with a thickness of 1.10-2.00 m.

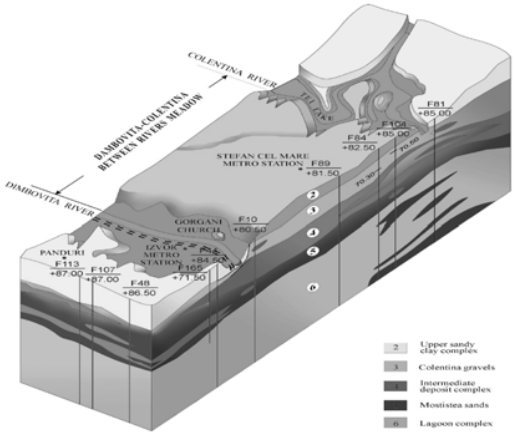


Figure 8. Interfluvium field Dambovita - Colentina

- Type 2 stratum: Upper Sandy-Clayey Complex is constituted of loess formations, brown, stiff with calcareous concretions, more frequent in base. The link with the next layer is about 3.80-4.00m depth.
- Type 3 stratum: Colentina Gravel Complex, made up gravel and sand (with large variations in grain size) and frequently with water bearing clayey layers. There is a lentil of clayey sand from 8.15-8.40m to 9.00-9.50m depth. The base of the complex is about 11.10 and 11.50m.
- Type 4 stratum: Intermediate Clay Complex, made up of alternating brown and grey clays, clays, sandy clays and clayey dust. This stratum is plastic and consistent and becomes plastic and stiff at the base with intercalation of hydrological fine confined sandy layers (15.00-18.00m).

By comparison the lithological successions from the borings placed on Millennium Business Centre and Armenian Centre area resulted that the layers with less or higher consistency are placed at the same quota.
Hydrogeological conditions from the Armenian Centre and Millennium Business Centre are:
- Colentina Gravel Complex aquifer, with free level at 5.60m depth,
-„ water pressure level", placed on permeable layers of type 4 stratum with phreatic level at 5.85m.

The small difference of 25cm between the depths of the two aquifers levels is due to their hydraulic communication (because of the geological discontinuity).
The hydrogeological aspects for Armenian Centre area were almost the same as initial ones during the construction of diaphragm walls and excavations at Millennium precincts.
Rush afflux of material (sand) with water through the gaps of anchors and deficiency during excavations revealed that the aquifer layers reacted naturally in relation with hydraulic gradient.

## 4 IMMEDIATE/URGENT REMEDIAL MEASURES

The types of works for the safety of the precincts and the nearby buildings were as follows:
- supplementation of the lining system of the diaphragm walls on the area affected by the gaps (Library), setting a line of inner supports made by metallic elements, between the first and second line of anchors;
- founding a raft of 2.30m thickness which assured the stability of the diaphragm walls and minimized the infiltrations with sandy material into the precincts;
- performing a collecting and evacuation system for infiltration waters from the precincts, through the walls gaps;
- waterproofing the precincts using the injections in the gaps, tie rods limits, base excavation;
- accelerating the work to finish the infrastructure works;
- load compensation because of the material loss using sinked lances for groutings;
- improving the foundation ground under the Millennium Business Centre nearby buildings using forward breakdown groutings;
- putting up- to- date the technical reports about the buildings nearby the precincts with diaphragm walls so that the consolidation projects could be prepared in the new context of the site.

## 5 REHABILITATION MEASURES FOR THE GROUND AND NEARBY BUILDINGS

„Hydrogeological study about Armenian Cultural Centre state of ground after Millennium Business Centre precincts with diaphragm walls execution " referred to the first stage, site conditions and data collection.

There were made in-situ investigations (drillings and dynamical penetration tests) and determinations of physical and mechanical parameters on samples from 20m depth. After that, the limits of modified areas were set out and detailed in a vertical and horizontal plane.

The conclusions of this reference material and especially the graphic support (plans, sections and lab diagrams) were the reference elements for the final solution of ground compensation and consolidation. The project title was „The compensation measures for the loosening solid material near the Armenian Centre and also foundation ground consolidation".
The project included the concept of compensation for the material which was hydrodinamically circulated through the diaphragms walls gaps and the consolidation solution of the foundation ground near the Armenian Church, Armenian Library and Armenian School in order to bring it to the initial state. There were foreseen special technologies for site conditions (strain groutings) and the minimum necessary to intervention.
Experimental tests for groutings and information correlations were carried out in order to establish the solutions, as follows:
- tests for research the building foundations inside the Armenian Cultural Centre,

- groutings using different receipts for injection materials to identify the optimal one (in relation with characteristics of component parts),
- leading the groutings in relation with lithological characteristics and constructive elements of the buildings
- penetration tests to determine the injectors network and its depth in order to find out the initial carrying capacity,
- graphic interpretation of the settlements measured using bench mark placed on the buildings foundations so that the areas with priority for injection could be identified and also the number of groutings (which were affected by the loosening of their foundation ground) prediction of actions in case of emergency situations during construction.

The solutions for the site consolidation were:
- immediate interventions for settlements stabilization and continuous erosion of the buildings by groutings at the foundation area,
- final works for the emergency groutings which weren't finished,
- sinked tubes in the basements in order to obtain a compensation of the loosening material by injection and also to bring back the initial state of the ground under the interior walls,
- consolidation performance by groutings using the drillings equipped with socket tubes. The borings were placed outside the buildings, so that the loose ground under the foundations could be consolidated,

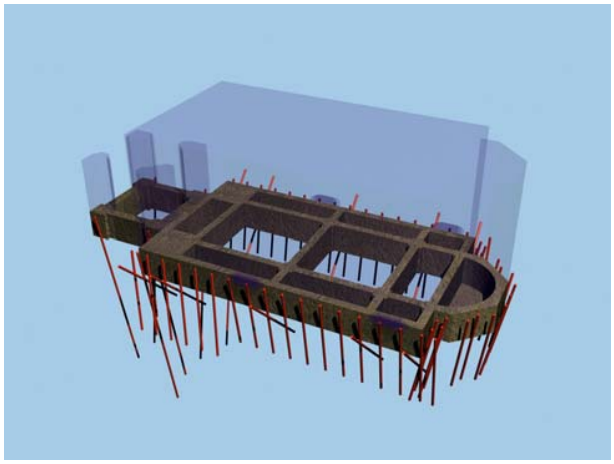

Figure 9. Consolidation groutings at Armenian Church

- sinked tubes into the ground disposed on plane in order to obtain a support for external walls stabilization. Their position wasn't accessible for the boring tool and the degradation situation imposed immediate intervention.

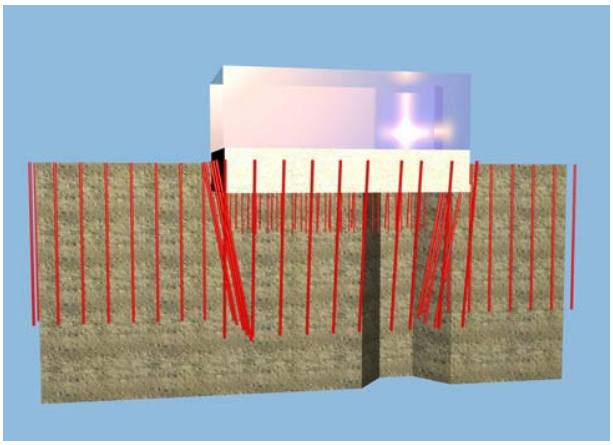

Figure 10. Consolidation groutings at Armenian Library

Consolidation groutings were ascensionally by forward breakdown ground with a suspension for aprox. 1 cubic meter: 600 kg of concrete, 50 kg of bentonite, 10 litres of sodium silicate and 730 litres of water.

The injection material had the following characteristics:
- water separation in an hour after preparation, under 2%
- Marsh viscosity (at 15 to 20°C) is 45-50 second,
- density is 1.38-1.40t/mc,
- $R_{7\ days}$ is over 100kPa and at 45 days is over 300kPa

The quantities of grouting material were:
- Armenian Church – 142.7 $m^3$,
- Armenian School → 199.3 $m^3$,
- Library → 61, 8 $m^3$,
- along the diaphragm wall, parallel with Carol Blvd– 62.4 $m^3$
- along the diaphragm wall, between School and Library- 40.2 $m^3$

Total injection material was 518.4mc.
The quantity of injection described by monitoring cards when technical accidents started was 583.494mc.
Injection pressure was set down at maximum 4 atm but not to determine the displacements of the ground and the building structure more than 1/100mm.
Obviously the low values of pressures were nearby diaphragm walls, beside the gaps.

The objectives of groutings were:
- to fill the gaps resulted after the rush afflux of noncohesive material,
- to stuff with as initial state as possible the loosening layers,
- to protect temporally the buildings until new methods of structures consolidation would be applied.

## 6 DATA REGARDING THE INTERVENTION EFFECTS ON THE ARMENIAN CENTRE AREA

The effects of the consolidation works could be revealed on three directions:
- settlements measures,
- injection parameters,
- dynamical penetration tests.

The measures revealed an active period for the settlements and the grouting works reduced them gradually.

Grouting process was in fact a ground prospection because groutings filled all the gaps, even if there are at an important distance.
This grouting process revealed the differences of absorption capacity between layers.
The ground gaps pointed out by the groutings were gravitational filled, no suplimentary pressure, only by pomping near the diaphragm wall, an aspect very important for Armenian Centre case.

Total volume of grounted fluid revealed a real estimation of the material lost from Armenian Centre area towards Business Centre precincts. It was grouted a stabile suspension which determines, in generally, a stone volume of 95-100% from total suspension volume.
Groutings were performed until the fluid couldn't penetrate any more under a 4-6 atm pressure or was rejected at the surface. After consolidation or surface swell, before groutings were resumed, the grouted fluid was strengthened.
As a consequence we could certify that the groutings determine the bringing back of ground to the initial state, before MBC works have started.

Dynamical penetration tests (qualitative tests) reveals relative information and strictly punctual. There are significant when the ground is suspected as resistant to penetration test or two close penetration tests are compared before and after the groutings.
In this case, dynamical penetration tests were incomplete because of the lack of penetration standards from the MBC area, in natural ground unaffected by sufossion phenomena. In order to verify the efficiency of the grouting works inside the Armenian Cultural Centre area, there were performed 63 penetration tests.
The site positions for penetration tests were chosen on a half distance between two grouting drillings so that the minimum values for consolidation results could be revealed (Figure 11).

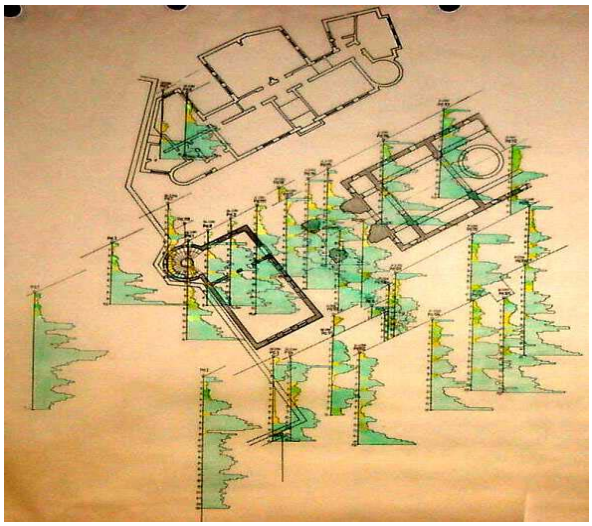

Figure 11. Diagrams of penetration tests

As a convention and information, the minimum curve for standard diagrams (penetration tests performed in natural ground, unaffected by Millennium Business Centre works) have been considered an estimation criterion for the rest of penetration tests.

The results of the diagram interpretations were;
- by comparison the points had positive results reflected in major increasing of the penetration resistance as a consequence of improving the state of the ground after groutings
- the points with lower resistance than the standards ones were corresponding with some limited levels marked by significant increase at penetration resistance.

The following motives confirmed the consolidation of the ground at the initial state:
- insert a volume of cca 565mc stone, volume resulted after the grouting stable fluid was strengthen,
- complete stabilization of the settlements (figure 12),

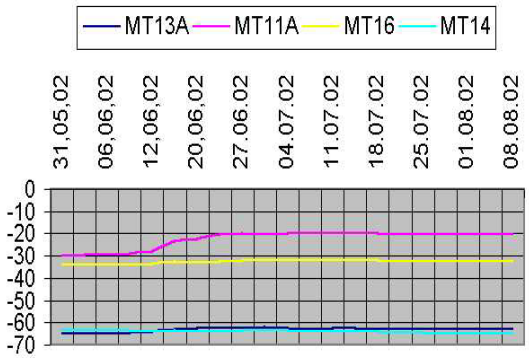


Figure 12. Settlements stabilization

- groutings performed until the fluid couldn't penetrate any more under a pressure of 4-6 atm and an upward tendency for the buildings pavements,
- comparative indications for the 63rd dynamical penetration tests.

## 7 CONCLUSIONS

The real confirmation for the consolidation at Armenian Cultural Centre precincts came at once with certification for ground foundation in order to start consolidation works for Armenian Church, when diggings revealed injection areas on chaotic directions from 0.50m to -2.5m (foundation quota). Figure 13.


Figure 13. Forward breakdown groutings.

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