The use of the Observational Method in Deep Excavations for the Realization of a Residential Compound in a Complex Hydrogeological Context

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ABSTRACT: The urban redevelopment works of the "Railway Station Area ex-Boschi", was developed on an area of nearly 17.0000 m2, it entailed the execution of deep excavations in a difficult geotechnical and hydrogeological context. In order to overcome these critical issues a design based on an observational approach was developed. This design considered several possible hydrogeological scenarios and staged excavations over small areas.
The Observational Method has been successfully extended from the more traditional case of tunneling works to the less usual case of deep excavations in large construction areas.
Keywords: Observational Method, deep excavations, diaphragms

1. INTRODUCTION

The urban redevelopment project of the "Railway Station Area ex-Boschi" area in Parma (Italy), involved the creation of a large road link, under-passing the existing eight-track railway line Station and the construction of five new buildings.
The works, developed on an area of nearly 17.0000 square meters, entailed the execution of considerable excavations and supporting structures.

The hydrogeological context was complex because of soils with poor mechanical characteristics and of two different aquifers. The presence of an important railway line in operation and several existing buildings next to the excavations, completed the project framework.

In order to overcome these critical issues and assure greater safety and continuity of the works, the Contractor developed a detailed design proposal based on an observational approach, which considered several possible hydrogeological scenarios and staged excavations over small areas.

In this case, the Observational Method has been successfully extended from the case of tunnels works, more traditional, to the less usual case of deep excavations in large construction areas, showing its own peculiarities and giving important indications for future applications.

2. RIQUALIFICATION PROJECT

In 2007, the Municipality of Parma (Italy), through its subsidiary company "STU Società di Trasformazione Urbana", launched a tender for the public works of the urban renovation of the Parma Railway Station Area.

The contract basic design was developed by an association of design firms with MBM Arquitectes from Barcelona as a leader and it essentially entailed the renovation and upgrading of the existing Railway Station of fascist epoch and of both the North and South Areas of the Station, as identified in figures 1 and 2. This was achieved through the following interventions:

- redesigning the respective squares with their green areas, the traffic roads and pedestrian walkways,
- linking the two areas with the creation of an underground roadway underneath the existing station and the entire railway tracks park,
- providing in the northern area, formerly dedicated to railway storage and maintenance, two floors of public and private underground car parks, a newly constructed bus station and buildings, including residences, offices and a hotel.

The works were awarded to the JV Bonatti SpA - Di Vincenzo under a Public-Private partnership procedure for a work amount of: € 98.3 mln, of which € 56 mln as compensation for the value of the Real estate surfaces and the remaining € 42.3 mln delivered according to periodic progress payment certificates, as per initial contract data. The Project contract duration was 57 months. From a technical and organizational point of view, the Project was characterized from the outset of the basic design phase, by a strong interaction with the existing urban context and with the local infrastructures. In fact, within the Train Station or in the immediate vicinity, there are:

- public and private buildings both in the north and south areas,
- the existing railway station, whose outer masonry envelope and steel decorations had to be preserved according to the constraints imposed by the local Superintendence of historic buildings,
- bus stops and terminals,
- road and pedestrian traffic ways,
- the Milan-Bologna railroad tracks, with the need to maintain at least four lines always running at the same time, being this the main Italian railway line.

As a result, the contract basic design solution was conceived to minimize as much as possible the impacts and risks associated with the execution of works.

For example, the need to carry out deep excavations required the execution of perimeter r.c. diaphragms along the entire project area. This technique permitted the use of machinery and workmanship from the top ground level before proceeding to the excavation and underground works.

3. GEOTECHNICAL WORKS IN THE NORTH AREA

The renovation project envisaged the creation of a pedestrian and traffic road under-passing of the rail tracks from the North to South areas of the Railway Station, from which the new access to the station would be created, and two levels of underground parking in the north area.

These works covered a very large area of approximately 17,000 square meters and resulted in significant excavations of varying depths ranging up to approx. 15m below the existing ground level.

The excavations were carried out in a complex and variable hydrogeological context because of the different excavated soil layers and their variable characteristics, due to the extension of the area.

Specifically, the geotechnical context of this area is characterized by an intermediate silty-clay layer with poor mechanical characteristics, while the hydrological context is characterized by the presence of a first phreatic water table in direct contact with the Parma river – called A0 – and a second artesian water table under pressure – called A1 – both characterized by seasonal level variations (fluctuation above 5 m annually).

Figure 1 Pre-existing status

Figure 2 Project simulation

The contractual basic design and the detailed design to be developed by the Contractor had to consider all these site issues, together with a context of inhabited buildings and existing infrastructure adjacent to the excavations, involving the need to limit interferences, as well as ongoing and long-term settlements. The following sequence of works was utilized:

1. perimeter barrier consisting of r.c. diaphragms executed from the ground level, followed by
2. excavation steps of about 2 m to 4 m depth each, followed by:
3. execution phases of supporting multistrand tieback anchors
4. execution stages of jet grouting soil consolidation treatments of the bottom ground, and finally
5. excavations down to design level and casting of final supports works (diaphragm foot restraint foundation r.c. slab).

The section with the deepest excavation height occurred in the North area. The contractual basic design typical cross section solution, named 1A, consisted of:

- n.2 underground levels used for under passing roads and walkways and car parkings (excavation from 56.50 m. down to 41.20 m above sea level - a.s.l.);
- excavation depth 15.30 m; Diaphragms depth 30 m x 100 cm thickness;
- n. 5 levels of provisional type supporting brackets (harmonic steel tie rods);
- jet grouting treatments at the foot of the excavation for a volume 9 m wide x 7,5 m deep;
- 1.4 m deep r.c. foundation slab acting as permanent contrast to the r.c. lateral diaphragms.

Figure 3 Excavations in the north area and railway tracks

4. GEOTECHNICAL AND HYDROGEOLOGICAL CONTEXT IN THE NORTH AREA

In order to better appreciate the geotechnical and hydrogeological context, it has been very useful to analyse, using historical maps, the events that determined the current stratigraphic structure of the area; they show that the stream of the Parma river extended, at the end of the last century, even hundreds of meters beyond today's shores.

Of great interest is the morphological configuration of the Parma river at the end of 1700, as represented by the Atlas Sardi (1767) in figure 4, characterized by the presence of an important meander in the area under examination.

The stratigraphic and hydrogeological structure of the area was investigated to the depth of 50 meters, by carrying out many continuous core drilling, pore pressure (piezometer) observations and laboratory tests and also by correlations with other site investigation surveys carried out in neighbouring areas.

As shown in figure 5, the stratigraphic succession is:

- Layer A - composed of polygenic gravel with sand and silt and it is characterized by high permeability. It is testimony of an ancient bend of the Parma river.
- Layer B - a complex of sediments with fine granulometry and cohesive behaviour.
- Layer C - composed of polygenic gravel, with sand and silt. It is present on the whole area at almost uniform depth.

It should be noted that, inside layer B, there are 6 sub-layers made of silty clays and clayey silts, locally sandy silts, characterized by significant differences in grain size distribution and in the over-consolidation ratio. The plasticity index values are within CL and CH classes. The grain-size analysis showed silt content ranging between 20% and 50% and clay content varying between 40% and 70%. This variability was also found between samples taken at the same depths, indicating the presence of lenses with different grain size distribution even in the same sub-layer. For structural calculations, the 6 sub-layers can be grouped in one layer (level B) with homogeneous mechanical characteristics (figure 5). On the other hand, the variability in the grain-size distribution and in the plasticity index values of the layer B has an important influence on strand anchor bond pull-out strength, on the homogeneity and on the mechanical characteristics of the jet grouting ground improvement.

The hydrogeological analysis allowed to identify the presence of two aquifers (A0 and A1) and to define the oscillations of water levels to consider in the design. The first aquifer (A0) is present within level A; it is a phreatic aquifer whose levels are directly correlated with the Parma river; during summer time the groundwater is absent, as it reaches the ground level in the river flood stages. The second aquifer (A1) is present within level C. This is an important artesian aquifer of considerable hydro-potable interest confined by the silt-clayey layer B.

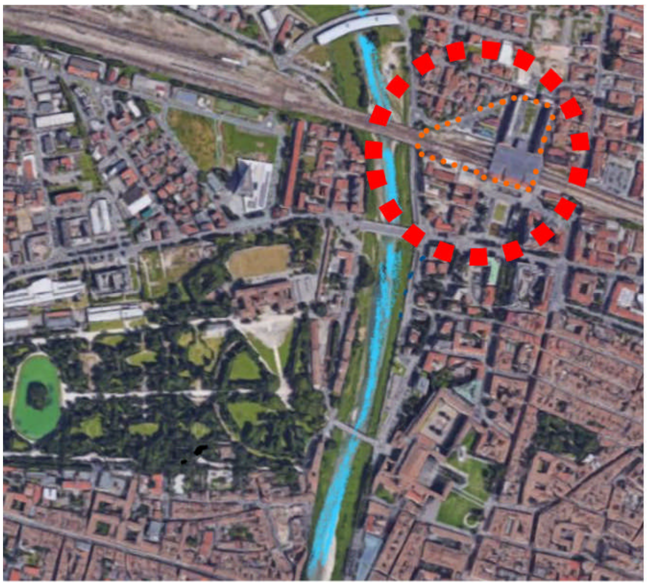

Figure 4A Current situation

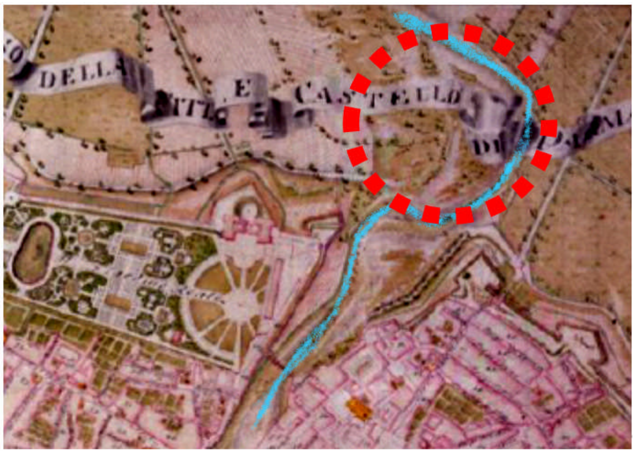

Figure 4B Eighteenth century (Atlante Sardi)

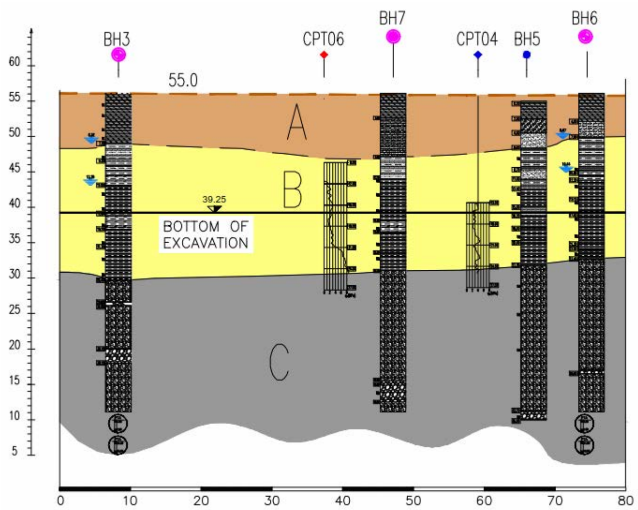

Figure 5 Stratigraphic section north area

Figure 5 shows a geotechnical section (layers A, B, C - boreholes (BH and CPT).

The most significant geotechnical parameters are shown below:

	Ɣ (kN/m3)	Φ (°)	c' (kPa)	Cu (kPa)
Polygenic gravel (layer A)	20.5	39	0	-
Silty clay/clayey silt (layer B)	19	21	15	80
Polygenic gravel (layer C)	20.5	39	0	-

5. MAIN DESIGN, ORGANIZATIONAL AND CONTRACTUAL CRITICAL ISSUES

From the Design point of view, the variability of the water levels affects the overall behavior of the structures (reinforced concrete diaphragms) representing a variation of the external load (water pressure); it affects the value of the resulting stresses in the diaphragms, the actions on the strand anchors and the resulting loads acting on the volume of solid ground in jet grouting at the foot of the diaphragm.

The variability in the chemical-physical characteristics of level B (point 2) does not affect much the actions on the structures, but it has a more direct and significant influence on the effectiveness of the consolidation interventions (mechanical properties of the jet grouted solid ground volume) and the tensile strength of the strand anchor bulbs).

From the Contractors point of view, the main issue was the management of the lump sum contract risk in terms of costs and execution times. In this case, the risk was characterized by: the verification and taking over of the Client's basic project design and the subsequent development of the design detail, the high degree of complexity of the works and the boundary conditions imposed by the operating context. From an organizational point of view, the urbanized area was a limiting factor for: the spaces dedicated to the construction of site installations and equipment, the internal and external road accessibility to the yard, the work shifts schedule, and it enforced the limits of noise and vibration emissions with impact on site productions rates etc. ...

In the light of the Client's basic project, substantially based on simplified average calculations and assumptions, and the actual variability of projected project hypotheses, the Company considered it appropriate to study, within the detailed design by the consultant designers, a proposal for a design improvement variation order, with the aim of reducing the risk in terms of time and cost of the project and increasing the safety factors of geotechnical works.

This was achieved by:

- developing a construction site and logistics plan respectful of the phases of the works and road access;
- deciding a rational sequence of the work phases with activities to be completed in one single shift (casting & pouring, drillings, injections, etc. ...);
- realization of propaedeutic field testing for geotechnical works and implementation of the results and sequences of the works in the sizing of the works themselves;
- introducing a variability concept in the design interventions and execution phases and using an “active tests and monitoring system” during construction to adapt the design to actual site conditions.

6. BASIS OF THE CONTRACTOR’S DESIGN IMPROVEMENT PROPOSAL

According to the Italian law in force at the time (2009-2010), the Contractor could, during the course of the work, propose to the Client modifications/ improvements to the works as long as:

1. they led to a reduction in the original amount of work,

2. they were intended to improve the functional aspects, as well as the individual technological elements or components of the project,
3. they did not entail a reduction in the performance of the Project itself and kept the work execution time and the worker's safety conditions unaltered.

In addition, for the Italian and European standards in force (Eurocode n.7 1997, NTC2008), the adoption of the so-called Observational Method in the design of provisional and final geotechnical works was innovative, if compared with the previous technical regulations, under the following main conditions:

- that the particular complexity of the geotechnical situation and the importance of the work was established;
- that the acceptability limits were established of the values of those parameters values which represent the ground-structures system's overall behavior;
- that other alternative solutions congruent with the project were verified as possible and envisaged;
- that an appropriate monitoring system was set in place during works and control plans aimed to confirm the assumptions made and the validity of the design solution adopted or the adoption of one of the proposed alternatives if the acceptability limits were reached.

As a result of the comparison between all the various available data and design proposals developed in a preliminary form, the choice was made in favor of an Observational Method of design (Peck 1969, Ciria 1999).

For the choice of the design parameters, the approach recommended by Peck was used with the adoption of "most probable" values, the evaluation of "most unfavorable scenarios" and the definition of mitigation measures for such situations. Schematically, the solution adopted, according to the national regulation requirements, was developed according to the following macro steps:

1. design and calculation of works by adopting "most probable" water levels;
2. analysis of possible scenarios with rising water levels up to "most unfavorable" values and definition of mitigation measures for such situations;
3. active monitoring during works of the two water table levels, to identify the real scenario.

We want to point out that the unavoidable geotechnical uncertainties identified in the previous chapter (with two possible scenarios: "more probable" and "most unfavorable") made it absolutely unsatisfactory to use a classic design approach based on a single "predefined design".

Indeed, in this case, the generalized use of "most unfavorable" values would have resulted in excessive costs. On the other hand, less prudent values, such as the generalized use of "most probable" values would have led to a risk level considered unacceptable.

With regard to the maximum piezometric load, detailed analyses and simulations were carried out on the basis of the historical data available from the hydro-potable wells in the Municipality of Parma, which showed a strong variability in the aquifer levels with annual oscillations up to 5m.

At the end of the analysis, for the detailed design it was decided to consider:

- as "most unfavourable" occurrence: the value of 48 m a.s.l. for the artesian aquifers (A1) and 51.50 m a.s.l. for the phreatic aquifer (A0),
- as "most probable" occurrence: the value of 45.50 m a.s.l. for the artesian aquifer (A1) and 49.00 m a.s.l. for the phreatic aquifers (A0).

The contractual basic design considered a single value equal to the value of 45.50m a.s.l. for the artesian aquifer (A1) and 49.00m a.s.l. for the phreatic aquifer (A0).

Regarding the aforementioned influence of ground composition and plasticity values variability, field tests have been performed before the detailed design phase in order to evaluate the "most probable" resistance characteristics of the jet-grouting and strand anchor bulbs to be used in the project.

Afterwards, during the works, specific testing and control fields were established and carried out to verify the actual anchor bulbs tensile strength and jet grouting mechanical resistance in areas where, even after preliminary investigations, the greatest variability remained.

The strand anchors tensile test field has determined the minimum design resistances of the ground layers interested by the anchor bulbs (superficial deposits and gravel, clayey limestone-clay) according to the drilling diameters, see figure 6. The jet-grouting test field has determined the technique (Bi-fluid), cement type and quantity, execution parameters (feed rate and rotation speed, injection pressure, etc.), see figure 7.

The introduction of local variability and execution phases in the detailed design related to the geotechnical and foundational works, together with the execution of such tests during the works, allowed to satisfy loading hypothesis of more conservative and wider variance and to absorb the uncertainties of geotechnical aspects of direct relevance on ground support interventions (strands anchors, jet grouting base r.c. foundation slab excavation and casting). Furthermore, as a result of the various studies, it was found that the basic design assumptions on material resistance could be improved and opening the finale excavation level (foundation slab) for limited phases and dimensions would have created improved conditions for the perimeter diaphragm stability, as further explained below.

Figure 6 Strand anchor tests

Figure 7 Jet grouting tests

7. CONSTRUCTION PHASES OF THE CONTRACTOR IMPROVEMENT PROPOSAL

The excavation methods involved progressive excavations stages of about 3m depth, starting from the existing ground level, down to the drilling and setting of the various strand anchor arrays down to the last level (+43.50 m a.s.l.). Specially studied construction site internal circulation, required continuous operability of the main access ramp from the only access situated to the North-west side of the site, adjacent to the B-C side of the diaphragms. For this purpose, six main stages of internal road configurations and execution phases were studied and implemented into the detailed design, of which phase no. 2 is reproduced as an example in fig. 8.

The excavation down to the bottom to the level of r.c. foundation slab from the last anchor strands array level (+43.5 m a.s.l.) was carried on according to finite square-shaped elementary trenches of small dimensions (approximately 10x10m ÷ 20x20m). The choice of limited dimension trenches allowed to combine multiple needs, among which:

- to avoid congestion of the work equipment circulation inside the yard and perform daily r.c. slab casting and pouring phases completed within single shifts;
- to optimize the resources used in the various trenches phases (excavation, lean concrete, waterproofing, reinforcement laying, casting and concrete pouring) and limiting the reinforcement overlapping between adjacent bars;
- to handle sudden increases in the level of the two aquifers.

In addition, the excavation and casting sequence of the r.c. foundation slab proceeded from the center of the north area up to the border of the perimeter, leaving to the last excavation stage a ground berm against the r.c. diaphragm in order to create the necessary contrast.

After the casting of the foundation slab in the central portion of the North area, the perimetral ground berm has been excavated according to a continuous "open and close" mode, for non-contiguous sections or cones, according to a "comb" scheme, to better manage the criticality due the perimeter supporting structures.

Figure 9 shows this concept.

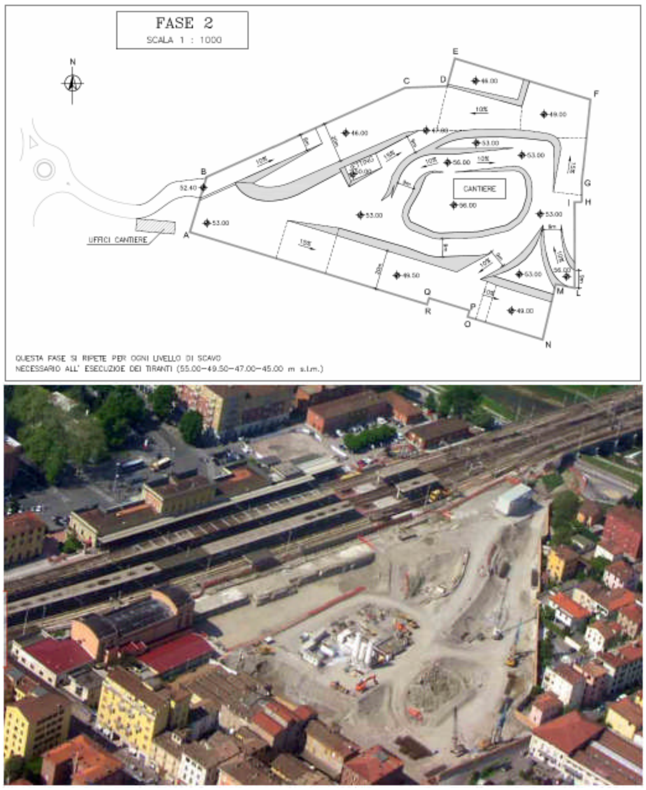

Figure 8 Step n.2 of internal circulation and execution phases

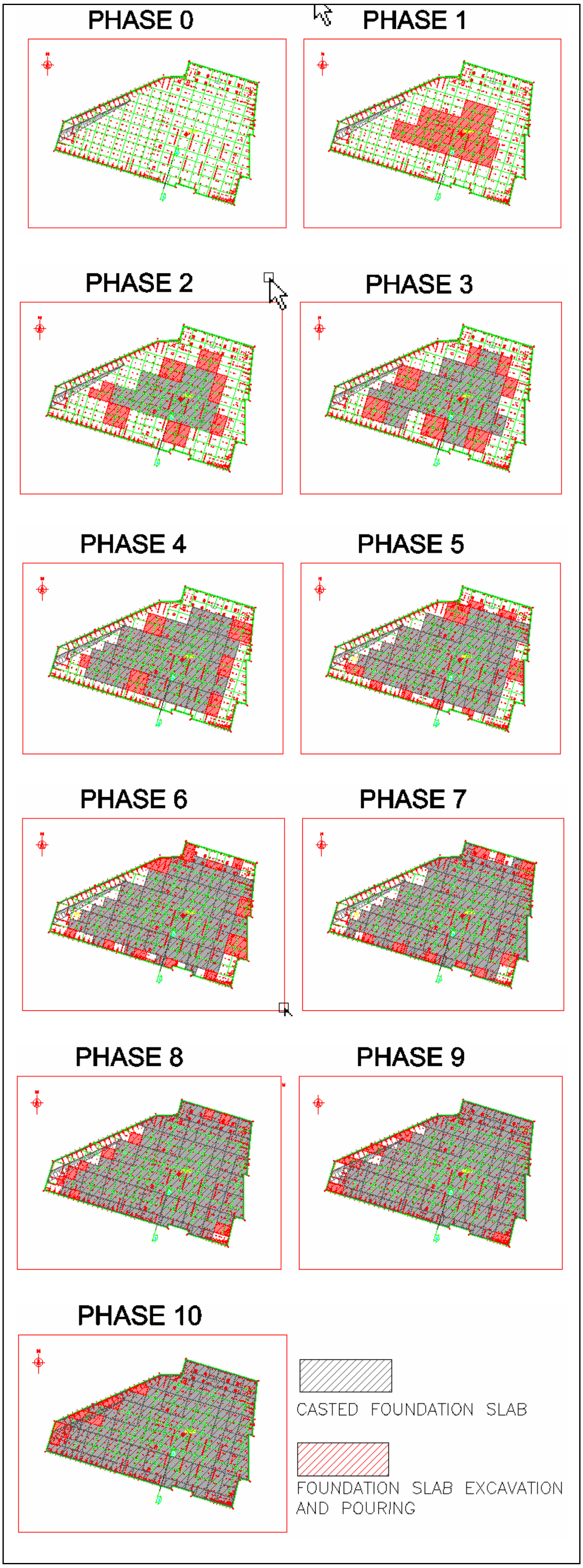

Figure 9 Execution sequence for the r.c. foundation slab

This also allowed the beneficial 3D effects to be developed, as described in the following paragraph.

8. DESIGN DETAILS OF THE CONTRACTORS IMPROVEMENT PROPOSAL

Following the "open and close" mode of execution, we could rely on a set of beneficial static effects otherwise unavailable with a general excavation:

1. three dimensional effect of contrast in the foot of the diaphragm wall due to the presence of the unexcavated perimetral berm and/or the foundation slabs;
2. plate behavior of the jet grouting band (the whole jet grouting volume is affected by a limited section of diaphragm than would be with a general excavation);
3. overload effect behind the diaphragm due to the weight of the cast foundation slab that allows the increase of the passive earth pressure by increasing the effective stresses;
4. undrained behaviour for the cohesive layer B during the construction phases below the excavation quota of 43.5 m. a.s.l.

Three-dimensional numerical analysis, using 3D Flac software, was performed to evaluate the beneficial effects on the stress-strain behaviour of the reinforced concrete diaphragm wall produced by the excavation and concrete pouring stages of small size segments (see figure 10). Two-dimensional analyses were not suitable to capture the confinement effects provided by the unexcavated berm and the diffusion of the stresses due to the jet-grouting band; indeed, in a traditional two-dimensional calculation, the excavation of the perimetral berms, even of a single segment, is equivalent to the complete removal of the berm through the whole longitudinal development of the diaphragm wall, situation this which does not correspond to reality.

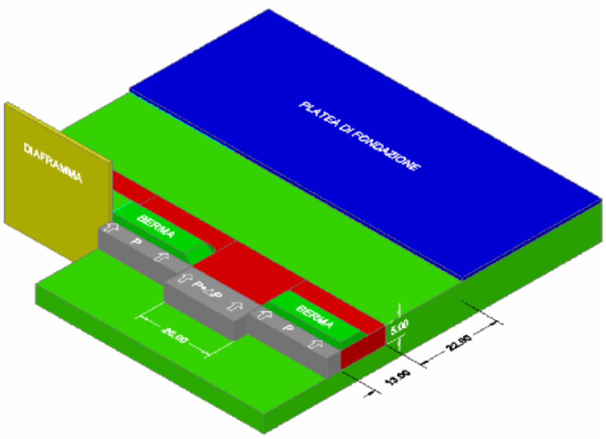

Figure 10A 3D model

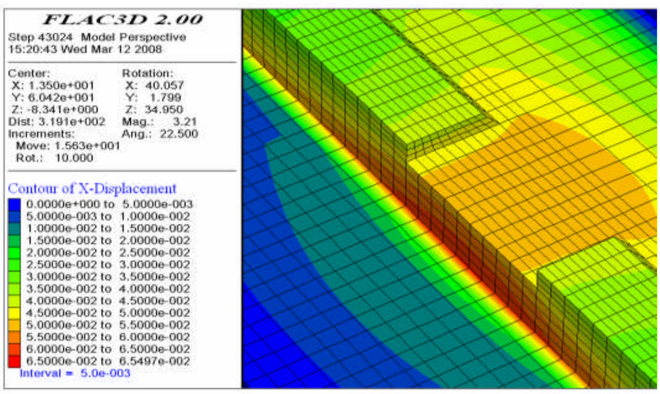

Figure 10B horizontal displacements caused by berm excavation

8.1 Variability in the sizing of the supporting works

The design improvement proposal establishes two “project limit configurations”: a “minimum configuration” and a “maximum configuration”, as a result of the approach described in the geology section referring to the levels of aquifers (they identify the “most probable” occurrence and the “most unfavorable” occurrence of water levels for aquifers A0 and A1).
Typical sections of the excavation support works have been defined, where a variability has been hypothesized for ground anchor characteristics (free strand length, bond length and drilling diameter), for jet grouting (geometries and spacing of columns, execution quotas) and for the execution procedures of the excavation steps below height 43.50 m a.s.l. as per figure 11.

By varying these parameters, it was possible to cover the combined effect of:

1. possible variations in the aquifers (A0, A1) level (i.e. load) within the considered range;
2. possible variations in the mechanical properties of jet grouting and anchor bond pull-out strength (due to the possible variations in layer B characteristics).

The method set out that the support works are dimensioned and verified in detail within the defined range (minimum to maximum), depending on actual site conditions encountered during works.

The definition of support works within the range defined in the detailed design occurred at each single excavation stage and in the presence of significant increases in the aquifers level, for which “in progress detailed design” documentations were issued.

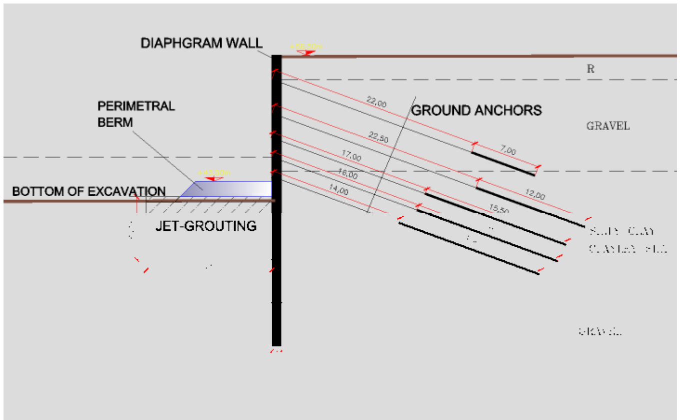

Figure 11 Typical transverse section with perimetral berm

8.2 Monitoring procedures during the works

In applying this approach, it was therefore crucial to implement a specific system of controls and monitoring during the works.
This monitoring system played an active role in the realization of the work because, through a constant interpretation and analysis of the collected data, it allowed the modulation of the interventions within the “minimum” and “maximum” design configuration.

The parameters monitored during works with an active role were: a) aquifers A0 and A1 levels, b) homogeneity and mechanical characteristics of the jet grouting ground improvement and c) anchor bond pull-out strength.

A topographic monitoring system to control the settlements of buildings and lateral diaphragms wall displacements during excavation was also installed, but this monitoring system plays a very much passive role, its aim was only to check original predictions and for general safety precautions, but it didn’t have any role in the design modulation.

A piezometric network was installed to control the groundwater level. Specifically: n.6 open standpipe piezometers to measure the level of aquifer A0, n.7 open standpipe piezometers to measure the level of aquifer A1, n.4 Casagrande Standpipe Piezometer to measure pore-water pressure within the cohesive layer B.

8.3 Field Testing of jet-grouting soil improvement and tieback stranded anchors

After the execution of the preliminary tests, by proceeding with the excavations, the execution of field tests during construction were also carried on according to an observational approach.
This was done along the perimeter, where there were expected particular situations, in order to assess in detail the influence of geotechnical and stratigraphic characteristics.
Detailed notes for the interpretation of the results of individual test fields and calibration of project support works have been issued. The execution of the field tests and controls during construction, followed by the issuance of the specific “in progress detailed design” reports, in conjunction with the "key" moments and execution phases, allowed to eliminate the geotechnical and stratigraphic uncertainties.

8.4 Parametric analysis based on groundwater levels

In the subsequent phases of work, the only variability is therefore considered to be the one linked to the groundwater levels.
This data keeps margins of uncertainty as it can be described as a range of values.
Such uncertainty requires to consider as always possible, albeit unlikely at comparable time scale of the individual work phases, a sudden and unexpected rise in the groundwater levels up to the maximum design limit.

If it was planned to proceed according to lower groundwater conditions than the maximum, this implied lower intensity support works than those required for the maximum configuration, with a reduction in acceptable values of the groundwater excursion.

In such hypothesis, in order to cope with possible increases in the water levels up to the maximum values of the project range, it was necessary to define a system of extraordinary measures of intervention and mitigation.

Many numerical analyses were carried out simulating possible rise in groundwater level for each possible excavation phase and for each possible configuration of support works, in order to define a set of mitigation actions to be taken when unexpected and sudden rise in the ground level occurred, with works in a configuration lower than the maximum floor level.

By proceeding this way, it was always possible to restore the starting safety level and allow for further work.

8.5 Implementation of mitigation actions and emergency measures

In principle, to cope with unexpected increases in the groundwater levels and in presence of support works performed in a lower configuration than the one required by the actual groundwater level (for example, it was proceeding on a configuration lower than the maximum and groundwater levels suddenly increased to the maximum values) it was necessary to either:

1. proceed immediately to the backfill of the excavated area adjacent to the diaphragm
2. or continue construction with more conservative phases and support works than those in agreement between groundwater level and existing design configuration; this was done by:
   - 2.i. reducing the height of excavation needed to install the single array of anchor strands;
   - 2.ii. raising the level from which (normally 43.50 m a.s.l.) the berm /finite trench excavation could start, for the execution of the bottom r.c. slab;
   - 2.iii. reducing dimensions of the last excavation trench for the execution of the bottom slab.

As it can be seen from the figure 12 below, the “most unfavourable” levels for the aquifer A1 have been nearly reached a couple of times during and near the end of the excavation works.

In these occasions activities proceeded either on less critical work fronts, or excavations proceeded according to the above strategies 2.ii or 2.iii.

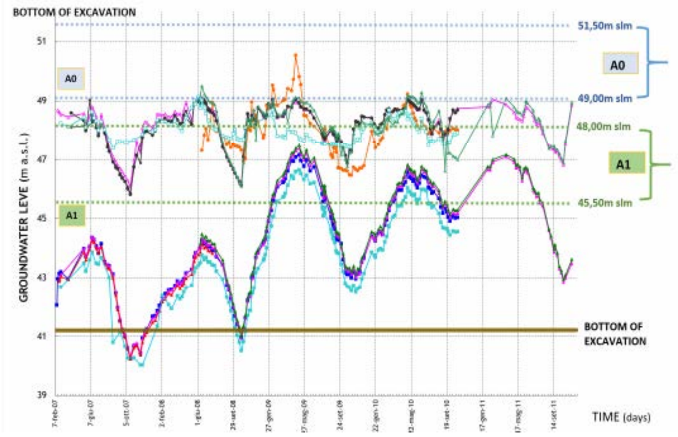

Figure 12 Aquifer levels A0 and A1 during excavation works

In the following, some pictures of excavation and pouring of r.c. foundation slab are presented.

Figure 13A Excavation and execution of r.c. foundation slab

Figure 13B Excavation and execution of r.c. foundation slab

Figure 13c Last excavation phase in east side diaphgram wall

9. CONCLUSIONS

The design improvement proposal based on the Observational Method as developed by the Contractor together with its design consultant Soil srl and approved by the Client, allowed to finish the excavation works on time and with no significant interruptions.

Under the more specific point of view of the Design process, it allowed for the main following benefits:

1. to include in the design possible "most unfavorable" groundwater conditions and absorb the uncertainties about the geotechnical aspects, extending the calculation hypothesis for provisional works, which have direct effects on the quality of the support structures, specially the maximum water table levels, in order to ensure a greater continuity of the site activities (excavations and casting of the foundation slab);
2. to rationalize the sizing and the dimensioning of the provisional works (strands number, diameter and barrel length and jet grouting extension) as a partial compensation of the execution burden related to the extension of the calculation hypothesis;
3. to offer greater guarantees and reliability in general terms of risk management related to the execution of the project (timing of the work and execution costs) both for the Client and for the Company.

Therefore, in this case, the Observational Method is a valid design support for the execution of complex geotechnical works and projects.

Its application has been successfully extended from the case of underground works, more traditional, to the less usual case of large “open-sky” excavation works.

This situation has shown its own peculiarities, which may affect the definition of mean values, most probable values and the limits of acceptability of project hypotheses as well as the alternative remedial solutions.

The Observational Method has also proved to be a mostly suitable design criterion when dealing with situations in which the construction methods, operating sequences and the statics of the works are particularly related and the quantities are to be rationalized.

The potential optimization of the quantities that the Method offers, must necessarily be supported by detailed studies and verifications, which ultimately lead to greater reliability of the project, both in terms of cost and execution times.

In this sense, the Observational Method may also be framed into Projects according to "cost-plus fee" or “fixed-rate” contractual schemes, and also according to "lump sum" logic as the present case, for the main benefit of the Client, especially where the limits of variability of the design parameters can be clearly established.

Figure 14 Works near completion in the north area

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