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COMPARATIVE STUDY OF DIAPHRAGM WALL SUPPORTED BY ANCHORS VERSUS TUBE SHORING

Jigar Shah[1], Javal J Patel[2], Dipak J Varia[3]
[1]PG Student, [2]Assiastant Professor, [3]HOD Applied Mechanics Department
Merchant Institute of Technology, Mehsana

ABSTRACT: A case study of mixed use of diaphragm wall and secant pile wall as an earth retaining structure for deep excavation is reported. A shoring wall of approx. 26m deep from existing ground level is designed for proposed construction of four basements and multi-story building. Diaphragm wall of 1m width and Secant pile wall of 1.2m diameter have been analysed by using finite element method with Plaxis 2D software in which they have been modelled as plate elements, ground anchors as node to node-to-node elements with embedded piles for fixed length, strut pipes as fixity points and soil layer and rock layers modelled as Harding Soil and Mohr Coulomb models respectively. During the excavation period, a monitoring instrumentations system including strain gauges for measuring loads on strut pipes and inclinometers for measuring the deflection of shoring wall have been implemented. Minor deflections have been observed in comparison to design estimation thereby confirming successful and safe performance of shoring wall.
Keywords: Diaphragm walls, Shoring, Deflections, Deep excavations, Anchoring.

I. INTRODUCTION

Shoring systems are deemed an integral part in modern day construction. Due to the increased demand of underground spaces worldwide, shoring systems for deep excavations plays vital role in the construction of underground tunnels, underground car parks, basements, underpasses and even in the construction of dams. Different shoring systems are used based on unique requirement of each and among all diaphragm Wall is one of the most robust and water tight earth retaining system especially for excavation depths greater than 15 meters.
Shoring is a term used to describe a system that functions to retain earth, water, and adjacent structures when an excavation is required. Shoring design can be a very complicated matter. The designer has to content with many unknowns and factors that influence the behaviour of the excavation shoring.

II. PROJECT DESCRIPTION

Diaphragm wall is envisioned for all roadside and parking side next to ADNOC building and at the existing gymnasium building side, secant pile wall of 1200mm diameter with 228mm over cutting is envisioned. The selection of secant pile wall was dictated by the fact that footing of gymnasium have been found 40cm inside the plot during the investigation pits excavated during the initial mobilization phase of the project. Such close proximity of footing together with already poor structural condition of the gymnasium building with existing cracks posed a great risk for the safe trenching of diaphragm wall with slurry. This risk has been mitigated by using a cased drilling system, thereby switching from diaphragm wall to a secant pile wall at this location.
Another similar risk for slurry trenching was the high advertisement hoarding on the Corniche Side, which has been decided to be temporarily shifted 5m away from the diaphragm wall. The relevant analysis in which this safe distance is determines is given in section 6. The advertisement hoarding on Al Khaleej Al Arabi Street was removed initially, only to be placed back after execution of diaphragm wall and before or after excavation. The timing of this placement (after diaphragm wall trenching) is due to the fact that 5m distancing was not possible at this side. So the surcharge load of the hoarding at the shorter side has only been considered for the lateral support design, but not for the trench stabilitycalculation.
The soil investigation for the proposed development was carried out. The investigation consisted of 13 boreholes drilled at different locations within the plot limits down to a depth of 40m to 60m.Ground water table was encountered at 1.5m to 2m fromEGL.

The design soil parameters required for the analysis of deep excavation system are Mohr Coulomb the shear strength parameters, i.e. Angle of internal friction (°), Cohesion (c) and Young Modulus (E) for sand and rock, which have been provided by M/s. ACES as listed below in Table 1.

Table 1: Soil parameters

Layers	Average Ground Level (NADD)		Avg. SPT / UCS	RQD	Angle of friction	Cohesion	Modulus of elasticity
	From (m)	To (m)	Blows /MPa	(%)	°	kPa	MPa
Compacted fill	2.05	1	Nil		10	0	20
Sand	1	-5	21		33	0	22
Calcarenite -1	-5	-13	2.5	56	32	142	277
Sandstone -1	-13	-14	1.2	24	25	39	190
Calcarenite -2	-14	-16	1	27	25	31	146
Sandstone -2	-16	-19	1	42	30	46	152
Gypsum-1	-19	-21	7	52	30	336	1521
Mudstone-1	-21	-24	3.6	61	27	144	332
Gypsum-2	-24	-26	11	55	31	548	2449
Mudstone-2	-26	-32	2.8	56	24	113	332
Sandstone -3	-32	-33	2.3	34	27	110	314
Mudstone-3	-33	-42	3	48	25	107	397
Gypsum-3	-42	-43	3.7	64	30	178	418
Mudstone-4	-43	-46	3.7	53	29	164	418
Gypsum-4	-46	-47	5.9	61	31	292	509
Mudstone-5	-47	-80	3.8	72	29	186	456

III. DESIGN ANDANALYSIS

The temporary shoring structures of diaphragm wall and secant pile wall have been analyzed for various stages in Finite Element Modeling (FEM) software Plaxis 2D in which they have been modeled as plate elements, Soil and rock layers have been modeled with Harding Soil Model and Mohr Coulomb Model, respectively.

The supporting systems of ground anchors consist of free length and fixed length, which are modeled as node-to-node anchor and embedded row pile, respectively. An unplanned excavation of 50cm has been considered in analysis as per requirement of municipality regulations, which refers to maximum value stipulated in BS8002:2015 Section 4.6.4.

As per shoring layout, excavation levels and surrounding structures, the five sections have been considered as follows.

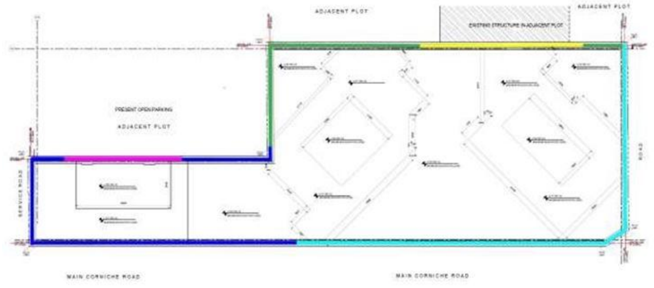

Figure 1 Section layout for Site

Design Section1

In this section, diaphragm wall of 1m thick with 1 layer of strut and 1 layer of anchor and final excavation depth -18.2 NADD where a general surcharge load of 20kPa have been considered behind thewall.

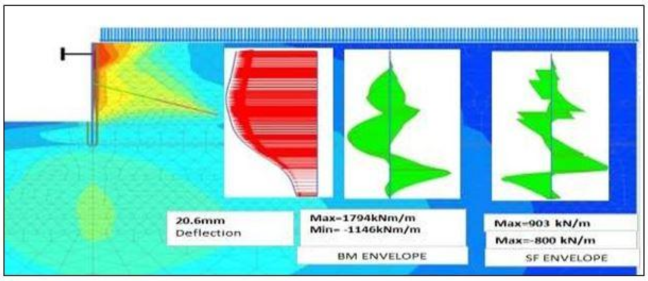

Figure 2 Deflection & BM analysis for Section 1

Design Section2

In this section, diaphragm wall of 1m thick with 1 layer of strut and 1 layer of anchor and final excavation depth -16.2 NADD where surcharge of 200kPa as hoarding load and 20kPa as general surcharge load have been considered behind the wall. The calculation for hoarding load is attached in AnnexureA.

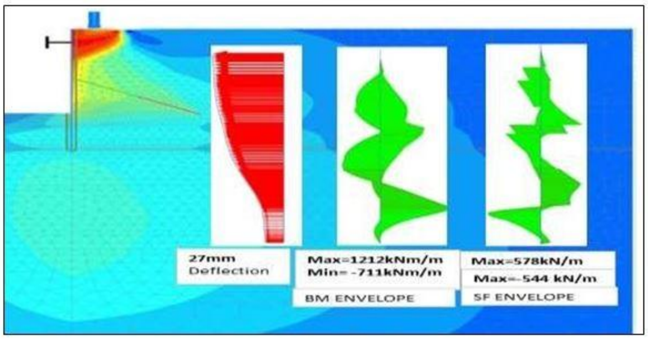

Figure 3 Deflection & BM analysis for Section 2

Design Section2A

Sharing same excavation level and supporting system, in these sections, diaphragm wall of 1m thick with 2 layers of strut and final excavation depth -16.2 NADD where surcharge of 200kPa as hoarding load and 20kPa general surcharge load have been considered behind the wall.

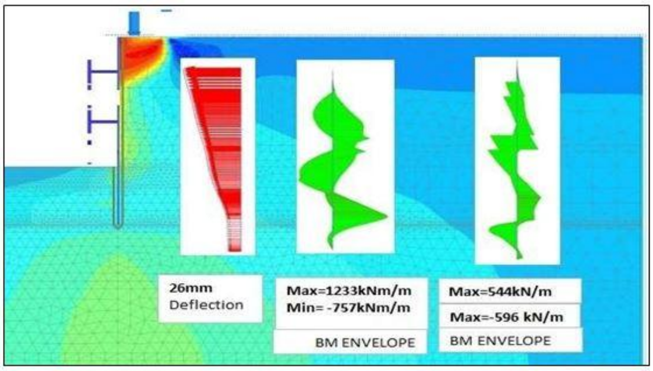

Figure 4 Deflection & BM analysis for Section 2A

DesignSection3

In this section, diaphragm wall of 1m thick with 2 layers of anchor and final excavation depth -16.2 NADD where 20kPa general surcharge load has been considered behind the wall.

Performance of Shoring wall in Deep excavation

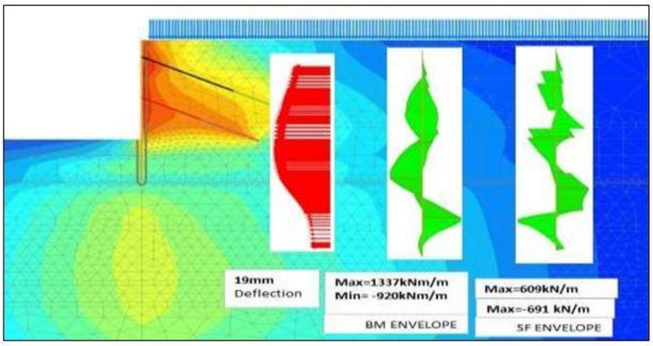

Figure 5 Deflection & BM analysis for Section 3

Design Section4

In this section, diaphragm wall of 1m thick with 3 layers of anchor and final excavation depth -16.2 NADD where surcharge of 200kPa as hoarding load and 20kPa general surcharge load have been considered behind the wall.

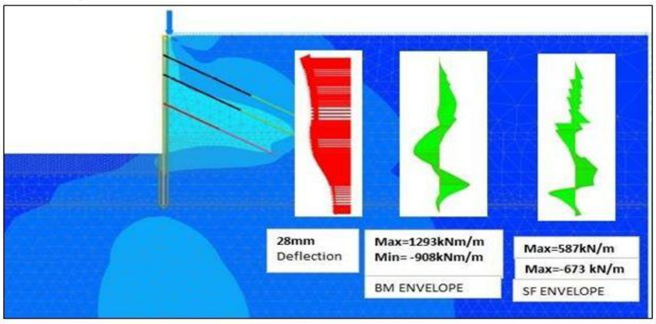

Figure 6 Deflection & BM analysis for Section 1

Design Section5

In this section, 1.2m dia. secant pile wall of with 3 layers of anchor and final excavation depth -16.2 NADD where surcharge of 141kPa as gym building foundation load and 20kPa general surcharge load have beenconsidered.

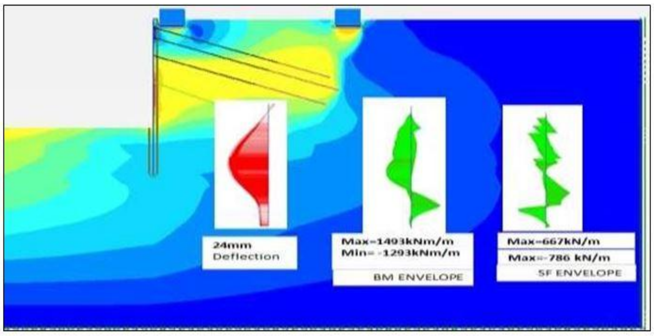

Figure 7 Deflection & BM analysis for Section 1

IV. MONITORING INSTRUMENTATIONS

Various monitoring instruments have been implemented to survey the performance of shoring system. Inclinometers were installed at 10 locations inside the diaphragm wall and all the struts were instrumented with strain gauges. Tilt-sensor was installed at one location of the wall along the roadside where an installed inclinometer was found to be contaminated with concrete. Location of all instruments has been given in the layout below. The monitoring of the wall was done was undertaken by independent third party lab M/s. James Fisher Strainstall Middle East. During the course of excavation, the frequency of monitoring was kept at 2 times a week since the measured values remained well below design expectations and upon completion of excavation. Later monitoring was done on weeklybasis.

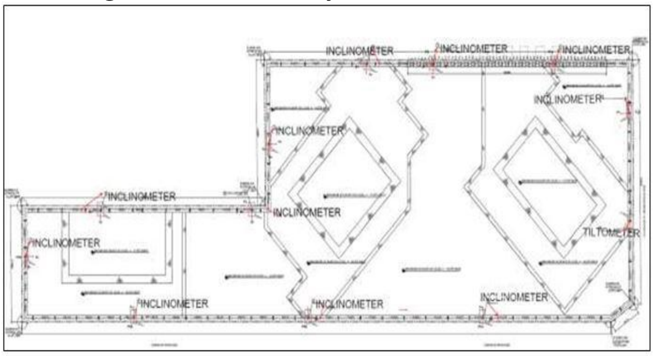

Figure 8 Instrumentation layout for Inclinometers &tiltmeter

Performance of Shoring wall in Deep excavation

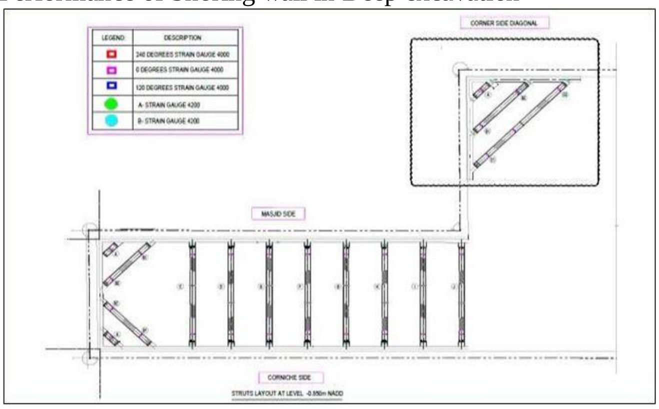

Figure 9 Strut Layout and Strain gauges locations at upper level

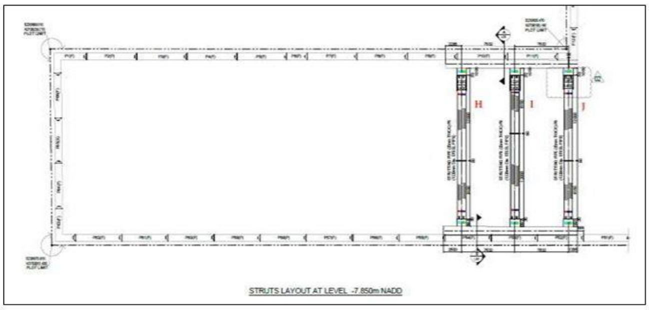

Figure 10 Strut layout & Strain gauge locations at lower level

V. COMPARISON OF PREDICTED WALL DEFLECTIONS TO THE ACTUAL WALLDEFLECTIONS

The prediction of wall deflection was made based on different loading conditions, site conditions, and excavation levels at various sections as listed previously.

The field deflection along diaphragm wall depth for all sections was observed lesser than theoretical deflection. Maximum deflection for whole system occurred for Section 3 as 8mm measured by tilt-meter (refer to below Figure 11) against the calculated design deflection of 19mm (refer to Figure 5).

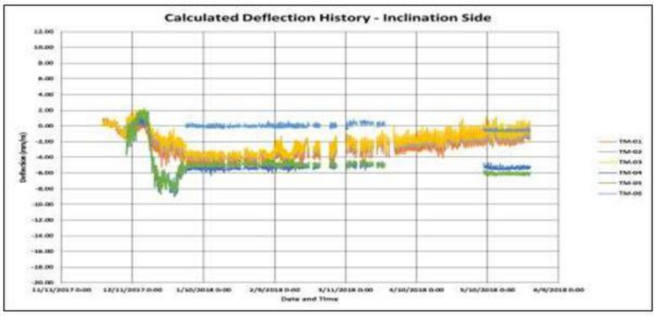

Figure 11 Tilt Meter Deflections

Inclinometer readings

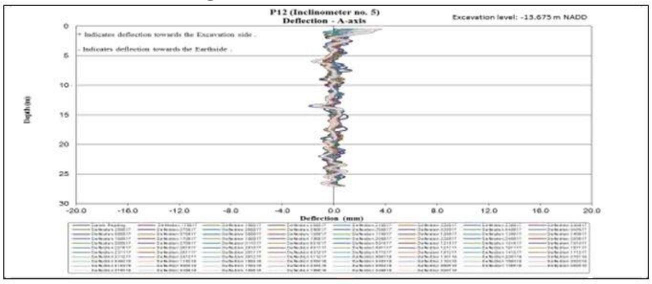

Figure 12 Deflection curve for Inc.05

Table 2 Theoretical deflections Vs. Field deflections

Panel No/ Section	Theoretical Deflection at different sections	Filed deflection & corresponding depth
P-4 (Inc.no. 6)/Section 1	20.6mm	1.93mm (19.5 m)
P-8 (Inc.no. 2)/Section 5	24mm	2.40mm (20.0 m)
P-12 (Inc.no. 5)/Section 1A	20.6mm	2.41mm (0.5 m)
P-14 (Inc.no. 4)/Section 3	19mm	3.01mm (24.5 m)
P-22 (Inc.no. 3)/ Section 3	19mm	2.11mm (26.5 m)
P-28 (Inc.no. 12)/Section 4	28mm	0.83mm (20.0 m)
P-42 (Inc.no. 10)/Section 4	28mm	2.60mm (27 m)
P-44 (Inc.no. 1)/Section 5	24mm	3.30mm (1.0 m)
P-50 (Inc.no. 9)/Section 4	28mm	1.59mm (0.5 m)
P-58 (Inc.no. 8)/Section 2	27mm	2.53mm (0.5 m)
P-64 (Inc.no. 7)/Section 2	27mm	1.93mm (0.5 m)

Strut Loading (Design load vs. ActualLoads)

Table 3 Corniche side Struts – Level 1

Strain Gauge location	Strut Diameter (mm)	Design Load (kN)	Max. Average Load measured since the beginning of monitoring (kN)
A1 1	1067	5566	-3444
B1 1	1067	4215	-3337
B2 1	1067	4215	-2426
C1 1	1067	7056	-3606
D1 1	1067	4670	-3796
E1 1	1067	5285	-4295
F1 1	1067	5243	-3690
G1 1	1067	5230	-3362
H1 1	1067	5220	-1467
I1 1	1067	5220	-1362
J1 1	1067	5220	-2305

Table 4 Masjid side Struts –Level 1

Strain Gauge location	Strut Diameter (mm)	Design Load (kN)	Max. Average Load measured since the beginning of monitoring (kN)
A1 1	1067	5566	-2613
B1 1	1067	4215	-1996
B2 1	1067	4215	-2466
C1 1	1067	7056	-3481
D1 1	1067	4670	-3857
E1 1	1067	5285	-3312
F1 1	1067	5243	-3328
G1 1	1067	5230	-2867
H1 1	1067	5220	-1082
I1 1	1067	5220	-779
J1 1	1067	5220	-2119

Table 5 Corner Side Diagonal Struts – Level 1

Strain Gauge location	Strut Diameter (mm)	Design Load (kN)	Max. Average Load measured since the beginning of monitoring (kN)
A1 1	1067	3876	-3002
B1 1	1067	3876	-2730
B2 1	1067	3876	-3654
C1 1	1067	3876	-3856
C2 1	1067	3876	-3579

Table 6 Corniche Side Struts -Level 2

Strain Gauge location	Strut Diameter (mm)	Design Load (kN)	Max. Average Load measured since the beginning of monitoring (kN)
H1 2	1220	8648	-7159
I1 2	1220	8648	-5693
J1 2	1220	8648	-5797

Table 7 Masjid Side struts- Level 2

Strain Gauge location	Strut Diameter (mm)	Design Load (kN)	Max. Average Load measured since the beginning of monitoring (kN)
H1 2	1220	8648	-5829
I1 2	1220	8648	-6840
J1 2	1220	8648	-6149

VI. CONCLUSIONS

The completion of the Corniche towers marks a new milestone of specialized foundation works for development of much needed underground space accompanying new high-rise development in live urban center. Following conclusions can be drawn from the design and measured behavior of the shoring system at Cornichetower.

- Precise and complying behavior of the shoring walls is closely related to the surcharge loads surrounding the wall. Presence of adjacent buildings, roads and temporary loading structures like hoardings have large impact on the design and selection of correct construction of the methods such as diaphragm and secant pile walls.
- Additional loading and proximity of nearby existing structures on particular areas of the shoring wall requires careful planning of internal supporting system with either struts and ground anchors as per feasibility andapplicability.
- The actual performance of the shoring system and comparison to the design expectations. Such comparison is the ultimate verification of the product quality delivered by the foundation worksspecialist.

Figure 13 Final View of shoring system in place

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