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Design schemes for treatment of thin soft clay in ground improvement project

Phuoc H. Dang[1], J.-M. Roh[1], T.-G. Ng[1], and I. Yogarajah[1]

[1] Golder Associates (Singapore) Pte Ltd, 18 Ah Hood Road, Singapore, 329983.

ABSTRACT

This paper presents design schemes for treatment of thin soft clay layer in ground improvement project. The main issue of the problem is that if no treatment is carried out within the thin soft clay layer, the settlement under the design loading may exceed the acceptance criteria. On one hand it is not cost-effective to use prefabricated vertical drain (PVD) to accelerate the consolidation process of thin clay layer. On the other hand, time taken to achieve the desired degree of consolidation may be too long if PVD is not adopted. A three-pronged approach has been proposed and adopted successfully in a ground improvement project with various thickness of soft clay. The approach includes three design schemes determine based on the engineering judgment and the characteristics of the in-situ soft soil. The schemes include: (a) No ground treatment is required if the soft clay thickness is < 2m, (b) Earth surcharge without PVD for soft clay thickness between 2m and 5m, and (c) Earth surcharge with PVD for soft clay thickness > 5m. Full scale field test with comprehensive instrumentation and monitoring was carried out to check the effectiveness of the various design schemes. Coefficients of consolidation and compression index are back-analyzed from the field observations. The soil parameters deduce from the field test are discussed and compared with those obtained from laboratory tests.

Keywords: Soil improvement; land reclamation; thin clay; PVD; consolidation; surcharge

1 INTRODUCTIONS

The use of prefabricated vertical drain (PVD) and preloading such as earth surcharge is commonly found and well established in ground improvement projects especially for thick deposits of soft clay (Choa 1995, Tang and Shang 2000, Chu and Yan 2005, Chu et al. 2009). The earth surcharge aims to eliminate the consolidation settlement due to future design load; meanwhile, the PVD is adopted to accelerate the consolidation. For a cost-effective design in ground improvement projects, two vital questions that need to be carefully considered are: (1) under which condition the preloading is required and (2) under which scenario the PVD should be adopted. The answers to these two questions lie in the allowable settlement and consolidation time specified by every ground improvement project as illustrated in Fig. 1.

It is well known that the consolidated settlement is accumulated settlements from all soft clay layers. Thus, the total ground settlement under the future design load will depends on the total clay thickness. If total settlement induced by future load is smaller than the allowable value, no preloading is required. On the other hand, time taken to consolidate the soft clay under the design load depends on the thickness of any single clay layer and its drainage path. Hence, maximum clay thickness needs to be taken into consideration in determining the need for PVD. Combining these two concerns of total clay thickness and maximum clay thickness, one would realize when the preloading and PVD are required.

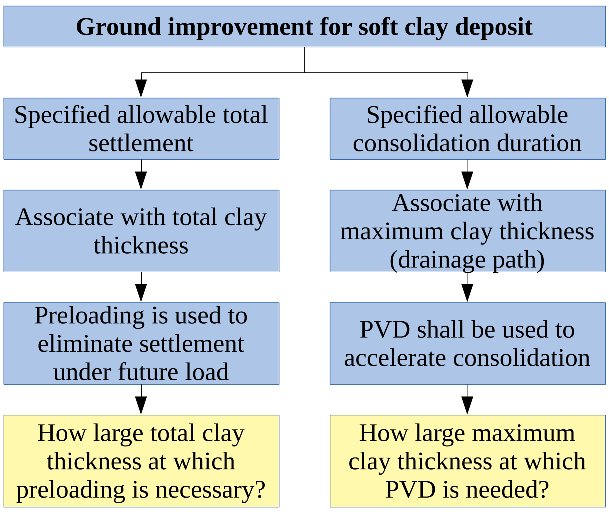

Fig. 1. Issues in ground improvement projects

2 DESIGN SCHEME AND CASE STUDY

This paper proposes a design scheme to determine the boundaries between preloading/no preloading and PVD/no PVD as illustrated in Fig. 2. This determination requires basic information on the project's specifications on the settlement and consolidation duration as well as history of the ground improvement in the past. In addition, the knowledge on the current soil characteristics is essential. It can be done by carrying out the soil investigation and the laboratory test. Based on the project and soil information plus the engineering judgement, two limits on the total and maximum clay thickness can be proposed. The contour maps shall be combined and different treatment methods for different areas shall be determined as illustrated in Fig. 3. Importantly, the design proposal needs to be verified by full scale field test. If the field measurement agrees well with the design's expectations such as the settlement and the consolidation time are within the project's requirements, the proposed treatment is feasible and will be employed for the project. In contrast, the proposed treatment shall be reviewed.

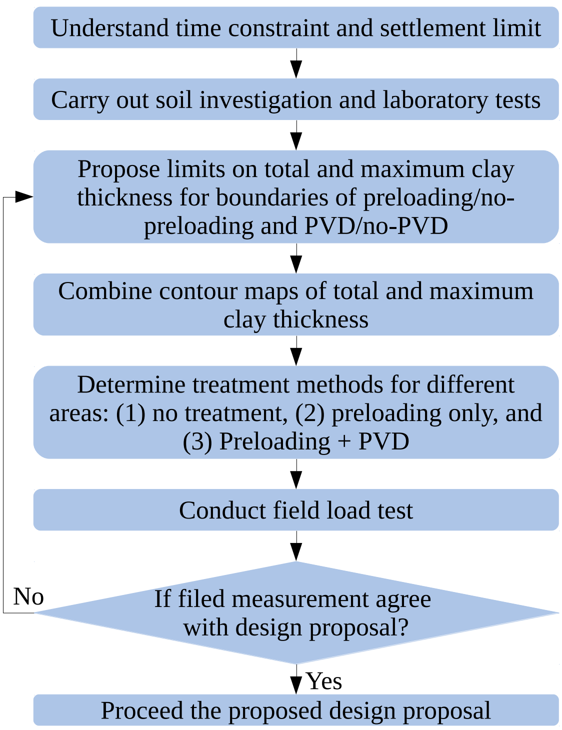

Fig. 2. Proposed design scheme

The proposed design scheme and its practice is demonstrated by a case study. A ground improvement project in Singapore is of interest. The basic information of this project on the allowable settlement and consolidation time is 50.0mm and 90 days (to achieve at least 90% degree of consolidation (DOC) under the future design load) , respectively. The site layout and its borehole locations are shown in Fig. 4. A number of undisturbed samples were obtained from these boreholes. Laboratory tests including grain size distribution, Atterberg limit, and oedometer have been conducted. The experiment results are summarized in Table 1 and Fig. 5.

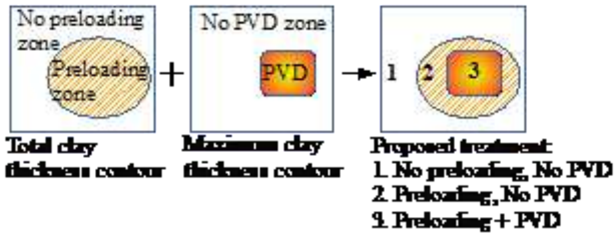

Fig. 3. Approach to determine treatment methods for ground improvement projects

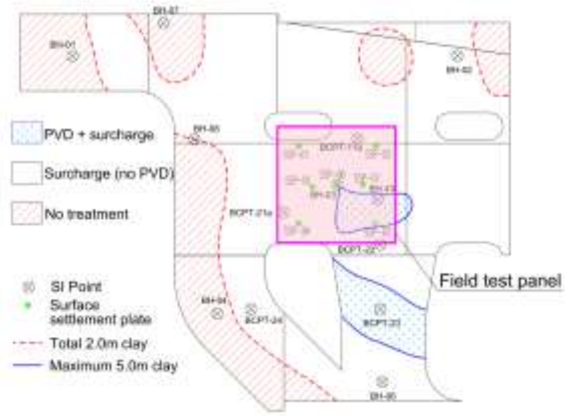

Fig. 4. SI layout and proposed treatment methods

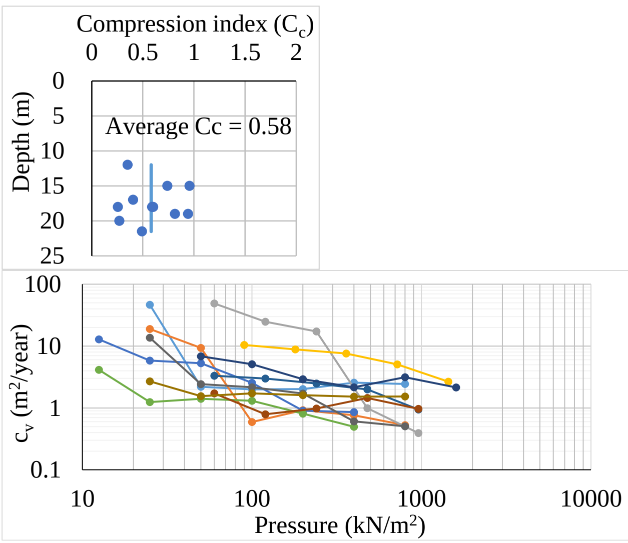

Fig. 5. Summary of C_c and c_v values from laboratory tests

From the fact of the project and soil, limits for total and maximum clay thickness proposed for this site are 2.0m and 5.0m, respectively. Thus, the proposed treatment methods for this project are: PVD and surcharge if maximum clay thickness is more than 5.0m, no treatment if total clay thickness is less than 2.0m, and surcharge only in other conditions. Accordingly, the contour of 2.0m total clay thickness and the contour of 5.0m maximum thickness are combined to determine which area corresponds to which treatment method as shown in Fig. 4.

A full scale field test is proposed at the center of the site as indicated in Fig. 4. It has the size of 90.0m×90.0m. This field test consists of two different treatments: PVD with surcharge and surcharge only. Earth surcharge is applied for entire tested area. Surface settlement plates are installed to measure the consolidation settlement. In which, the settlement plates SSP-01, SSP-02, SSP-04, and SSP-05 were in the surcharge without PVD area; while SSP-03, SSP-06, and SSP-07 were installed in the surcharge with PVD area. As a precautionary measure, the design surcharge was increased by 50% for the trial area.

Table 1. Laboratory results of clay samples.

BBH	Clay thick (m)	Sample depth (m)	Grain distribution* (%)				Atterberg limits			Moist. content (%)	e_0
			G	Sa	Si	C	LL	PL	PI		
BH-02	2.9	15	0	17	37	46	71	31	40	57	1.53
BH-03	5.0	17	0	0	46	54	77	29	48	46	1.30
		19	0	0	47	53	94	31	63	62	1.65
BH-06	5.0	16	7	34	26	33	58	25	33	43	1.17
		18	10	38	22	30	45	24	21	35	0.98
BCPT-11a	2.9	18	0	2	53	45	67	28	39	55	1.46
		20	7	18	36	39	65	27	38	48	1.29
BCPT-21a	4.0	15	0	3	52	45	84	36	48	68	1.85
		19	0	0	32	68	88	32	56	54	1.47
BCPT-22	4.2	18	0	4	49	47	74	31	43	66	1.74
		21.5	0	2	40	58	65	28	37	55	1.47
BCPT-23	6.9	15	1	13	40	46	69	29	40	55	1.52
		17	12	40	15	33	58	28	30	39	1.14
		19	0	2	48	50	97	40	57	66	1.81
		21	0	48	24	28	33	15	18	19	0.52
BCPT-24	3.0	12	5	31	20	44	64	25	39	40	1.08

*G = Gravel, Sa = Sand, Si = Silt, C = Clay

3 FIELD MEASUREMENTS AND DISCUSSIONS

3.1 For area with surcharge only (maximum clay thickness < 5m)

The measured settlement from the settlement plates is illustrated in Fig. 6. It is observed that the settlement increased quickly after the surcharge. Unfortunately there was no data taken from day 40 to day 60 due to the PVD installation discussed in the next section. Thereafter the settlement appeared to be steady from 60 to 140 days. The observations and settlement trends are consistent with those reported in the past studies. The maximum observed settlement was about 38.2mm to 52.2mm as shown in Table 2. It is slightly larger than the allowable 50.0mm. It is noted that the surcharge is 50% higher than the required preloading. Thus, it is likely that the total settlement in case of 2.0m total clay thickness is far less than 50.0mm. In other words, total clay thickness of 2.0m appears to be a reasonable boundary between the need to have or not to have preloading.

The consolidation time is approximated by fitting the field data with the hyperbolic method (Tan 1995). Table 2 summarizes the consolidation time. It can be seen that the consolidation duration is shorter than the specified time constraint. DOC of 90% was achieved after 35 to 68 days. It agrees well with the design expectations. Therefore, the limit of 5.0m maximum clay thickness is a reasonable boundary to determine the need for PVD.

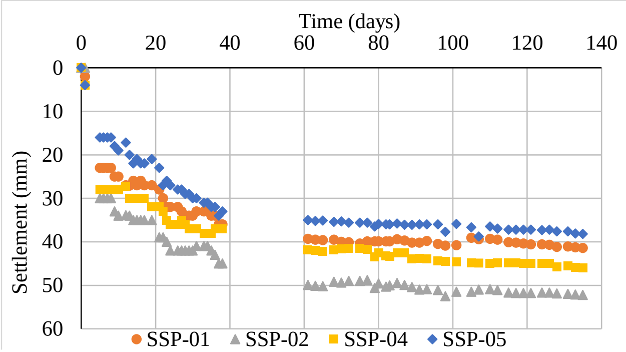

Fig. 6. Settlement measured from settlement plates at areas with surcharge only (no PVD)

Table 2. Consolidation time and maximum settlement at different SSPs for surcharge only area.

Settlement plates	Observed settlement (mm)	Estimated settlement (mm)	Allowable settlement (mm)	Duration 90% DOC (days)	Time constraint (days)
SSP-01	41.4	40.0	50.0	35	90
SSP-02	52.2	51.7	50.0	51	90
SSP-04	46.0	46.7	50.0	68	90
SSP-05	38.2	36.2	50.0	44	90

Based on the field measurements, the compression index (C_c) and coefficient of consolidation (c_v) can be back-calculated and compared with the experiment values to understand the differences between small scale (laboratory) versus full scale (overall site) consolidations. The final settlement and time to achieve 90% DOC from measurement and prediction are matched.

Fig. 7 compares the back-calculated values with laboratory values. It can be seen that the C_c is 50% lower than of the experiment factor and c_v is significantly larger than the preliminary design value of 1.0m^2/year or laboratory value of 1.5m^2/year. The discrepancy can attribute to the high sand content in the sand-clay mixture instead of pure clay soil and clay layer is localized instead of uniformly distributed. Excess pore pressure can dissipate laterally into nearby highly permeable layer in addition to dissipating along vertical direction. Therefore, the back-calculated c_v should be viewed as an equivalent c_v for entire layer (sand and clay) not only for clay layer itself.

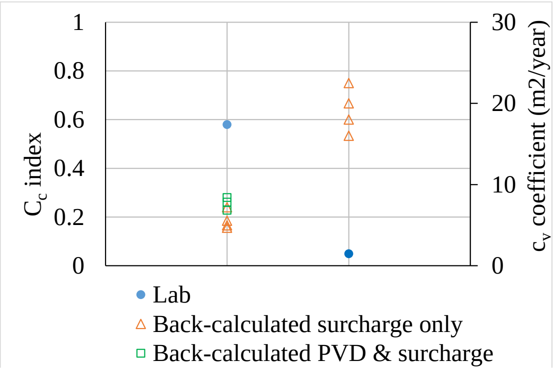

Fig. 7. Comparison between laboratory and back-calculated values of C_c and c_v

3.2 For area with both surcharge and PVD

The measured settlements from the SSPs within the PVD and earth surcharge are depicted in Fig. 8. It is noted that at beginning PVD was not installed. Instead, only earth surcharge was applied. It was found that the consolidation was significantly slow. The degree of consolidation would not be achieved the required DOC within the given 90 days. As a result, a portion of the surcharge was temporarily removed and the PVD with spacing of 1.0m was installed. The surcharge was replaced after the installation of PVD. Thereafter, the consolidation was accelerated. The maximum settlement measured ranged from 74.0mm to 90.0mm as summarized in Table 3.

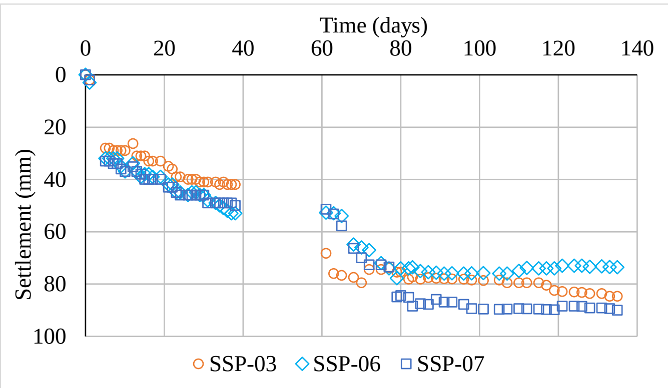

Fig. 8. Settlement measured from settlement plates at areas with PVD and surcharge

Table 3. Consolidation time and maximum settlement at different SSPs for PVD area.

Settlement plates	Observed settlement (mm)	Allowable settlement (mm)	Duration to 90% DOC if no PVD (days)	Time constraint (days)
SSP-03	84.7	50.0	261	90
SSP-06	74.0	50.0	101	90
SSP-07	90.0	50.0	213	90

The consolidation time if no PVD is installed is estimated using hyperbolic method, taking into consideration the initial part of the field settlement data (without PVD) and final settlement, as shown in Fig. 8. The results are summarized in Table 3. As shown the consolidation duration required to achieve the required DOC, without PVD, is longer than the design time of 90 days. This conclude that, if the maximum clay thickness is equal or more than 5.0m, PVD is required to accelerate the consolidation process. The compression index C_c back-calculated from the final settlement measured from the field test ranges from 0.23 to 0.28 as plotted in Fig. 7. The back-calculated C_c is consistently lower than the value from the laboratory tests as discussed in the previous section.

4 CONCLUSION

This paper presented a design scheme involving three treatment methods: (a) PVD with surcharge if maximum clay thickness is higher 5.0m, (b) no treatment (no PVD and no surcharge) if the total clay thickness is less than 2.0m, and (c) surcharge only in other scenarios according to given allowable settlement of 50.0mm and consolidation duration of 90 days. Field observations of the settlement from a full scale load test agreed well with the design proposal. For the surcharge only area, the consolidation time was shorter than the given constraint. In addition, the settlement was likely to be smaller than 50.0mm if the total clay thickness is less than 2.0m. Further, for area with more than 5.0m maximum thickness the consolidation appears to be slow. PVD was needed to accelerate the consolidation.

The values of Cc and cv were back-calculated to match the settlement-time relationship from the prediction and observation. It was observed that the actual Cc is less than 50% the value obtained from the experiment and cv is far higher than the laboratory value. It may be due to the discrepancy in the full scale soil condition and small scale tested soil sample.

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