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MONITORING AN EXCAVATION IN AN URBAN AREA

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ABSTRACT

A new building recently constructed in the centre of the city of Salerno, Italy, comprises a two level underground park with a maximum depth of 8 m below the ground surface and around 5 m below the ground water table. The excavation was carried out within a cast in situ reinforced concrete diaphragm wall, with a thickness of 0.6 m and a length of 18 m.
The subsoil profile consists essentially of sand and gravel, with horizontal layers of silt and silty sand. The main silty layer, located near the toe of the diaphragm, appears to be continuous over the excavation area. Other thinner layers are found between the main one and the bottom of the excavation, giving rise to some concern for a possible bottom heave. To eliminate such a risk, the water was pumped from wells with the filter above the main silty layer.
The excavation is close to existing buildings and infrastructures; accordingly, a monitoring program has been carried out to control the effects of excavation and dewatering on the surroundings. The horizontal displacements of the diaphragm wall have been measured by means of inclinometers, while vertical displacements of points at the ground surface and on the nearby buildings have been observed by means of precision levelling. Finally, the ground water level has been monitored by standpipe piezometers inside and outside the excavation.
The paper reports the results of the measurements and compares them to the previous available experimental evidence.

INTRODUCTION

In recent years the growth of the cities and the subsequent lack of available land led to a steadily increasing use of the subsoil of urban areas for transportation, parking and storage. The design and construction of underground facilities in urban areas has to face a number of constraints. The surrounding buildings, often ancient and sometimes in precarious static conditions, have not to be damaged; the traffic of nearby roads or railways has not to be interrupted, etc.
The retaining structures are designed to insure a proper safety against failure but focus is moving more and more on the prediction of the displacements in order to prevent damages to the surroundings. Anchors or props are provided to control displacements, and designed with different methods; but the uncertainties in the predictions remains still significant (Boissier *et al.*, 1978; Pane & Tamagnini, 1997).
In these conditions the availability of well documented case histories and their back analysis is one of the most powerful tools for a significant advance in design criteria. A number of comprehensive State-of-the-Art papers review and comment the available evidence (Clough & O' Rourke, 1990; Caputo, 1997). An updated picture of the matter has been presented in a recent Workshop (GNCSIG-CNR, 1997).
The case reported in this paper is intended as a further small contribution to this picture.

THE SCHEME

The building area (Fig.1) is located in the centre of the city of Salerno, in Southern Italy. It is bounded on the north side by one of the most important and busy street of the city; on the south side it is close to a 6-storey reinforced concrete framed building founded on pad footings at a depth of 3.2 m. The area is approximately rectangular in plan, with sides of 50 and 27 m.
A two-level underground car park will be located in the basement of the new building (Fig. 2). It will be excavated within a perimeter diaphragm wall, made by panels excavated in bentonite slurry and cast in situ. The panels are 2.5 m long, 0.6 m thick and

18 m deep; the maximum excavation depth is 8 m.

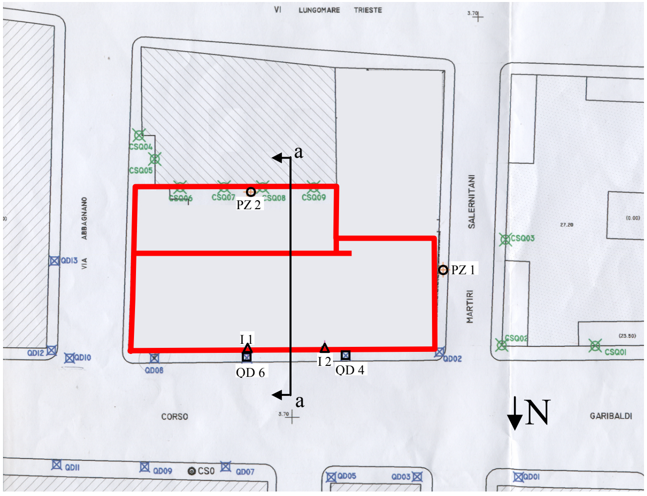

Fig. 1. Plan of the site.

On the south side, an intermediate diaphragm wall separates the parking area from the access ramp; at the time being, only the wider parking area has been excavated.

A 0.75 m thick reinforced concrete slab has been cast at the bottom of the excavation. To resist uplift in the early stages of construction, when the building weight is not yet acting on it, the slab is anchored to a number of foundation barrettes.

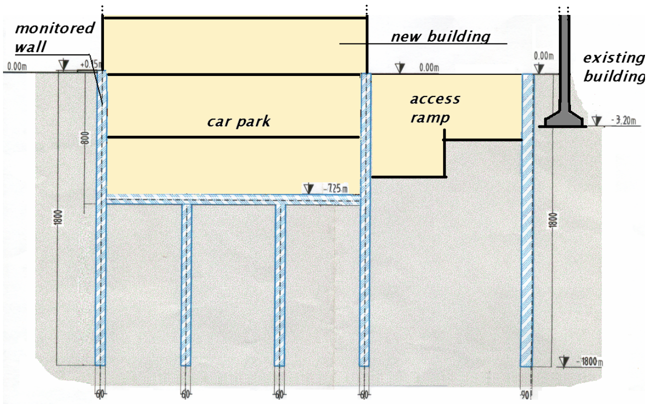

Fig. 2. Section a-a.

The site is located about 100 m away from the shore line, in a narrow coastal plain with steep calcareous hill behind it. The area has been partly reclaimed in the 19th century. The subsoil has been investigated by boreholes, SPTs and CPTs, and a calcareous bedrock has been found at a depth of approximately 21 m below the ground level. The bedrock is overlain by irregular layers of essentially sandy and gravelly soils, including some horizontal silty layers whose permeability ($k=3x10^{-6}$ m/s) is significantly lower than that of the sandy and gravelly sediments. The main silty layer is found between 17 and 19.5 m below the ground level, and appears to be continuous over the excavation area. Other thinner silty layers are found at lower depths. The subsoil profile and the results of penetration tests are reported in Fig. 3. The water table is found at a depth of around 3 m and undergoes slight oscillations in connection with the rainfall.

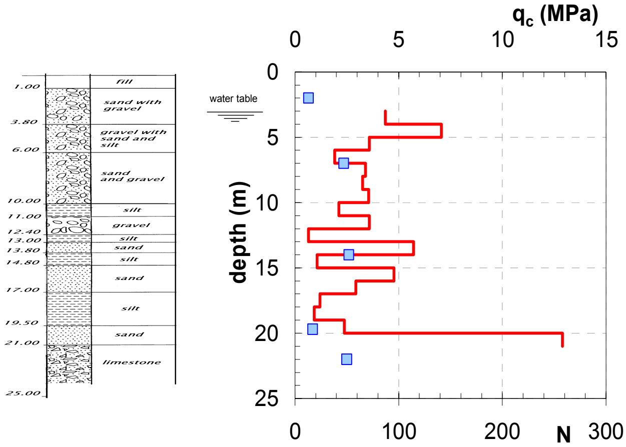

Fig. 3. Ground conditions.

The excavation has been carried out in stages. As a first step, half of the area was excavated to a depth of 3.5 m and a set of props (steel pipes with diameter 500 mm, thickness 25 mm and spacing 5 m) was installed. Thereafter, the excavation was continued until reaching the depth of 8 m over half of the area (around 25 m on the north side). The excavation bottom was connected via a 45° slope to the non excavated area without props. At the same time the water level inside the excavation was depressed by pumping from 4 wells located in the corners of the area and drawing water from a depth of 14 m, above the main silty layer.

Once the bottom slab and columns had been cast over the excavated area, the intermediate floor was constructed just below the props level. It was tightly fitted against the diaphragm wall, thus acting as a horizontal support. The whole procedure was then repeated in the second half of the excavation. The ground was excavated to a depth of 3.5 m. The props were removed and installed in the second excavation area; the excavation and the bottom slab were completed. After anchoring the slab to the barrettes, pumping was stopped, the remaining columns constructed, the intermediate floor completed and the props removed. The ground floor was finally constructed on the top of the diaphragm wall

MONITORING

Groundwater Regime

Two standpipe piezometers had been installed outside the south and west sides of the area, close to the diaphragm wall. Piezometer PZl (Fig. 1) reaches a depth of 20.6 m, while PZ2 of 12 m, i.e. respectively below and above the main silty layer.

The groundwater levels measured in the two piezometers during the excavation period are plotted in Fig. 4. It is worth noticing that pumping started at the same date as the excavation.

Judging from the results reported in Fig. 4, the deep silty layer acts as an effective bottom seal. The inflow into the wells has been very low (around 1 l/s each) and the influence of pumping outside the diaphragm wall negligible. In fact, the water level in both piezometers is approximately constant, apart from small oscillation (less than 100 mm) consistent with the rainfall regime.

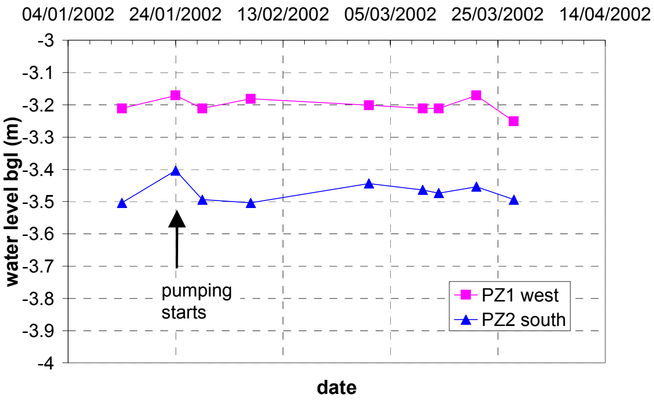

Fig. 4. Groundwater levels measured in the two standpipes.

Vertical Displacements

A net of measuring points had been installed on the ground behind the diaphragm wall and on some nearby buildings. The vertical displacements of these points have been measured daily by means of precision levelling.
The settlement of points QD4 and QD6, located in the vicinity of the two inclinometers (Fig. l) are reported against time in Fig. 5. The small sketches superimposed to the figure summarise the advancement of the excavation at significant dates. The first vertical displacement occurred between 24th and 29th January 2002, when the first half basin was excavated from 3.5 to 8 m depth. The settlement of point QD6 (around 5 mm) was higher than that of QD4 (around 3 mm); this difference is probably due to the presence of the props at the location of QD4, while at the location of QD6 the excavation had not yet started. After this date, QD4 nearly stopped moving; at the end of the excavation (14th March 2002) the displacement reached around 4 mm. The point QD6, on the contrary, kept settling; the main displacements have been observed during the excavation of the second half basin till 3.5 m (which ended on 7th March), and from 3.5 to 8 m (which ended on 14th March). It may be seen that point QD6 settled in this stage more than point QD4 did in the first stage, in spite of the identical excavation procedure. At the end of the excavation, point QD6 totalled a settlement of around 11 mm.

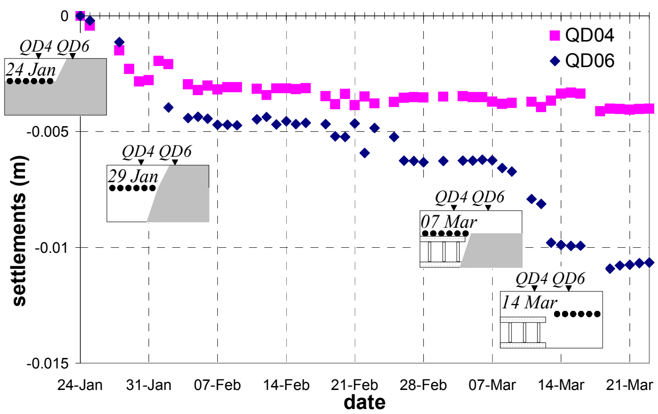

Fig. 5. Settlements as measured behind the wall close to the locations of the two inclinometer tubes.

At a distance of 20 m to 25 m from the diaphragm wall, no settlement has been observed at the ground surface.
Clough & O'Rourke (1990), collecting data from a large number of retaining structures of different type, have shown that the maximum settlement behind the wall averages 0.15% (and in any case never exceeds 0.5%) of the retained height H. The area affected by the excavation does not exceed a distance x = 2H from the wall.
The data collected by Clough & O'Rourke for walls in sand are reported in Fig. 6, together with the results obtained in the present investigation. The maximum measured settlements have been equal to 0.05% and 0.15% of the excavated height; at a distance x = 2H the settlement has vanished. The values measured in Salerno are thus fully consistent with the previous available evidence.

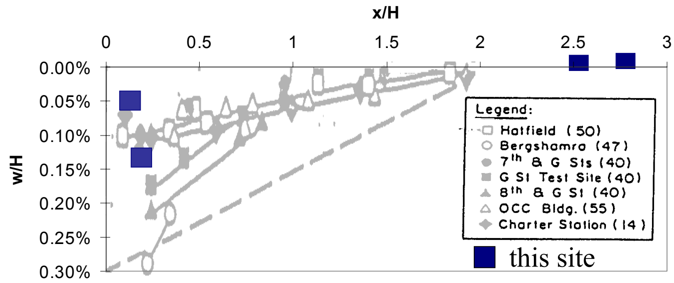

Fig. 6. Measured settlements behind the monitored wall and profiles for sand after Clough and O'Rourke (1990).

Horizontal Displacements

The north side of the diaphragm wall had been equipped with two inclinometer tubes (Fig. 1). The readings were taken at 0.5 m intervals. The zero reading for both tubes was obtained when the excavation in the first half basin had reached the depth of 3.5 m. Thereafter, readings were taken at the main excavation stages.
The profiles of the horizontal displacements perpendicular to the wall, as measured in the two inclinometers at different stages, are plotted in fig. 7. The maximum horizontal displacements at the wall top are equal to 20 and 28 mm, or 0.25% and 0.35% of the retained height H.
The arrow in the figure indicates the prop level. The displacement profiles at inclinometer I2 show the constraining effect of the props, which on the contrary is missing in the inclinometer I1 before 11th March, because the props were not yet installed at that location and the wall was retained by the soil not yet excavated. After the removal of the props, the supporting action has been exerted by the intermediate floor.
The horizontal displacements u at the top of the inclinometer tubes I1 and I2 are plotted against time in Fig. 8. The settlement w of points QD6 and QD4, very close to I1 and I2 respectively, are also plotted in the same figure. It is evident that horizontal and vertical displacements are generated by the same excavation events.

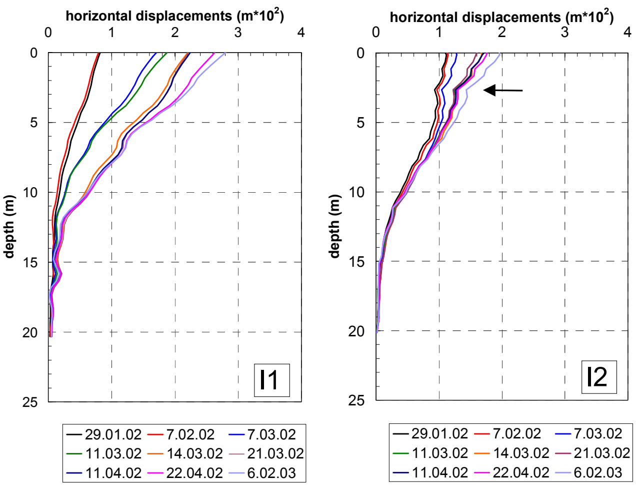

Fig. 7. Measured horizontal displacements.

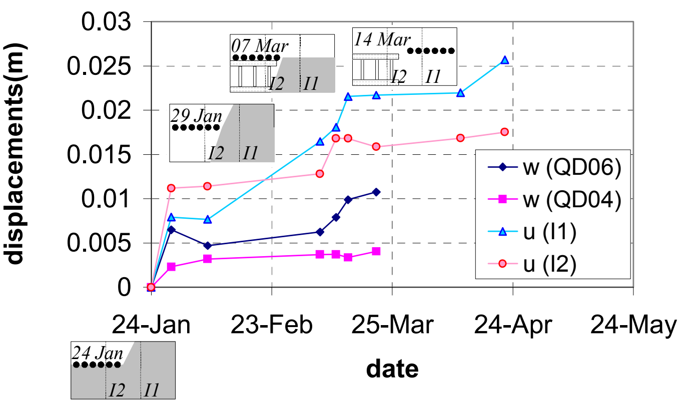

Fig.8. Significant displacements plotted along time

The maximum horizontal displacements at the top of the wall are plotted against the corresponding settlement in Fig. 9. The ratio between the maximum settlement of the ground behind the wall and the maximum horizontal displacement of the wall is in the range from 0.2 to 1.

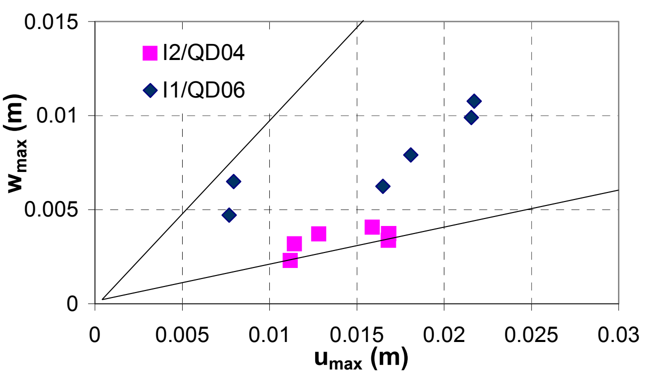

Fig.9. Settlements versus relevant horizontal displacements.

For a more detailed analysis, the horizontal displacement profiles at the inclinometer tubes I1 and I2, already presented in Fig. 7, are compared each other at different dates in Fig. 10. At 29th January and 7th February the displacements along I2 are larger than along I1, because the excavation interested the part of wall were I2 is located. On 7th March the displacements in the top four metres along vertical I1 increased, because that part of the wall had been excavated to 3.5 m without props. As soon as the props were removed from the first part of the wall (11th March), the two profiles superimposed each other.

Starting from this date the inclinometer I2 did not move significantly anymore, while the displacements along I1 kept increasing in connection with the excavation of the second half basin.

On 21st March and 11th April, while the bottom slab and the intermediate floor were being completed, no increments of the displacements were observed. As soon as the props were removed (22nd April) the wall moved again, which demonstrates the effectiveness of props.

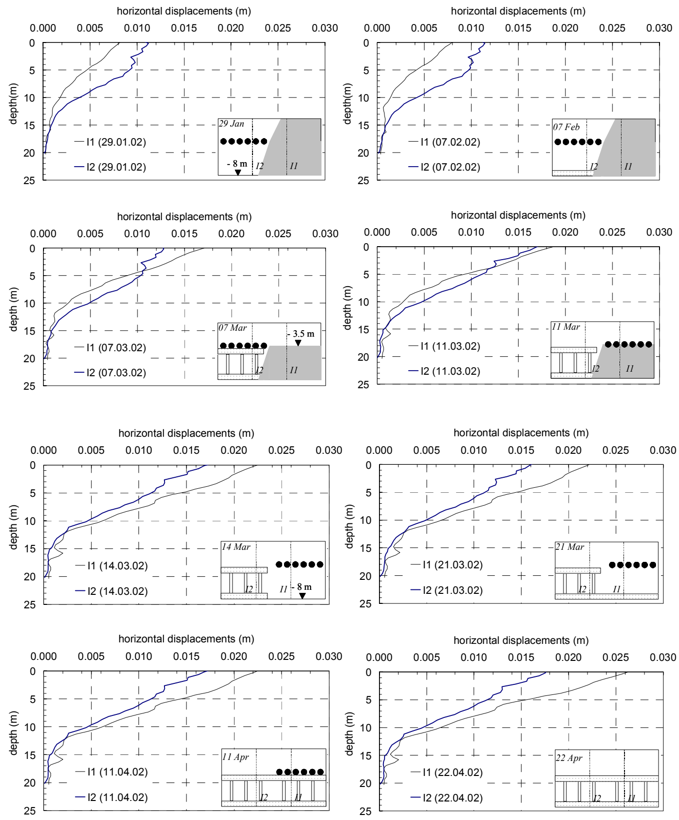

Fig.10. Horizontal displacements: comparison between profiles at I1 and I2.

After the end of the excavation, in a period of about 10 months from 22nd April 2002 to 6th February 2003, a further slight movement of about 2 mm has occurred at both measuring points (Fig. 7).

CONCLUDING REMARKS

The monitoring program had been essentially intended to observe the movements induced by the excavation in the surrounding area, including some buildings and a busy road. The groundwater

level has been also monitored, due to the concern for a possible bottom heave.
Due to the characteristics of the subsoil and to the depth of the diaphragm walls, the water inflow into the excavation has been very small. As a consequence, the groundwater regime around the excavation was practically unaffected by dewatering inside the basin.
The settlement of the ground surface in the immediate back of the wall and the horizontal displacements of the wall are in the range identified in the literature for similar structures in sand. The extent of the settlement through at the back of the wall is also consistent with previous available evidence.
The excavation has been carried out in two main stages, each one interesting half of the area. An inclinometer tube was located in each of the two parts of the wall. The comparison between the profiles of the displacements along the two inclinometers in the various stages of the excavation allows to recognise the influence of props, of the intermediate floor and of non excavated soil on the movements of the diaphragm wall.
The final horizontal displacements did not exceed 28 mm, the settlement 10 mm. These results support the choice to prop the walls and to carry out the excavation in parts, in order to reduce the movements of the adjacent ground and prevent any damage to the structures. As a matter of fact, these goals have been completely attained.
Apart the use of monitoring to prevent possible troubles during the works, the data collected represent a further small contribution to the existing data base and to empirical design criteria.

ACKNOWLEDGEMENTS

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