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Monitoring Diaphragm Wall Performance in Egypt's 4th Metro Line: Insights on Lateral Earth Pressure

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ABSTRACT: The accumulation of field data on lateral earth pressure performance of embedded walls during deep excavations has historically been essential for developing the appropriate design parameters for optimal behavior. This paper presents a set of field measurements of lateral earth pressure and horizontal deformations on the diaphragm walls of Egypt 4th Metro line stations. Measurements have been recorded using jack-out pressure cells, strain gauges, and inclinometers. Variations of lateral earth pressure and horizontal movements have been recorded during the successive phases of the top-down construction technique. Such set of field measurements introduces important insights towards verifying/revising empirical apparent lateral earth pressure charts, early developed by Peck (1969) and its further revisions, (e.g. FHWA,1996). The findings expand our understanding of soil-structure interaction in urban underground constructions, laying the groundwork for future projects and offering new ideas in geotechnical design and earth pressure control.

KEYWORDS: Jack-out pressure cells, Field Monitoring, Lateral earth pressure, Lateral deformation.

1 INTRODUCTION

One of the main challenges in designing deep urban excavations is accurately predicting the lateral earth pressures on diaphragm walls, especially for metro systems where rigorous deformation control is crucial. Although diaphragm walls are the ideal option for these kinds of applications because they combine groundwater containment capabilities with structural stiffness, their intricate interactions with nearby soils still require careful study. While traditional frameworks such as Tschebotarioff's (1973) refinements and Peck's (1969) apparent pressure diagrams have been crucial for design guidance, their development primarily from case histories in particular geological contexts raises concerns about their universal applicability, especially given the unique soil conditions found in Middle Eastern metro projects.

Research has shown for decades that wall stiffness plays a crucial role in earth pressure mobilization. Field studies repeatedly show that more flexible systems mobilize active pressures at the expense of increased deformation, whereas stiffer diaphragm walls tend to create pressure distributions that approach at-rest circumstances due to constrained displacement Clough & O'Rourke (1990). Potts and Fourie (1984) used sophisticated numerical modeling to further demonstrate how structural stiffness affects both the distribution patterns and the quantity of pressure, with construction sequencing adding even more intricacy to these relationships.

This study presents a sample of the detailed monitoring data from Egypt's 4th Metro Line diaphragm walls, providing critical insights for calibrating empirical charts and improving soil–structure interaction models in regional contexts.

2 SITE DESCRIPTION AND FIELD MONITORING PROGRAM

The greater Cairo Metroline, Egypt, phase 1, extends over 18,766 km connecting 12 stations as shown in figure 1. The construction work has been extensively instrumented for field monitoring, this work represents samples of the monitoroing data of two stations for lateral earth pressure. The selected stations were chosen as the soil profile consists mainly of sandy soil with no ground water table appearance during the site investigation, the soil profiles are depicted in figure 2a and 2b. The stations are composed of diaphragm wall (DW) panels, raft (R), concourse and intermediate slabs (C) and roof slab (F), as can be seen in the typical section in figure 3.

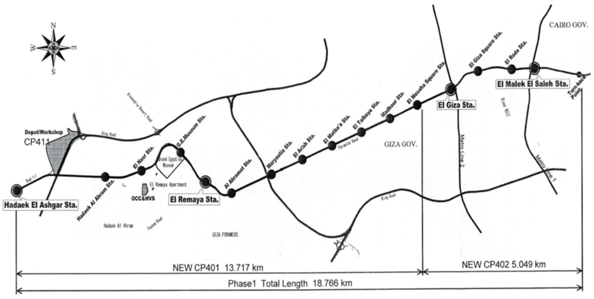


Figure 1. Cairo Metroline 4.

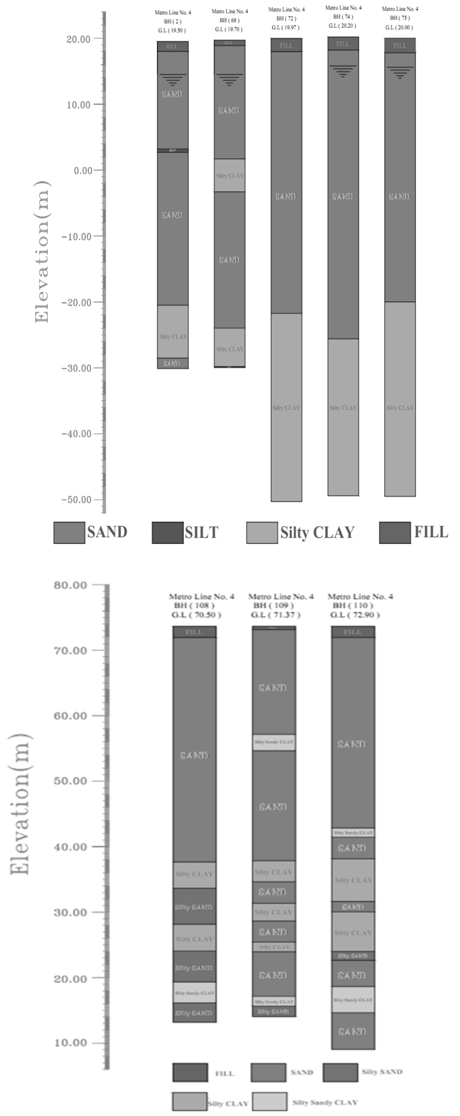


Figure 2. Soil profile for a) station 3 and b) station 5.

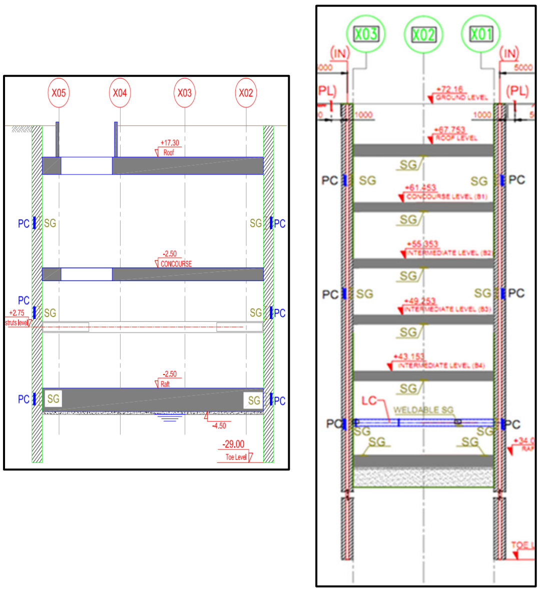


Figure 3. Typical cross section of stations 3 and 5.

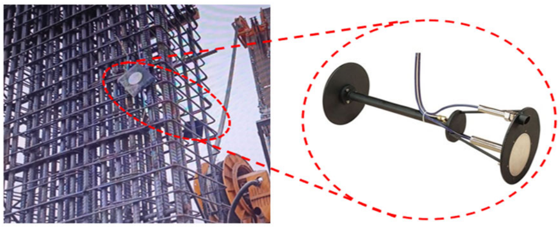


Figure 4. Jackout pressure cell.

3 FIELD MONITORING RESULTS AND DISCUSSIONS

3.1 *Jackout Pressure cells*

Jackout pressure cells are embedded instruments used to measure lateral earth pressures acting on diaphragm walls in deep excavations. Instrumented to the reinforcement of the wall as shown in figure 3, they provide real-time data on stress changes along the construction time. Their working principle involves a fluid-filled chamber enclosed between two steel plates; when soil pressure deforms the plates, the resulting fluid pressure is transmitted to a pressure transducer, which converts it into an electrical signal.

3.2 *Preshearing of soil*

The initial PC readings presented in figure 5 show the different stages at which readings were taken, as follows:

- Stage 1: before excavation of the panel, the PC is at air pressure while the soil is at K_o condition.
- Stage 2: after excavation of the panel in slurry, the PC is attached on the cage in the slurry while there is a change in the horizontal pressure of the soil due to allowance of the soil to strain with no change in the soil overburden pressure.
- Stage 3: Just after pouring concrete in the panel (Fresh concrete). There will be change in the horizontal stress in the soil depending on the slump of the fresh concrete. The more the slump of the fresh concrete, the more the horizontal stress the fresh concrete imposes on the soil.
- Stage 4: the concrete curing stage and the horizontal stress in the soil stabilizes with time (reduces). during this stage the no lateral strain condition is imposed on the soil and first reading of PC shall be taken.

Mesri and Hayat's (1993) preshearing effect can explain the fluctuations in horizontal pressure observed in stage 3. Preshearing soil away from laterally limited deformation changes its structure permanently, causing it to remain larger than K_o even after passive shear. When a soil is presheared away from the K_o line, it reaches equilibrium at an earth pressure that falls between the K_o line and the maximum preshear condition. Figure 5 illustrates a unique relationship between the horizontal pressure increment imposed to move soil away from the K_o line, $[\Delta\sigma_h]_I$, and $[\Delta\sigma_h]_S$, which defines the position of the pressed soil with respect to the K_o line when laterally constrained conditions are re-established. The empirical relation between $[\Delta\sigma_h]_I$, and $[\Delta\sigma_h]_S$ which is independent of σ'_{vo} is :

$$[\Delta\sigma_h]_S = \frac{1}{1.7}[\Delta\sigma_h]_I \qquad (1)$$

This value is the result of actual field conditions compared to the value of 2.5 by Mesri and Hayat's (1993) which was deduced from laboratory experiments.

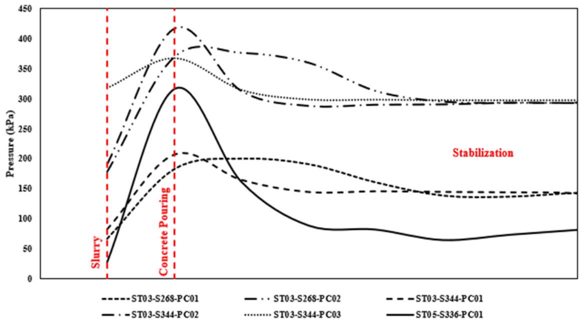


Figure 5. Preshearing through different stages.

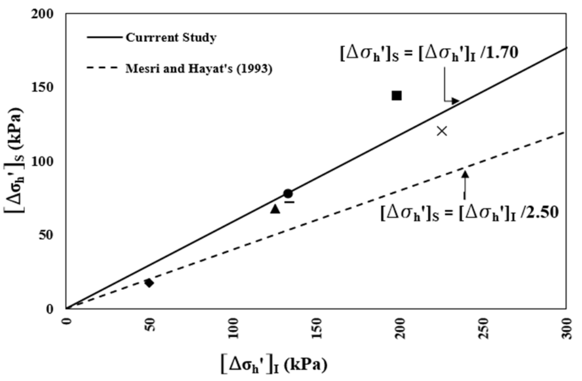


Figure 6. Relationship between $[\Delta\sigma_h]_I$ and $[\Delta\sigma_h]_S$.

3.3 *Lateral earth pressure coefficient*

A number of 8 DW panels have been instrumented with 3 pressure cells (PC) distributed at different levels, with a total of 24 (PC) measured with time from 2022 to 2025. The horizontal earth pressure (σ_h') after the full construction of the station and and before operation is calculated for each PC, and the results are compared to those previously constructed by Peck (1969) and Tschebotarioff (1973) as depicted in figures 7a and 7b.

Results show that the values of the horizontal earth pressure (σ_h') are smaller than those of Peck (1969) and Tschebotarioff (1973) in the upper levels, while they are larger for the lower levels. The lateral earth pressure coefficient at each level is calculated as the ratio between the effective vertical stress (σ_{vo}') and the effective horizontal earth pressure (σ_h'). These values are compared to Jaky's (1944) formula of the at rest earth pressure of normally consolidated sand (K_o) and to Rankine's active earth pressure (K_a). The results for both stations are shown in figure 8(a) and (b). It can be observed that the K values exceed both K_o and K_a by a factor of 1 to 2, except for some points. The high K value is believed to be attributed primarily to the high rigidity of the DW, which constrains wall deformations and inhibits the mobilization of active earth pressure conditions. In rigid retaining structures, limited deflection restricts the lateral strain in the retained soil, resulting in pressures closer to or even exceeding at-rest conditions (Powrie, 2014).

The comparison is made with K_a as it represents a constant value for a given friction angle, and with K_o for normally consolidated soil. However, it is believed that the sand at the site may be overconsolidated, which would justify the higher measured K values. Nevertheless, no sufficient data is available to confirm this assumption.

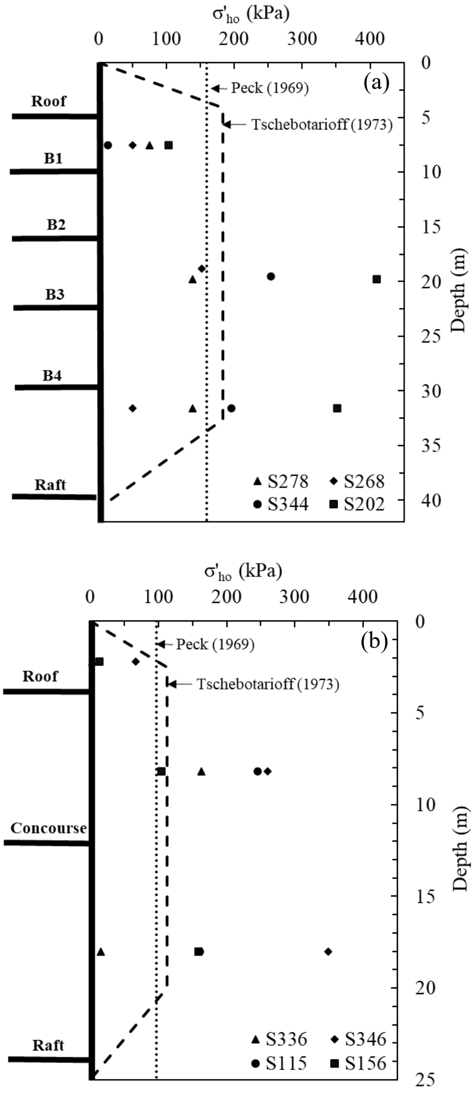
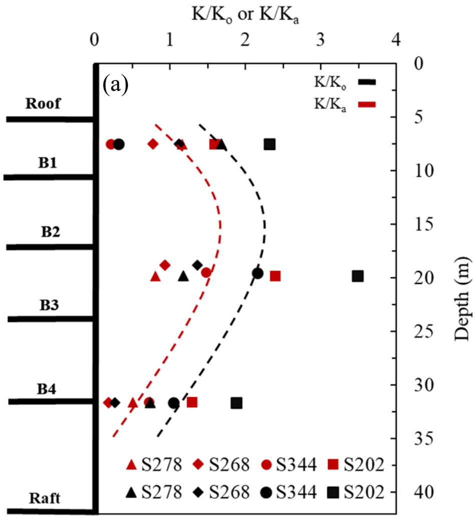


Figure 7. Lateral earth pressure with depth at panels of a) station 3, and b) station 5.



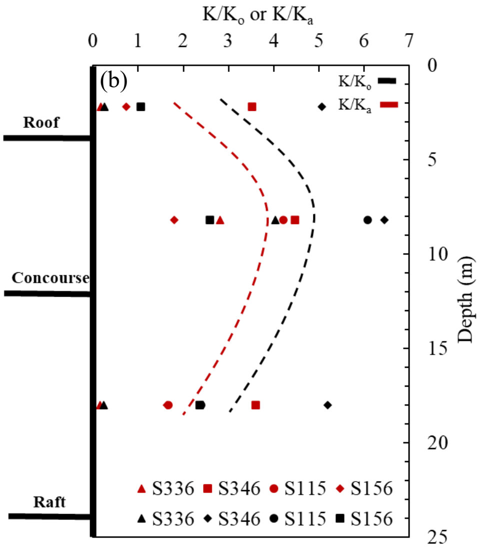


Figure 8. Lateral earth pressure coefficient for a) station 3 b) station 5.

4 SUMMRY AND CONCLUDING REMARKS

The present study investigated a series of jackout pressure cell measurements for Cairo Metro Line 4 located in a series of diaphragm wall panels that is supported by multilevel slabs. The manin findings can be summarized as follows:

- Preshearing of soil has been observed in the jackout pressure cells in diaphragm walls, due the concrete pouring process of the wall panels, where it finally reaches equilibrium at an earth pressure that falls between the K_o line and the maximum preshear condition.
- Measured apparent earth pressure goes along with the increase of diaphragm wall stifness and rigid supports which lead to higher lateral earth pressure coefficients, in comparison with those earlier of Peck 1969 from berlin wall which were flexible members.
- The current observations apply only for dry sand while the effect of water table may lead for the same conclusion provided limited data is available.
- The sand may be overconsolidated; without OCR data, implying $K_{o(NC)}$ is less accurate, and $K_{o(OC)}$ could be more representative.

In summary, the findings indicate that preshearing and wall stiffness significantly increase apparent earth pressures beyond values reported for flexible walls, with evidence pointing toward overconsolidated behavior where $K_{o(OC)}$ offers a more representative reference than $K_{o(NC)}$.

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