AVOIDANCE OF GEOTECHNICAL FAILURES

by

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ABSTRACT

Many geotechnical failures could be prevented if some extra care is given to the geotechnical aspect in the design and construction of a project. This paper illustrates two cases; one on the damage to permanent piles due to failure of the temporary cofferdam, and the other the tilting of a silo due to the 'myth' that driving piles to set is all that is required for the successful foundation of a structure. The existing weaknesses and proposals for improvement are tabulated. Some suggestions to avoid the geotechnical failures are also given.

1.0 INTRODUCTION

The recent spate of failures reported in the mass media, particularly on the collapse of Block 1 of the Highland Towers which claimed 48 lives just over three years ago have caused deep concern to the public and the parties involved in the construction industry, especially the engineers who were involved in their design and construction. However, there were several failures which escaped the attention of the mass media because they occurred during construction behind the hoarding fence of the construction site. This paper is prepared with the objective of highlighting two such failures. It is hoped that these case histories will increase the awareness of engineers engaged in the design and construction of structures.

2.0 CASE A: FAILURE OF A TEMPORARY WORKS AFFECTING PERMANENT WORK

2.1 Movement of permanent piles due to failure of a temporary work

Reinforced concrete piles were driven in marine deposits at the original ground level to support a high rise building with a basement carpark. After the installation of the reinforced concrete piles, excavation was carried out for the construction of the basement and the pilecaps. A 12 m deep sheet pile (FSP III) cofferdam was installed to facilitate the excavation. When the excavation reached a depth of about 3.5 m to 4 m, the sheet piles started tilting as the lorry carrying the excavated materials on the retained side was moving out of the site. The base of the excavation also heaved up. The failure of the temporary sheet pile cofferdam also pushed the permanent piles. Some of the permanent piles moved laterally for more than a metre, damaging the integrity of the piles.

2.2 Investigation

The site was a flat marine deposits with the original ground level at grade with the access road. The site was a former residential lot with a detached house and planted with various fruit trees. The boreholes drilled during the design at the site indicates that the thickness of the soft marine clay varies from 18 to 20 m followed by 25 to 32 m of soft to stiff clay with an intermittent layer of dense to very dense sand of less than 3 m thick. The top layer of marine clay has an undrained shear strength of about 10 kPa near the surface and increases to 15 kPa at a depth of 5 m.

The methods statement submitted by the contractor indicates the maximum depth of excavation is as 2.5 m.

2.3 Analysis and Conclusion

The preliminary check on the factor of safety against base heave failure, given in Appendix A, indicates the factor of safety to be 1.43 which is close to the normal required factor of safety of 1.5. When the actual excavation exceeded 4 m, the factor of safety dropped from 1.43 to 0.97 which is less than unity and hence it failed. The cantilever section of the sheetpile did not yield at the 4 m excavation as indicated by the calculations given in Appendix B, it was a base heave and overall failure.

This case illustrates the use of the simple base heave equation to estimate the limiting depth of excavation to prevent failure and the consequent delay in construction.

3.0 CASE B: A FAILURE FROM THE 'MYTH' OF PILING TO SET

3.1 The Tilting of a Silo

After completion of two storage silos which are supported on 600 mm diameter spun concrete driven piles, one of the towers was observed to tilt during the filling of the storage material. The most obvious sign of tilting was observed particularly at the connection near the feeder pipe on the top of the tower. The gap between the two tower was also noted to close during the filling up of the storage silos.

3.2 Investigation

The site was undulating and the two silos were built on a 1.5 m thick filled platform on the granitic formation. There was no borehole at the exact location of the silos. Two boreholes were drilled at some distance away to the north and south of the cement silos during the design stage. One of these boreholes indicated the presence of a very dense gravelly materials at 5 m - 8 m depth (SPT values varied between 45 to 80) as shown in Figure 1. Underlying the very dense materials was a 5 m thick layer of medium stiff sandy silt with N_{SPT} of about 20.

Tracing back the pile driving records indicated that there was a cluster of 26 piles which set at depths varying from 6 m to 7 m. The rest of the piles set at about 17 m as shown in Figure 2.

The construction drawing only specified that piles are to be driven to set to achieve its structural capacity. Hence all piles were terminated when a set of 2 mm per blow or less (20 mm per 10 blows) was achieved.

3.3 Analysis and Conclusion

The pile bearing capacity was checked using the following standard equation:-

$$Q_{ult} = \varepsilon Q_{su} + Q_{bu}$$

$$Q_{su} = f_{su}A_s$$

$$Q_{bu} = f_{bu}A_b$$

f_{su} = $K_sN_{av}A_s$ (K_s = 2.0 for driven piles in sand and 3 in clay)

f_{bu} = $K_bN_bA_b$ (K_b = 400 for driven piles in sand and 100 in clay)

N_{av} = Average SPT 'N' over the pile shaft

and N_b = SPT 'N' under the pile tip

The Q_{ult} for the 6 m to 7 m pile is about 1.2 times the working load of the pile and the Q_{ult} for the 17 m pile is about 2.5 times the working load. The Q_{ult} for the group is about 2 times the working load. The settlement analysis indicates that the settlement of the shorter pile group is about 90 mm, which is about twice that of the settlement under the longer piles.

The results of the analysis indicate that the piles have a factor of safety of 1.2 to 2.5 for the short and long piles respectively and the group has a factor of safety greater than 2. However the settlement of the shorter piles was twice higher than that of the longer piles. Hence when the silo on the cluster of short piles was loaded by storage material filling, the cluster of short piles settled more than the longer piles, thus causing the silo to tilt towards the short piles.

The monitoring of settlements and tilts of silos is still in progress to check the rates of settlements and tilts during loading and unloading. The remedial measures will only be decided after the results of the monitoring confirm the prediction of future movements.

The above case history reminds those in the construction industry particularly the young engineers at the site that successful pile foundation depends on:-

1) adequate pile bearing capacity, and

2) permissible settlement of pile and pile group both in the short and long terms

The long term bearing capacity and settlement should be considered. The induced negative skin friction on piles due to settlement of surrounding soil should also be assessed. This case clearly sets at rest the 'myth' or the belief of someone that a pile foundation is acceptable when the piles are driven to set irrespective of the soil conditions.

CONCLUSION

Although only two case histories are presented in this paper, the weaknesses revealed in the investigation into many similar failures encountered are tabulated in Table 1. The proposals to prevent failures are also included in the table. Suggestions to design engineers on the content of a project quality plan are given in Table 2.

REFERENCES

1) Bolton, M (1979), A GUIDE TO SOIL MECHANICS, The Macmillan Press Ltd., London.

2) Chin, F K (1982) "Basement Excavation in Clay", Asian Regional Conference on Tall Buildings and Urban Habitat, Kuala Lumpur, Malaysia.

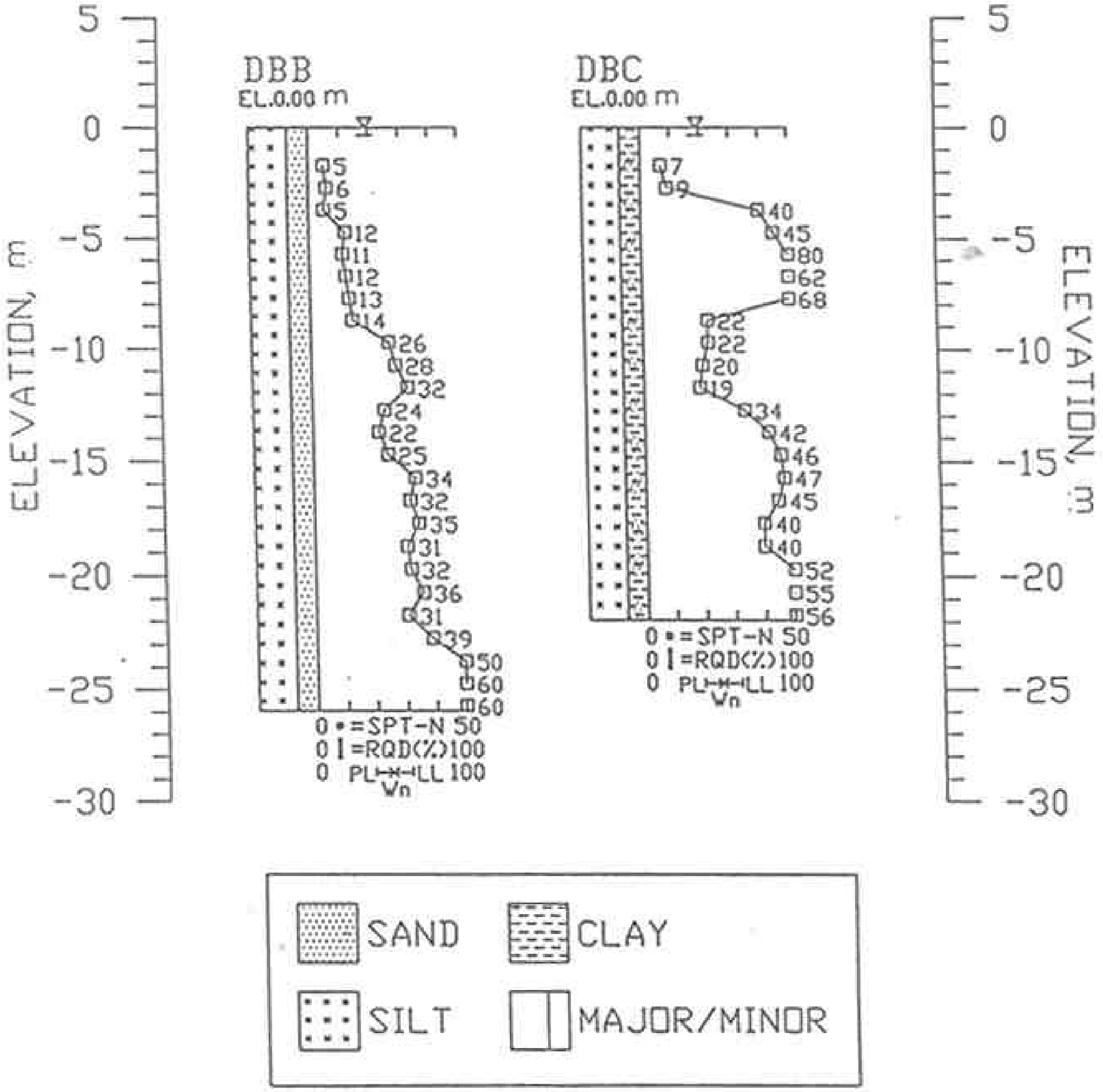
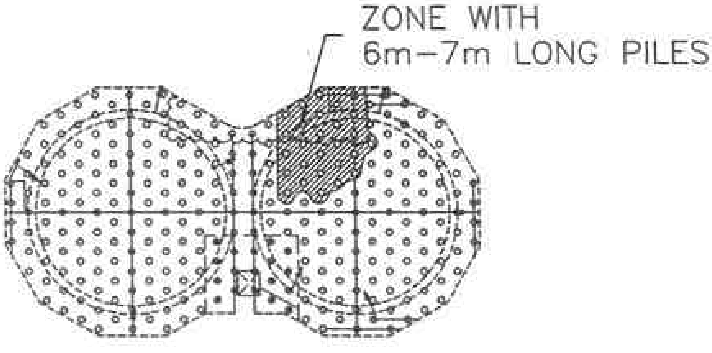
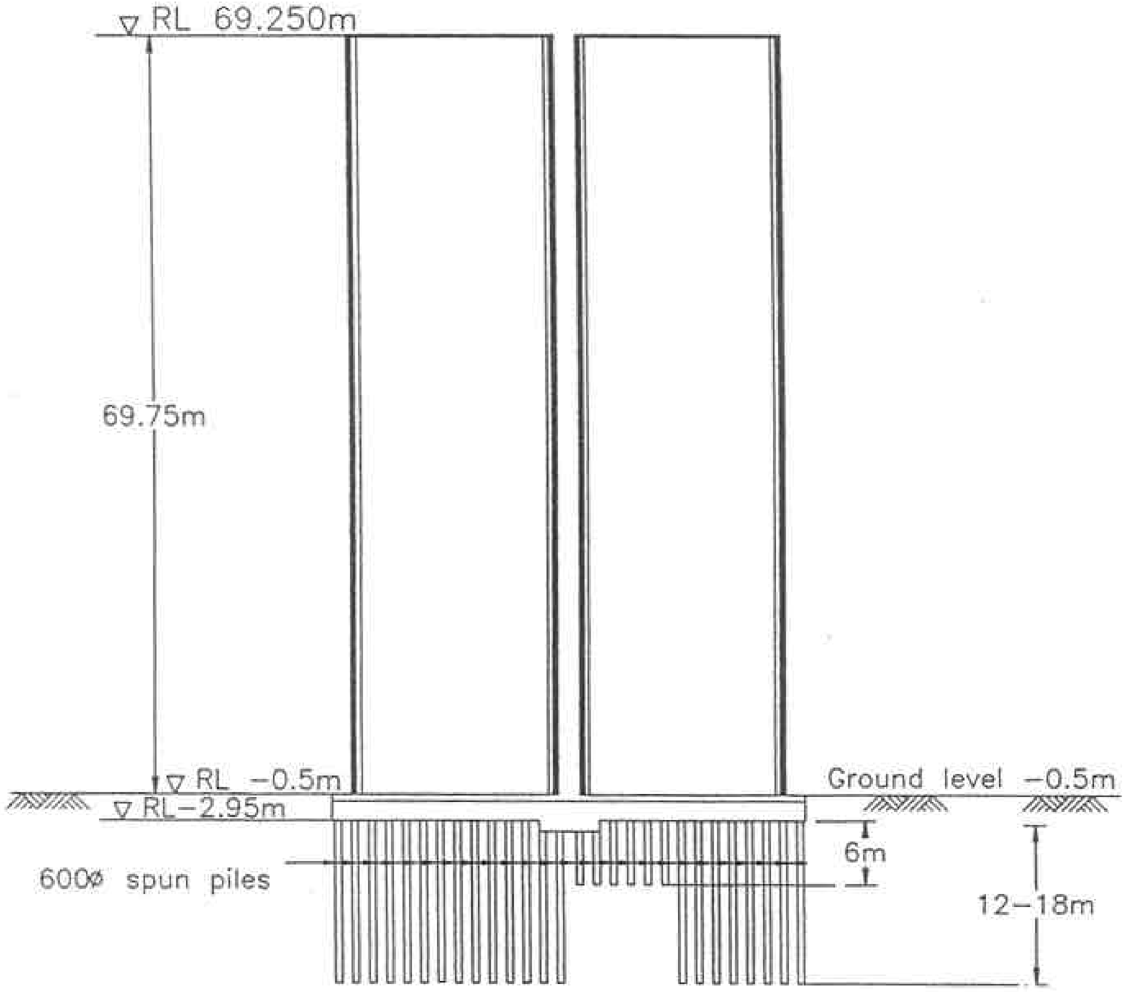


FIG 1 BORELOGS

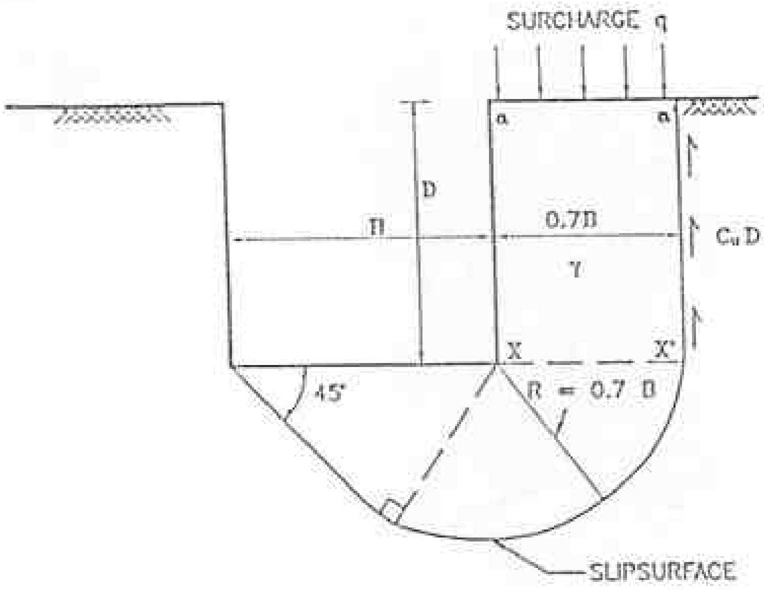


SECTIONAL PLAN



SECTIONAL ELEVATION

FIG 2 PILE ARRANGEMENT



Net pressure on plane x - x'

$$= D\gamma - \frac{C_u D}{0.7B} + q$$

Bearing capacity

$$= N_c C_u \left(1 + \frac{0.3B}{L}\right)$$

Factor of Safety (FOS) against Base Heave

$$FOS = \frac{N_c C_u (1 + 0.3\ B/L)}{D(\gamma - C_u/0.7B) + q}$$

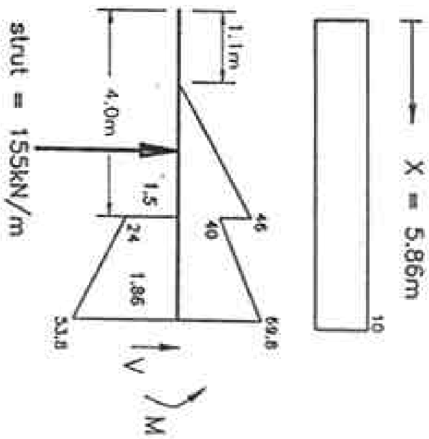
Based on the contractor proposal for C_u = 10 kPa, γ = 16 kN/m³
B = 30 m
D = 2.5 m
L = 40 m
q = 10 kPa

$$FOS = \frac{55\ (1 + 0.3 \times 30/40)}{2.5\ (16 - 10/21) + 10} = \frac{67.38}{48.81} = 1.38$$

Simplified

$$FOS = \frac{N_c C_u (1 + 0.3\ B/L)}{D\gamma + q}$$

= 1.35



At x = 5.86 m

$$\text{Active Force} = 46 \times \tfrac{1}{2} \times 2.9 + \frac{(69.8 + 40) \times 1.86}{2} + 10 \times 5.86$$

$$= 66.7 + 102 + 58.6$$

$$= 227.3 \text{ kN/m}$$

$$\text{Passive Force} = 155 + \frac{53.8 + 24}{2} \times 1.86$$

$$= 227.3 \text{ kN/m}$$

Therefore V = O

$M = M_{max}$

$$M_{max} = 155 \times (1.5 + 1.86) + 24 \times 1.86 \times \frac{1.86}{2} + 29.8 \times \frac{1.86}{2} \times \frac{1.86}{3}$$

$$- 10 \times 5.86 \times \frac{5.86}{2} - 46 \times \frac{2.9}{2} \times \left(\frac{2.9}{3} + 1.86\right) - 40 \times 1.86 \times \frac{1.86}{2}$$

$$- 29.8 \times \frac{1.86}{2} \times \frac{1.86}{3}$$

$$= 520.8 + 41.5 + 17.2 - 171.7 - 188.5 - 69.2 - 17.2$$

$$= 132.9 \text{ kN-m/m}$$

For Sheet Pile FSP III

$f_y = 140 \text{ N/mm}^2$

$Z = 1340 \text{ cm}^3\text{/m}$

$$M_{ult} = 140 \times \frac{1340}{1000} = 187 \text{ kN-m/m}$$

$M_{ult} > M_{max} \rightarrow$ Sheet pile did not yield

TABLE 1 PREVENTION OF FAILURES

AREAS OF WEAKNESSESS AND PROPOSALS FOR IMPROVEMENT

AREA		WEAKNESS		PROPOSAL
Design	-	Insufficient guidance from Experienced seniors - Insufficient data - Inaccurate results	-	Improve check and review processes
	-	Practice in areas of insufficient expertise and experience	- -	Introduce checklist Seek external help
	-	Inadequate check and review	-	Target ISO Certification
Supervision	-	Lacking in team and experience	-	Dedicated independent team is a must
	-	Lack of communication between designer and supervisor	-	Checklist on supervision
			-	More visits and random checks by designer
Construction	-	Inexperienced team and operators	-	Use experienced team and conduct training
	-	Lack of quality assurance and quality control	-	Target ISO Certification
Maintenance	-	Lacking	-	Prepare and follow a schedule

TABLE 2 SUGGESTIONS ON DESIGN

Project Quality Plan

	Check	Review
- Proper planning on the scope of geotechnical investigation and laboratory testing	/	/
- Supervision plan	/	/
- Summary of geotechnical investigation	/	/
- Analyses and designs	/	/
- Documentations	/	/