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Forensic Study of An Earth Retaining System Failure

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Abstract. Forensic civil engineering can be considered to be "The investigation of materials, products, structures or components that fail or do not operate or function as intended, causing personal injury or damage to property''. This paper presents a case history of analysis and review of a touch pile system failure during deep excavation for a commercial building (3 basements, ground floor and 8 floors) near Metro Station Kaloor, Ernakulam, Kerala, India. An excavation to a depth of 10m from the ground level was required to reach up to the foundation level of the structure and to retain the soil to facilitate the excavation, a touch pile system with strutting was adopted. As the excavation was in progress, the shoring system collapsed at 9.30pm on 19/04/2018. A technical expert committee was formed by District disaster management authority, which comprised of the authors to evaluate the reasons of failure. The immediate restoration steps adopted, various tests conducted to analyze the reasons for collapse, temporary measures adopted and the precautions to be adopted for the future construction are presented. From the study it was found that the strutting system was inadequate to take up the lateral thrust from the touch piles and the soil at the dredge line has turned out to be very soft and has caused considerable loss of strength of the interface soil. Subsequent increase in unsupported length of pile is also a reason for the failure of pile in bending.

Keywords: Touch Pile; Collapse; Integrity test; Strutting

1 Introduction

Forensic engineering is an upcoming science that enables Engineers to predict the possible failure. It gives the insight to find the causes of failures of the structures and to upscale understandings on how to respond to close calls and to prevent a disaster. With increasing cost of land in urban areas, vertical growth has become essential in city centers. With the requirement of service facilities like car parking and the restriction for height of buildings, construction of deep basement has become a necessity. Structures in the immediate vicinity of excavations, dense traffic scenario, presence of underground obstructions and utilities have made excavations a difficult task to execute. In this context, analysis and design of deep excavations and their supporting systems are essential. Even in complicated urban settings, deep retaining systems have been deployed successfully by overcoming construction challenges Joseph and Murali (2015) [1]. For several infrastructure projects like metro rail, parking lots in commercial area, shopping malls etc. underground structures are preferred to preserve the landscaping in the area Gandhi (2011) [2]. The basic steps which should be carried out by design engineer for deep excavations are: site characterization, selecting dimensions of excavation, surveying adjacent structures, establishing permissible movements, selecting earth retaining system, selecting supporting and construction scheme, predicting movements, compare predicted with permissible movements, alter supporting (bracing) and construction scheme if needed, monitor instrumentation, compare monitored results with predicted and permissible values, alter bracing and construction scheme, if needed Puller (2003) [3], Moh and Chin (1991) [4], Pearlman et al (2004) [5]. Since deep excavation is a total technique, proper coordination and integration of design and construction are of utmost important Chang (2006) [6].

Structural engineers work with engineered materials such as concrete and steel that possess unique and well-defined properties of density, elastic modulus, compressive/tensile strengths, and flexural stiffness among others. On the other hand, geotechnical engineers deal with soil, a material made by Nature/God with highly variable spatial and temporal properties. Structural designs are code-based since theoretical closed-form solutions are derived based on the given geometry, material properties, and loading. However, geotechnical designs are judgement-based due to highly variable geometry, complex loading, and material properties that are not precisely determinable Madhav and Abhishek (2016) [7]. A practicing geotechnical engineer cannot provide services without the fear of a lawsuit. Services of geotechnical engineers experienced in jurisprudence system are commissioned to investigate such failures Saxena (2008) [8]. This paper presents a case history of analysis and review of a touch pile system failure during deep excavation for a commercial building (3 basements, ground floor and 8 floors) near Metro Station Kaloor, Ernakulam, Kerala, India. An excavation to a depth of 10m from the ground level was required to reach up to the foundation level of the structure and to retain the soil to facilitate the excavation, a touch pile system with strutting was adopted. As the excavation was in progress, the shoring system collapsed at 9.30pm on 19/04/2018. A technical expert committee was formed by District disaster management authority, which comprised of the authors to evaluate the reasons of failure. The immediate restoration steps adopted, various tests conducted to analyze the reasons for collapse, temporary measures adopted and the precautions to be adopted for the future construction are presented.

2 Project Description

2.1 Details of the proposed structure

The proposed commercial building consists of three basements, ground floor and eight floors, in which four floors were meant for parking and 8 floors are for commercial use. The location of the proposed project site was near to Metro Station Kaloor Ernakulam, Kerala, India. The location map of the proposed project area is shown in figure 1

Fig. 1. Location map of the proposed project area of commercial building at Kaloor.

2.2 Structural and piling details of the project

Geotechnical parameters of the soil and foundation were studied using five boreholes extending up to a depth of 50m in the project location. Standard Penetration tests were conducted at regular intervals and test was performed on the disturbed samples and undisturbed samples. Water table was noted at a depth of 0.40m from GL at the time of investigation. Bored RCC DMC (direct mud circulation) piles extending to depth of about 47m terminated in very dense sand with a minimum penetration of 2000 mm, using M35 concrete were suggested based on soil profile. Touch piles of 900 mm diameter extending up to 30m was adopted for 10m excavation as a retention system. Touch piles were supported using 600 mm diameter soldier piles. Touch pile layout of the proposed project is shown in figure 2.

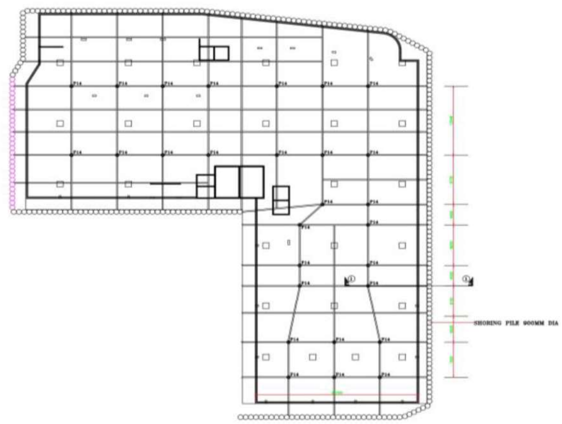


Fig. 2. Touch pile Layout of the proposed project

2.3 Execution of piling at site

The touch pile system comprised of 337 piles of 900 mm diameter extending to a depth of 30m depth and 28 soldier piles of 600 mm diameter extending to depth of 30 m. Propped cantilever design was adopted in the design of touch piles to resist the lateral loads. Trench of 900 mm width and 1.5m depth was excavated at the boundary and touch piles were done in an alternate manner.

Excavation was done in 3 phases after completing the shoring works: During phase 1, excavation was carried up to 2m and strutting work supported on soldier pile was provided, in the phase 2, excavation was carried up to 6.50m and in the phase 3, excavation was planned up to 10m as directed by the structural consultant. Considering the general impervious nature of clay in Cochin, Dewatering system was not suggested by the consultant. Section details of the proposed project is shown in figure 3.

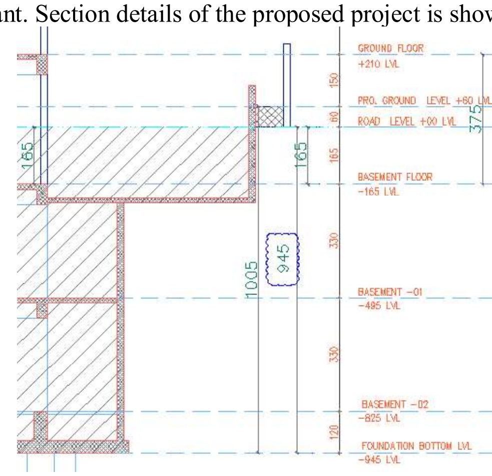


Fig. 3. Section Details of proposed commercial building

3 Collapse at site

3.1 Touch pile system

When the excavation reached a depth of 9.5m at 5.30 pm on 19/04/2018, a slight deflection of 20 mm was noticed on the shoring walls towards the north (excavated area) and the deflection increased to 100 mm by 7.00 pm. Excavation was completely stopped and workers were evacuated. Further shift increased to about 200 mm by 8.30 pm along with some creaking sound and water jets were noticed on the shoring walls and by 9.30 pm the shoring piles on the southern side came down suddenly. The photos of project area before and after collapse are shown in figure 4 (a) and 4 (b).

Fig 4. (a). Photos at different stages of touch pile system failure at Kaloor, Cochin

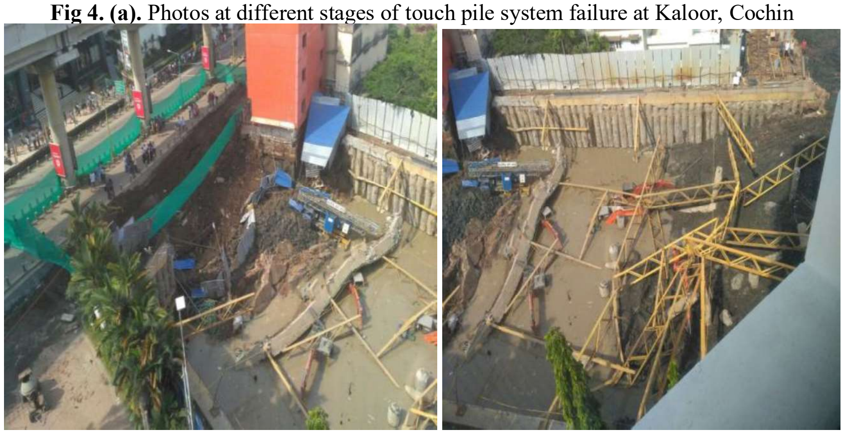


Fig. 4 (b). Photo of collapsed touch pile system at Kaloor, Cochin

3.2 Observations after collapse

The following observations were made at the site immediately after the touch pile failure.

1 The nearby road and earth had sunken by approximately 3.0m on the south side of the excavated area due to the collapse of touch pile system.

2 Lateral shifting of the piles was noted and the nearby earth was sunken on the south west side of the excavated area.

3 The building near the south west corner had a slight tilt towards the east side and cracks were noted in the building and part of the foundation was exposed. The possibility of sudden collapse of the building could have happened as this is indicative of progressive failure.

4 In all the other three sides of the excavated area, cracks were noted at ground level.

5 Differential settlement was noted in the roads with pavement of interlocking tiles.

6 Due to collapse, the public utilities such as road traffic, electricity and water supply were adversely affected.

7 The working of Kochi metro was also stopped since the structure was located close to the metro station, Kaloor.

4 Expert Technical Committee

District Disaster Management Authority (DDMA) formed an expert technical committee for the immediate restoration of the damages caused during collapse and also to study

i) Reason of collapse of touch pile system
ii) Verification of statutory government approvals
iii) Suitability of the touch piles system for further construction and scrutiny of the initial design

4.1 Immediate rectification

Immediate rectification works were carried out under the supervision of the technical committee and the owners of the building was directed to bear all the expenses by District Collector. The committee after inspection implemented the following

1. To avoid the progressive failure in the southern portion where the excavation was done up to 10m depth, red earth was refilled immediately up to 5m below the ground level.
2. Coconut timber piles extending up to 6m depth at 1m centre to centre was provided to strengthen the sunken portion of the road and red earth was filled in layer after proper compaction.
3. For ensuring the strengthening and protection of unaffected main water lines and public utilities, coconut piles were driven as an additional safety measure.
4. For the protection of the sides of the road and the soil to be filled up to formation level, double layer braced sheet piles was provided.

The public works department, with the assistance of technical committee supervised the immediate restoration works and the remedial measures were completed by 25/04/2018. The traffic was restored with speed restrictions. Images of refilling of soil and two-layer braced sheet pile adopted is shown in figures 5 and 6 respectively.

Fig 5. Refilling of soil after touch pile collapse

Fig. 6. Two-layer braced sheet pile system adopted near public road

5 Forensic Studies of The Failure

The following tests were conducted by the expert committee in order to evaluate the reasons for the collapse of touch piles.

i) In-situ concrete strength of concrete using core test.
ii)To assess the depth at which pile failed and to check whether the actual pile depth matches the design depth, Pile integrity test was suggested.
iii) To confirm the geotechnical parameters of subsoil strata adopted in design, additional soil investigation was suggested.
iv)PLAXIS and STADD software's was used for the geotechnical and structural analysis of the touch pile system to identify the causes of failure.

5.1 Core test

To ascertain the strength of concrete in piles and tie beams, test was conducted on touch piles and tie beams. Tests were conducted on 8 samples taken from touch pile and 3 from tie beams. It was found that cube strength values were higher than designed values. The photo of core collection and the results is shown in figure 7(a) and 7(b).

Fig. 7 (a). Extracting core from failed pile at site

Core Identification	Core length (mm)	Core diameter (mm)	Core Weight (kg)	Maximum failure load (kN)	Core comp. strength (N/sq.mm)	H/D Ratio	Correction factor for (H/D) ratio	Corrected Cylinder Comp. strength (N/sq.mm)	Equivalent cube strength (N/sq.mm)
Pile S-54	116.6	69.0	0.972	98.6	28.48	1.69	0.97	27.52	34.4
Pile S-303	117.0	67.7	0.983	138.5	41.55	1.73	0.97	40.32	50.4
Tie Beam HY	115.0	67.5	0.930	74.4	22.45	1.70	0.97	21.73	27.2
Pile S-16	115.9	68.0	0.866	98.9	29.41	1.70	0.97	28.46	35.6
S-300	115.4	67.5	0.914	60.2	18.17	1.71	0.97	17.59	22.0
Tie Beam 7X	111.2	68.0	0.942	83.2	24.74	1.64	0.96	23.76	29.7
Pile S-46	96.8	68.5	0.844	137.7	40.35	1.41	0.94	37.78	47.2
Pile S-65	116.3	68.0	0.876	46.5	13.83	1.71	0.97	13.39	16.7
Pile S-21	85.0	68.0	0.688	85.2	25.34	1.25	0.92	23.28	29.1
Pile S-23	80.0	68.0	0.611	116.8	34.73	1.18	0.91	31.63	39.5
Tie Beam 11X	90.0	68.0	0.725	66.8	19.87	1.32	0.93	18.41	23.0

Fig .7 (b) . Core Test results of Piles at the project site

5.2 Integrity test

Pile integrity testing (PIT) was done on 8 R.C. bored piles which were installed in the site. The aim of testing was to assess the pile integrity for potential problems like cross-sectional changes, honeycombing, concrete quality, continuity etc. The tests were conducted in accordance with ASTM D5882 [9]. As per the test results, the collapsed piles failed at depths around 14.5m to 15.5m from the ground level. And length of the standing piles was found to be approximately 30m as specified in the drawings. The photos of integrity test in progress and the results are shown in figure 8(a), figure 8(b) and figure 8(c)

Fig. 8(a). Conducting pile integrity test on piles

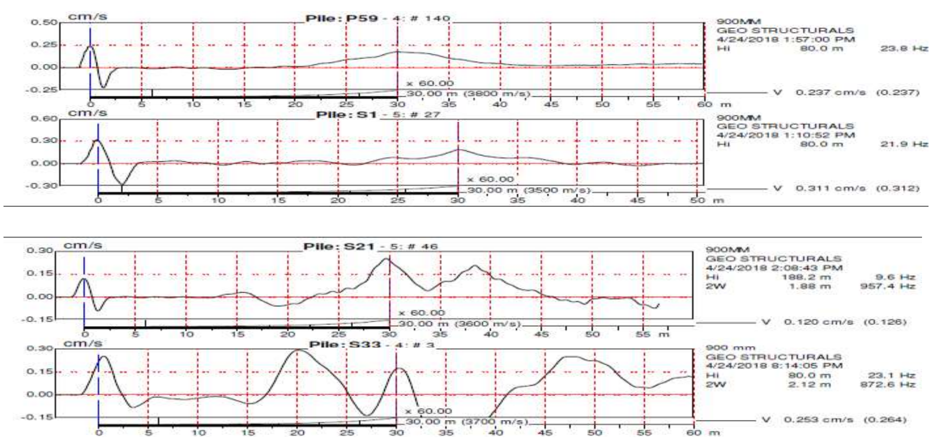


Fig. 8(b). Results of pile integrity test

Sr. No.	Pile No.	Toe Response	Length of Pile from test level (m)*	Wave Speed (m/sec)	Shaft Cross-Section and Soil Changes (From test level)	Pile Integrity	Comments
Date of Testing : 24th April, 2018							
1.	P36	Evident	30.0m	3800	Fairly uniform pile shaft,	OK	--
2.	P39	Evident	30.0m	3800	Fairly uniform pile shaft,	OK	--
3.	P57	Evident	30.0m	3600	Fairly uniform pile shaft,	OK	--
4.	P58	Evident	30.0m	4000	Fairly uniform pile shaft. Bulge/increase in soil resistance seems evident around 12m from test level.	OK	--
5.	P59	Evident	30.0m	3800	Fairly uniform pile shaft,	OK	--
6.	S1	--	30.0m	3500	Possible defect seems evident around 6.6m from the test level.	OK	--
7.	S21	--	30.0m	3600	Possible defect seems evident around 15m from the test level.	--	Damaged pile
8.	S33	--	30.0m	3700	Possible defect seems evident around 20m from the test level.	--	--

Fig. 8(c). Results of pile integrity test

5.3 Additional soil investigation

Additional investigation soil profile was found in conformity with the initial soil investigation carried out. From the study of the borehole it was noted that the top 5.70m comprise of fill. Below this soft clay was noted extending up to a depth of 11.40m. This was followed by medium dense to very dense sand extending up to a depth of 19.10m. Below this stiff to very stiff clay was noted extending up to a depth of 27.80m. This was followed by very dense sand extending up to a depth of 32.50m. From 32.50m to 40.00m decayed wood was noted. Below this vey dense sand was noted up to a depth of termination of borehole at 48.00m. Water table was noted at 4.80m below ground level in the borehole during the time of investigation. Soil test in progress at site is shown in figure 9.

Fig. 9. Confirmatory soil investigation in progress.

5.4 Geotechnical and Structural analysis of touch pile- Back Analysis approach

Back analysis are required to provide technical evidence to prove or disprove the hypotheses made on the cause of failures and to establish the scenarios of failure Wang et al (2013) [10], Rao and Babu (2016) [11] used back analysis to find the settlement response of different type of foundation and structures. PLAXIS and STADD software was used for the evaluation of the touch pile system and its stability as an earth retaining structure against lateral loads at different stages of excavation. Earth retention for 5m, 6m, 7.5m and 10m with 900 mm touch piles (M35, Fe 500, 30m depth) soldier piles and strutting system was checked for stability. The moment of resistance of the pile was 815 kNm. The overturning moment for excavation of 5m, 6m, 7.5m and 9.5m was 350 kNm (44 mm deflection), 633 kNm (90 mm deflection), 1110 kNm (179 mm deflection) and 2090 kNm (400 mm deflection) respectively. Strutting system provided comprises of two ISMC200 section connected by 65 mm x 65 mm x 6 mm L laced sections on both sides. Figure 10 shows the details of braced steel strutting system. The touch pile system comprising of 900 mm diameter piles without strutting was adequate for excavation upto 6m depth. The strutting system was found to have marginal deficiency, when the depth reached 7.5m, to take up the earth pressure and it was observed that for the depth of 10m, the provided touch piling system and strutting was grossly inadequate to take up the lateral thrust.

Figure 11(a) and figure 11(b) shows the 3D STADD model and utility ratio of bracing system in the touch pile system for 9.5m retention. Figure 12 shows the deflection and bending moment diagrams. Figure 13 (a) and 13 (b) shows the analysis model of excavation using PLAXIS.

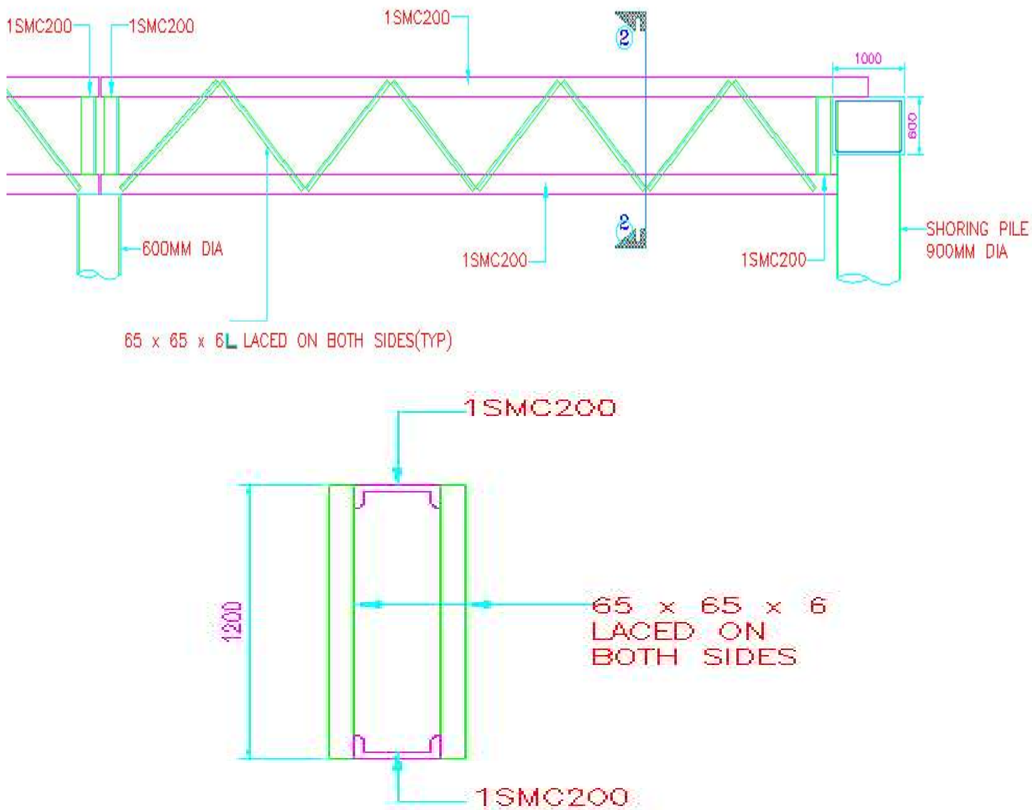


Fig. 10. Section of Braced steel strutting system

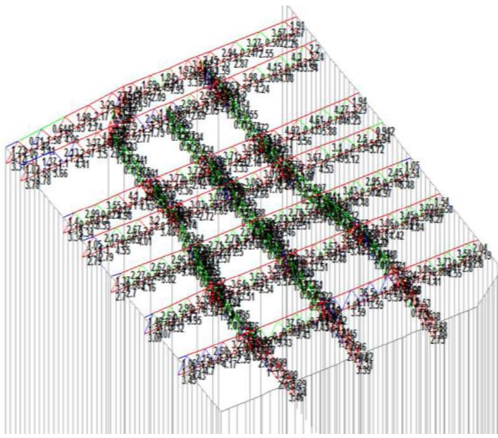


Fig. 11 (a). Utility Ratio of provided bracing system for 9.5m retention

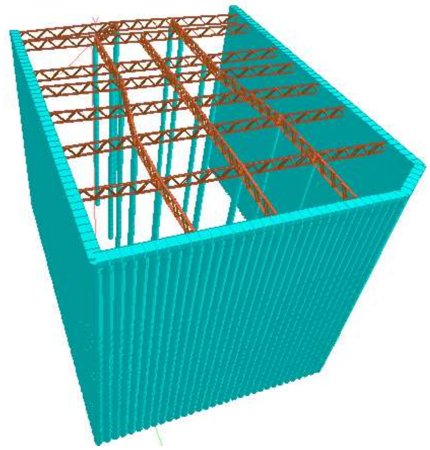


Fig. 11 (b). 3D model of provided touch pile system for 9.5m retention

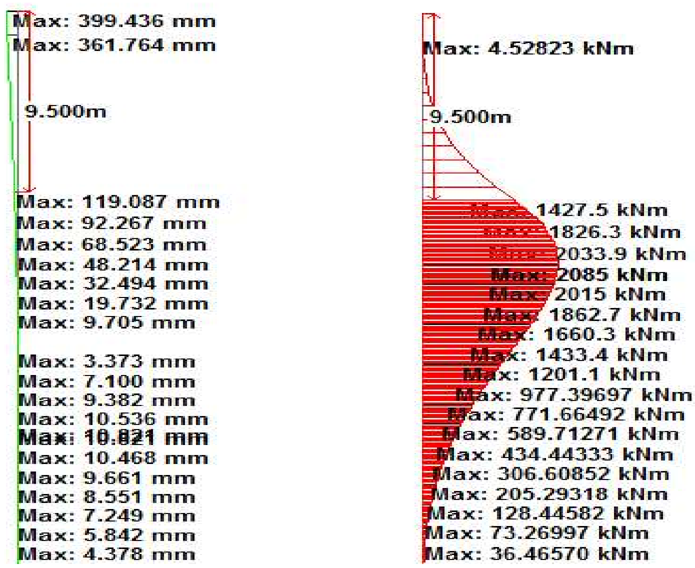


Fig. 12. Deflection and bending moment diagram for 9.5m retention

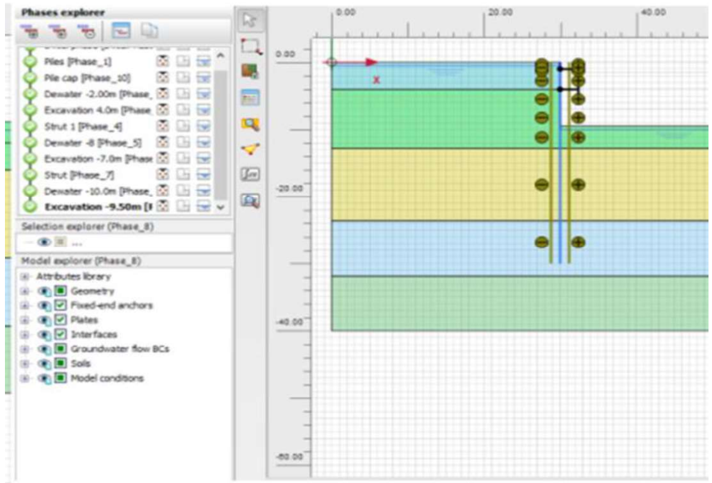
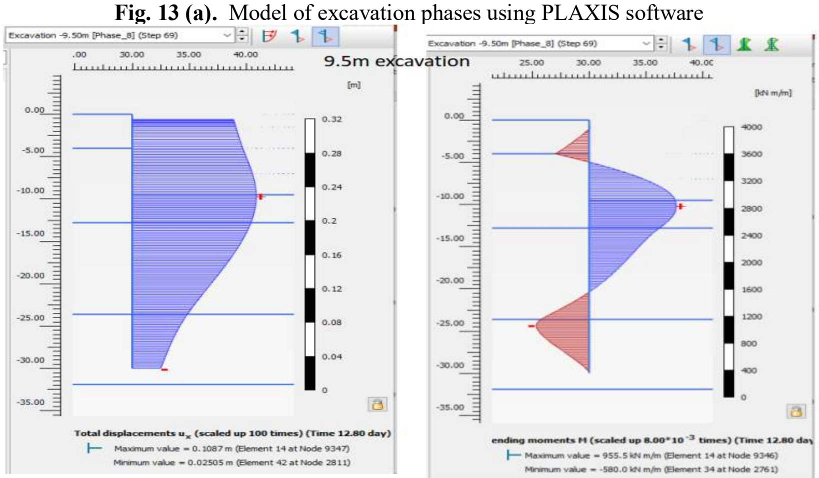


Fig. 13 (a). Model of excavation phases using PLAXIS software



Deflection and Bending moment per pile will be BM x 0.90 kNm

Excavation -9.50m [Phase_8] (Step 69)

Structural element	Node	Local number	X [m]	Y [m]	N [kN]	N_{min} [kN]	N_{max} [kN]	Φ_z [°]	Length [10^{-3} m]
FixedEndAnchor_1_1	11083	1	30.000	-1.000	574.019	-784.306	574.019	0.000	200.000
FixedEndAnchor_2_1	10755	1	30.000	-4.000	-2518.543	-2518.543	0.000	0.000	200.000

Fig. 13 (b). Deflection and Bending moment in excavation phases using PLAXIS software

The findings from the analysis are

1. For the proposed depth of excavation of 10m, the shoring pile with single strut propping system used in this project is found inadequate to take the lateral forces.

2. The reinforcement of the shoring piles is found inadequate against bending with single strut propping system at top provided for the proposed depth of excavation of 10m.
3. The strutting system currently used is a series of trussed beams in grid pattern, but not orthogonal to each other. This will have a tendency to make the grid system skewed and to facilitate further yielding of the props.
4. The soil at current depth of excavation has turned very soft on account of water seepage. This has caused considerable weakness of the interface soil. High thrust from the shoring pile at the interface has caused yielding of this soil. Subsequent increase in unsupported length of pile is also a reason for the failure of the pile in bending.

5.5 Statement of Key Stake Holders

The committee as part of natural justice, gave opportunity to the owners of the building, project management team, architect for the project, structural engineer, foundation consultant and piling and civil contractors to present their observations or points of view regarding the failure and probable reasons that led to it and this was also considered in the analysis and evaluations.

6 Conclusions

1. The failure is due to the fact that the strut system was inadequate to take up the lateral thrust from the touch piles and to provide the required stability as per the geotechnical and structural analysis. The soil at the dredge line has turned out to be very soft and has caused considerable loss of strength of the interface soil, high thrust from the shoring pile at the interface has caused yielding of this soil. Subsequent increase in unsupported length of pile is also a reason for the failure of pile in bending. A second tier of strut system at a lower depth could have been helpful in retaining the touch pile system in position.
2. The team scrutinized all the approval documents needed for the project and they were found in order.
3. With regard to the suitability of touch pile system for further construction, the present touch piles installed can take up the lateral earth pressures due to the excavation up to the proposed depth of 10m, provided adequate bracing system with higher sections and proper balanced geometry is adopted. Diagonal cross bracings especially at the corners have to be provided to bring in the required rigidity.
4. It is also suggested that the set back of the touch pile system near the road be increased by additional four meters so that the road and the public utility systems remain unaffected.
5. The committee felt that the collapse of the touch pile system of the building should serve as a wakeup call to the authorities and engineers in the construction industry. It is only sheer luck that there was no loss of human life. There was only one building close by and this is to be dismantled now. With workers in the excavated

area and with buildings close by, it would have been not just a failure but a catastrophe.

6. It is true that the cellars are going deeper and deeper and floors going higher and higher. The construction industry is slowly getting attuned to modern design techniques and construction procedures. The trends cannot be discouraged but the authority should exercise greater caution and control when projects with such trends are approved.

Acknowledgements

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