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Prediction versus performance of Land Reclamation Bund

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1 INTRODUCTION

Prior to the placement of landfill in a reclamation project, a perimeter bund which may stretch tens of kilometers in length needs to be constructed. Fig. 1 shows a typical design scheme of a water front bund in Singapore with the seabed level located at -8 m ACD (Admiralty Chart Datum). The deep deposit of the underlying soft marine clay extends to approximately -20 m ACD. To prevent potential slope failure, the underlying soft marine clay is reinforced with sand compaction piles (SCP) with a replacement ratio ranging from 30% to 50%. The lateral extent of the SCP is 5 m behind the crest of the slope and 10 m beyond the toe of the seaward slope. The SCPs are installed through the entire depth of marine clay and rest on the underlying stiff residual soil. The desired factor of safety for the bund against global slope failure is at least 1.5. However, it has been reported occasionally bund failures have occurred during bund construction despite adopting a high safety factor value. The causes of slope failure are often unknown and there are many possible factors involved such as overfilling, uncontrolled bund slope gradient, unforeseen underlying soil profiles and strengths, as well as deviation of alignment of bund from designed positions. In this paper, parametric studies are performed to examine various factors to evaluate the peformance of water front bund and to identify the degree of risks these factors pose to the bund stability.

2 LIMIT EQUILIBRIUM ANALYSIS

Parametric study of slope stability using conventional limit equilibrium analysis (Slope/W, 2002) was conducted. For the original design, it was assumed that the marine clay has a unit weight of 16 kN/m^3, undrained shear strength of 5 kPa at the top with strength increasing by 1.32 kPa/m depth. The composite soil, consisting of SCP with marine clay in-between, has an average unit weight of 17.2 kN/m^3, apparent cohesion of 3.5 kPa and friction angle of 20°. The parametric study involved small perturbations from the parameters for the standard problem described above and a summary of all the parametric analysis results is tabulated in Table 1 (Leung and Shen, 2004). It can be seen that the bund slope stability is sensitive to the relative deviation between the bund slope and the reinforcing SCP. It should not be taken lightly during site survey and monitoring in controlling the bund alignment. This is especially critical in locations where the alignment of the bund is not straight and hence more difficult to control. Overfilling, bund gradient variation as well as unforeseen soil strength are all common occurrences in bund construction, each having considerable effects on the stability of the bund slope. Comparatively, unforeseen soil profile and the variation of water table within the bund are less critical factors affecting the slope stability of water front bund.

It should be noted that none of the single factors alone listed in Table 1 can trigger the bund failure. However, when several adverse conditions happen simultaneously at the same location, bund slope failure may become imminent. For example, if factors 2, 3 and 5 in Table 1 occur simultaneously at the same location, namely the underlying soft marine clay is weaker than typical value, the bund alignment deviates landward for say 13 m relative to the SCP, and the bund has been overfilled too fast to +7.5 m ACD without proper control, the bund slope will fail with the factor of safety dropping below unity, as shown in figure 2. It is likely that localized concurrence of several adverse conditions will trigger local failure of the bund slope and propagates progressively to larger areas leading to catastrophic effects.

3 FEM ANALYSIS WITH PLAXIS

Compared to the use of limit equilibrium, FEM stability analysis needs fewer a priori assumptions and the failure mechanism is a natural outcome of the shear stresses exceeding the shear strength of the ground (Griffiths and Lane, 1999). The geotechnical FEM program PLAXIS Version 8 (2002) is used for this study. The program has the strength reduction calculation option, which automatically reduces the strengths of all soil elements systematically in small increments up to the strength reduction factor that would lead to a natural failure mechanism (not assumed apriori) and soil collapse. In line with the findings in limit equilibrium slope stability analysis, the FEM analysis

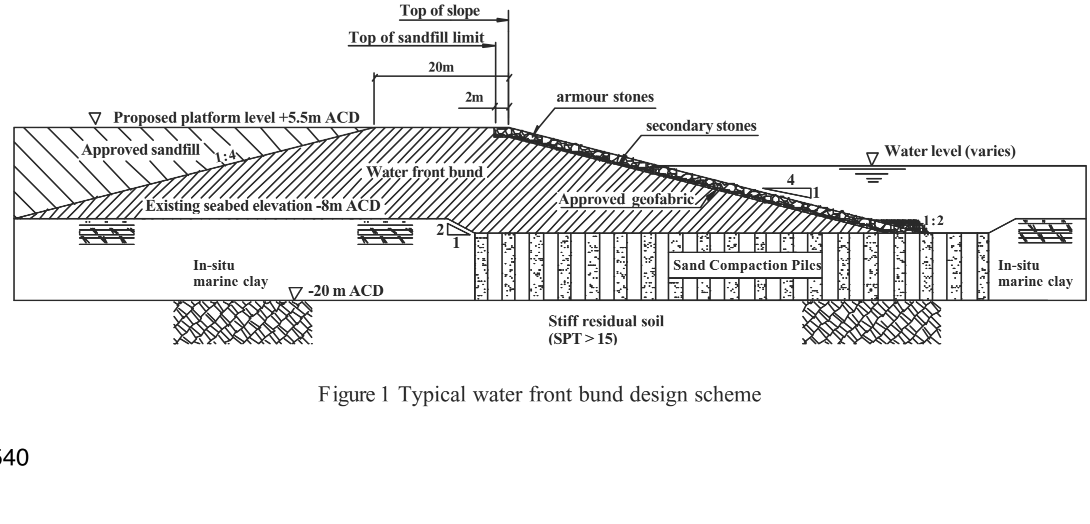

Figure 1 Typical water front bund design scheme

Table 1 Summary of parametric analysis

Case	Factors considered	Brief description	FOS	Sensitivity
1	Original design	Slope gradient 1:4; Top level of bund +5.5 m ACD; Water level within the bund 1.5 m above sea water level; Marine clay has an undrained strength of 5 kPa at top and increases by 1.32 kPa/m below seabed surface. The composite soil extends to -20 m ACD and have an average cohesion of 3.5 kPa and friction angle of 20°. Sand fill has a friction angle of 30°.	1.502	
2	Alignment of bund slope	Relative position of bund shifted landwards for 5 m, 10 m, 20 m and 30 m relative to SCP.	1.391~ 0.946	high
3	Overfill	Bund top overfilled to +7.5 m ACD.	1.335	medium
4	Bund gradient	slope gradient 1:3.5 instead of 1:4 of original design.	1.387	medium
5	Unforeseen soil strength	Marine clay has a strength of 5 kPa for the first 2 m and thereafter increases by 1kPa per meter downwards.	1.346	medium
6	Unforeseen soil profile	Base level of the marine clay extends from -20 m ACD assumed in the original design to -23 m ACD.	1.486	low
7	variation of water table within bund	Water table within bund is set to 3.0 m higher than the mean sea water table.	1.434	low

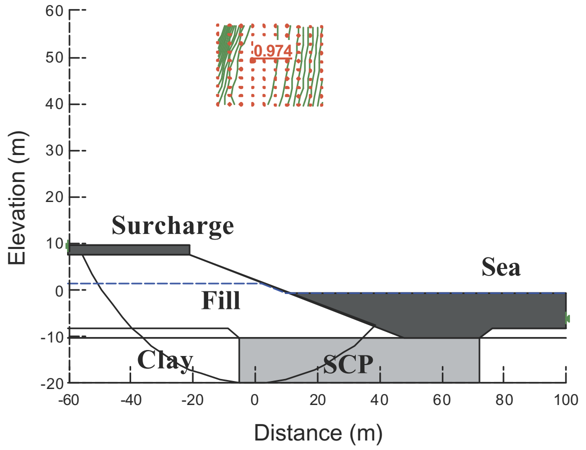

Figure 2 Failure of bund slope under a combination of adverse conditions

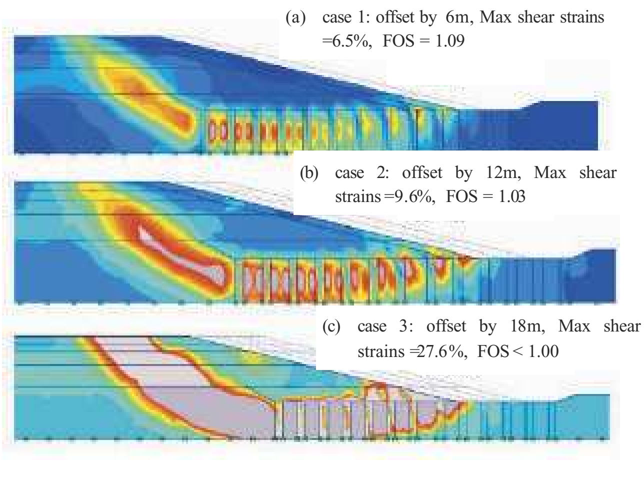

Figure 3 Shear strains for 7.5m bund with bund alignment offsets by (a) 6m (b) 12m and (c) 18m

clearly shows the significant impact of the offset of bund alignment on the slope stability. As shown in Fig. 3, with the bund offset increases from 6m (case 1) to 12m (case 2), the FOS reduces from 1.09 to 1.03. When the offset reaches 18m (case 3), the FOS drops below unity, indicating a slope failure. The maximum shear strains also increase from 6.6% to 27.6% from case 1 to case 3 as shown in the figure.

4 CONCLUSIONS

A geotechnical study of a large coastal bund for land reclamation is made using both limit equilibrium and FEM methods. From the parameters considered, changes in bund slope and water variation make little changes to the bund FOS. Overfilling, bund gradient variation as well as unforeseen soil strength are found to have considerable effects on the stability of the bund slope. The bund slope stability is especially sensitive to the relative deviation between the bund slope and the reinforcing SCP. Therefore the combined effects of these variations must be considered for a prudent and economical design of coastal bunds. For a sound risk management system, detailed SI should be conducted to determine accurately the soil profile and strength of soft clays along the perimeter length of bunds. Proper site control using GPS for bund and SCP positioning should be employed to minimize the risk of bund positioning error. A comprehensive ground monitoring system must be in place prior to bund construction, as this can provide timely data for assessment of bund stability during bund construction. Proper adjustments to filling schedule can be made to prevent bund failure.

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