Behaviour of diaphragm walls during construction of Cairo Metro

Le comportement des parois moulées pendant la construction du Métro du Caire

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SYNOPSIS Over ten kilometers of precast and cast-in-place diaphragm walls were used during construction of the underground portion of the regional line of Cairo Metro. These walls were used to support the sides of deep excavations and formed the side walls of five underground stations and the connecting cut-and-over tunnel. This paper examines and compares the geotechnical in-situ behaviour of the diaphragm walls based on the results of monitoring instrumentation program. The effects of bracing systems, wall stiffness and soil profiles on magnitude and shape of measured soil deformations are discussed.

1. INTRODUCTION

Construction of the underground portion of the regional line of Cairo Metro, between Mobark underground station and El-Saiyida Zeinab surface station, was completed during 1987. This portion of the first metro line in Cairo connects the existing Helwan surface railway line to the south with the surface line extending northeast to El-Marg as shown on Figure 1. The central section of the regional line runs under the urban core of Cairo through intensely developed areas, with buildings and other structures closely adjacent to the walls of the tunnel and stations.

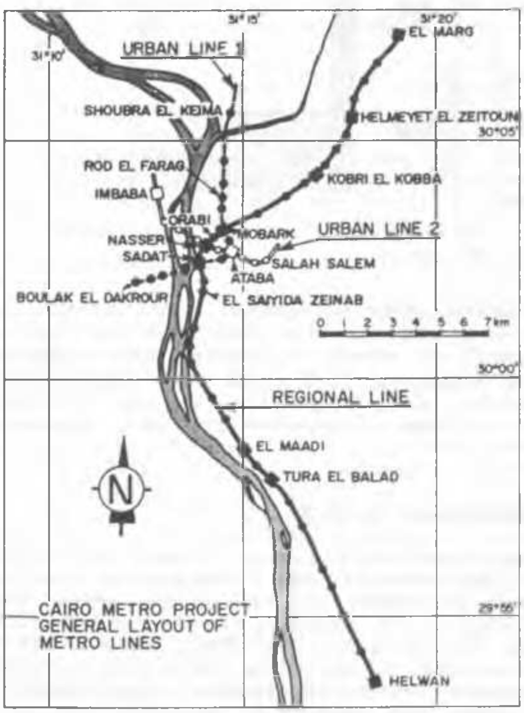

Figure 1 Cairo Metro Project-General layout of metro lines.

Precast reinforced concrete diaphragm walls were used to form the walls of the cut-and-cover tunnel connecting the new five underground stations. Side walls of these stations were built of cast-in-place diaphragm walls. Both types of walls were built into slurry trenchs extending to an average depth of about 18 metres through alluvial and diluvial Nile deposits.

A geotechnical monitoring program was implemented during construction. The instrumentations were installed in two test sections. The first section was located at about 600 metres north of El-Saiyida Zeinab Station while the second instrumentation array was installed at Orabi Station.

This paper focuses on the geotechnical in-situ behaviour of the two types of diaphragm walls based on the results of the monitoring instrumentation program.

2. GEOLOGY AND GEOTECHNICAL PROPERTIES

The general geology of Nile valley and delta is described by Attia (1954) and Said (1981). El-Ramli (1985) and El-Sohby and Mazen (1985) examined several geological and geotechnical aspects of different deposits in Greater Cairo.

Underground portion of the regional line of Cairo Metro was constructed within the recent deposits which consisted mainly of silt and clay layers several metres thick underlain by sand and gravely sand layers. Surficial fill layer of heterogeneous mixture of silt, clay, sand, bricks, pottery and blocks of limestone was encountered along the chosen alignment. Table 1 contains average geotechnical properties of the main soil layers in central area of Cairo. The groundwater table is present at shallow depth of less than three metres.

Table 1 Average geotechnical properties.

	Fill	Clay-Silt	Medium Sand	Dense Sand
Bulk Density (kN/m^3)	18	17.5	18	20
Natural Moisture Content%	38	32	22	N/A
% Clay	25	40	8	zero
% Silt	30	45	15	5
% Sand	23	15	78	95
% Gravel	22	zero	zero	zero
Plastic Limit %	30	25	--	--
Liquid Limit %	50	60	--	--
Permeability (m/s)	$3.5x10^{-8}$	10^{-6}	$3x10^{-5}$	$2x10^{-4}$
Undrained Shear Strength (kPa)	50	60	--	--
Effective Cohesion Intercept (kPa)	N/A	10	--	--
Effective Angle of Internal Friction (deg.)	N/A	20-30	25	30
Standard Penetration (blows/0.3m)	4-20	11	20	35

3. CONSTRUCTION PROCEDURES

Final configurations of the cut-and-cover tunnel and underground Orabi Station at the instrumented test sections are shown on Figures 2 and 3 respectively. The following paragraphs contain the construction procedures followed at these sections.

3.1 Cut-and-Cover Tunnel

The side walls of the tunnel was formed of precast panels. Each panel is 15m long, 2.5m wide and 450mm in thickness. Adjacent panels were connected with rubber water-stops over the full length of the panels. As illustrated in Figure 4, these panels were lowered into 600mm wide slurry trenches which had been excavated to a depth of about 20 metres. The self hardening cement and bentonite slurry was used for supporting the vertical walls. The tunnel was also divided in the longitudinal direction into sections by lateral cutoff walls made of cement and bentonite slurry.

A horizontal grouted plug was then constructed by pumping bentonite-cement slurry and silica gel from ground surface through plastic pipes. Subsequently, dewatering was carried out between the diaphragm walls with minimum disturbance to groundwater levels under surrounding buildings. In-situ pumping tests were carried out for each section of the tunnel in order to confirm the integrity and performance of the grouted plug. Experiences gained during the early stages of construction of grouted plug are discussed by Salam (1984).

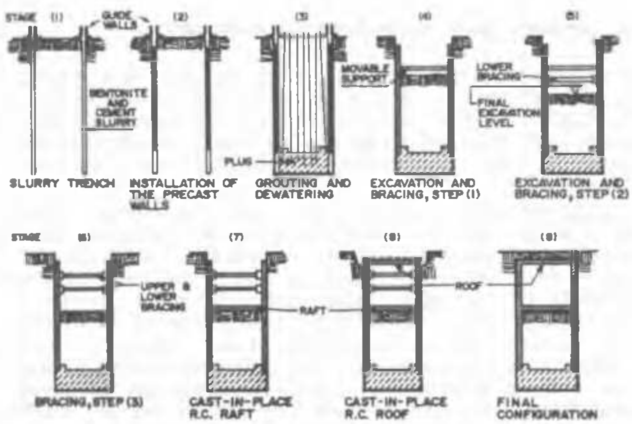

Figure 4 Construction procedure at tunnel test section.

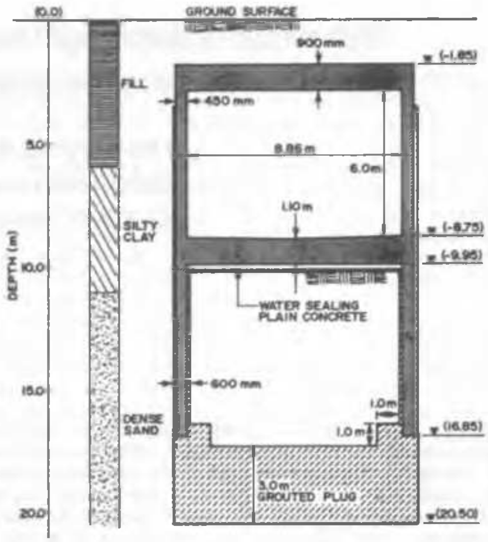

Figure 2 Configuration and soil profile at tunnel section.

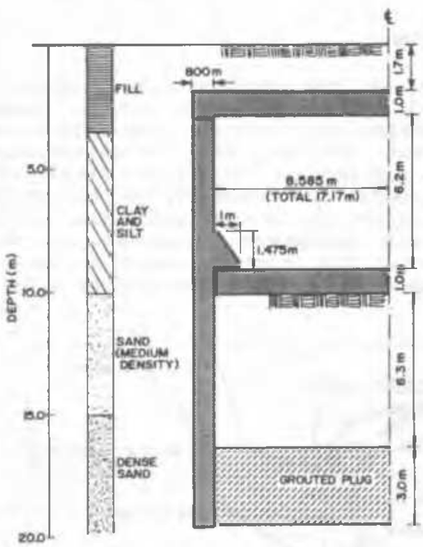

Figure 3 Configuration and soil profile at station section.

3.2 Underground Station

The construction procedure shown on Figure 5 was followed at the instrumented section of Orabi Station. It should be noted that this station is located at the intersection of the Ramsis with the Orabi Streets which are considered to be among the busiest streets in downtown Cairo. Therefore, the excavation under cover was considered suitable for these conditions.

The construction of this underground station started with installation of guidewalls and drilling of 800mm wide bentonite slurry trenches. Once the trenches were excavated to the required depth, a reinforcement cage was lowered into the trench and the bentonite slurry was then displaced from the bottom by cast-in-place concrete. The configuration of grouted plug used at the station was slightly different from that of the cut-and-cover tunnel, however, it was formed using the same procedure.

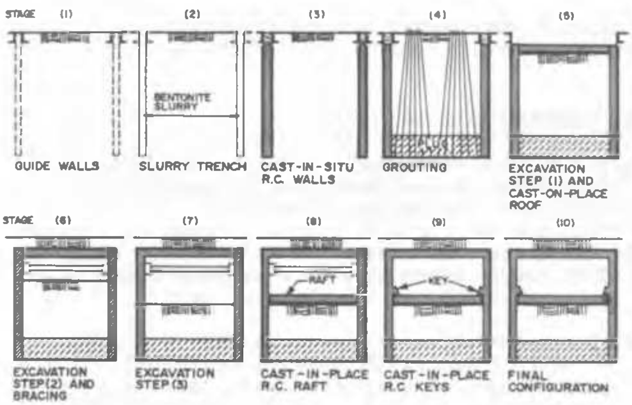

Figure 5 Construction procedure at station test section.

4. GEOTECHNICAL MONITORING PROGRAM

4.1 Test Sections

An in-situ monitoring program was implemented during construction. Instrumentations were installed in two test sections. The first section was located on the cut-and-cover tunnel at about 600m north of El-Saiyida Zeinab Station while the second instrumentation array was installed at Orabi Station. Layout of the instruments at the tunnel test section are given by El-Nahhas et al (1988) and details of Orabi Station test section are given by El-Nahhas et al (1989).

4.2 Field Measurements

The final profile of lateral deformation of precast diaphragm wall of the tunnel at end of construction is shown on Figure 6. This figure also includes the final lateral soil deformation as measured by a slope indicator located at a distance of about 2 metres from the wall.

Figure 7 shows final soil lateral deformation at a distance of about 2 metres from the cast-in-situ diaphragm wall of Orabi Station. Measurements of settlement troughs and pore water pressure at the tunnel test section are given on Figures 8 and 9 respectively.

Complete records of all field measurements of the two test sections are given by Eisenstein et al (1987).

5. DISCUSSION ON MEASUREMENTS

It is interesting to note the differences in the magnitude and shape of lateral soil deformation adjacent to the tunnel section

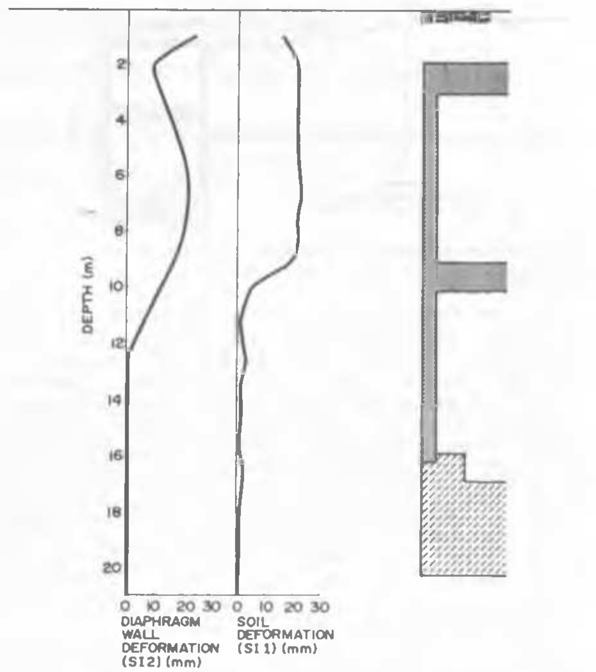

Figure 6 Final lateral deformations of diaphragm wall and soil-tunnel test section.

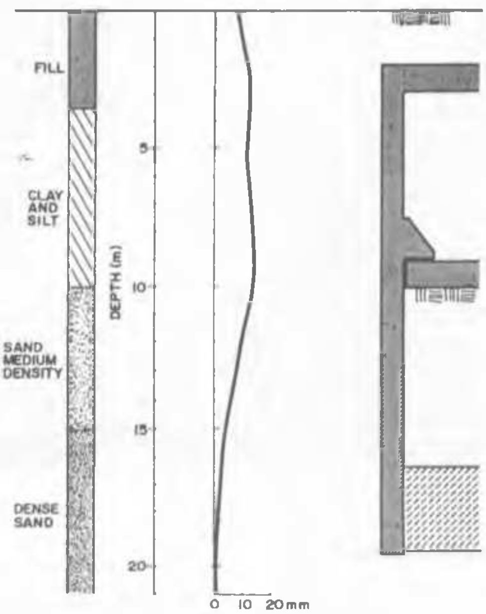

Figure 7 Final lateral soil deformation-station test section.

(Figure 6) and those measured adjacent to Orabi Station (Figure 7).

Providing top permanent support at an early stage of excavation at Orabi Station constrained the relatively stiff 800-mm cast-in-place diaphragm wall. Hence, deformation of adjacent soil was smaller than those experienced by the relatively flexible 450-mm precast diaphragm wall which was laterally supported at later stage of excavation using temporary bracing system.

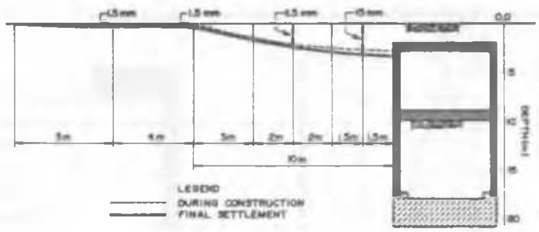

Figure 8 Settlement troughs adjacent to diaphragm wall-tunnel test section.

The difference in soil profiles at the two test sections had undoubtly the most significant effect on different shapes of measured lateral soil deformations. Presence of the dense sand layer directly underneath the silty clay at the tunnel section resulted in localized high soil strains near the final level of excavation during unloading by excavation. On the other hand, stiffness of soil layers adjacent to Orabi Station varies gradually with depth from silt-clay through sand of medium density (about 5m in thickness) to the dense sand. Therefore, soil adjacent to the station responded in a continuous smooth mode of deformation.

The ratio of maximum ground settlement adjacent to the diaphragm wall (Figure 8) to the corresponding maximum lateral deformation of the wall (Figure 6) was about 0.6. This ratio is considered relatively low according to the limits and guidelines proposed by Peck (1969) Mana and Clough (1981) and Schlosser et al (1985). As discussed by El-Nahhas et al (1988), this low ratio is considered an indication of good performance of the controlling elements during excavation between the diaphragm walls. Bracing systems controlled deformations in general and the grouted plug minimized changes in pore water pressures adjacent to the diaphragm walls (Figure 9) during excavation.

6. CONCLUSION

In-situ behaviour of two types of diaphragm walls is examined in this paper. It is concluded that the difference in magnitude and shape of lateral soil movement adjacent to these walls is the combined effect of differences in bracing systems, wall stiffness and soil profiles.

7. ACKNOWLEDGEMENTS

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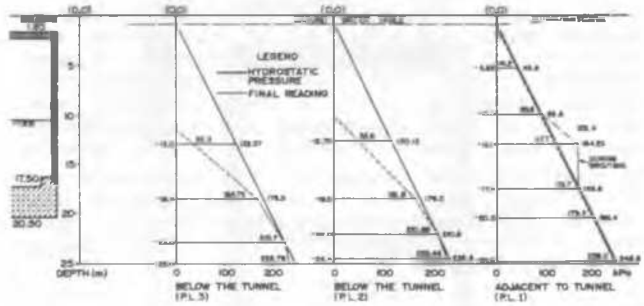

Figure 9 Pore water pressure around diaphragm wall-tunnel test section.

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