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Pilot tests on methods to form working platform on soft clay

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Pilot tests on the usage of vacuum preloading combined with short prefabricated vertical drains (PVDs) to form a working platform for future soil improvement work were conducted at a land reclamation site in Tianjin, China. The short PVDs were connected using three methods – the conventional vacuum preloading method, fish-bone connectors and embedded horizontal pipes. To investigate the influence of PVD spacing, short PVDs were installed in square grids with spacings of 0.4 m and 0.6 m. The ground surface settlement, pore water pressures, water content and undrained shear strength of the soil were measured during the specific period of vacuum preloading. The pilot tests indicated that short PVDs connected using embedded vacuum pipes installed at 0.4 m spacing were the most suitable method to form a working platform on the surface of the dredged marine clay. This method yields a substantial saving on construction cost and time while exhibiting similar efficiency to the conventional vacuum preloading method. The undrained shear strength and degree of consolidation of the soil after 60 d of vacuum preloading were 23.6 kPa and 85.1%, respectively, which met the requirements for the working platform.

Notation

c_h	coefficient of horizontal consolidation
c_v	coefficient of vertical consolidation
D	diameter of an equivalent cylinder influenced by PVD
d	equivalent diameter of PVD
e	void ratio
H	drainage path
n	drain spacing ratio, $n = D/d$
R^2	regression coefficient
s	drain spacing
S	ground settlement
S_{60}	ground settlement at $U = 60\%$
S_{90}	ground settlement at $U = 90\%$
S_∞	ultimate ground settlement

S_{PVD}	ground settlement during PVD installation
S_t	ground settlement at time t
s_u	undrained shear strength
t	consolidation time
t_{60}	consolidation time for $U = 60\%$
U	degree of consolidation
u_s	applied vacuum surcharge
w	water content
w_L	liquid limit
w_P	plastic limit
γ	unit weight
Δt	sampling period in Asaoka's plot
Δu_t	pore water pressure at time t
$S_0, S_1, \dots, S_n$	ground settlement at time $(0, 1, \dots, n)\Delta t$ in Asaoka's plot

1. Introduction

Dredged marine clay has been widely used as a filling material for land reclamation in Tianjin, China (Chu *et al.*, 2000, 2008; Yan and Chu, 2005). Marine clays are often dredged from the seabed using a cutter suction dredger and pumped into the reclamation site. The vacuum preloading method is often adopted to improve the engineering properties of newly pumped marine clay slurry (Artidteang *et al.*, 2011; Bergado *et al.*, 2002; Chai *et al.*, 2005; Chu *et al.*, 2000, 2008, 2009a, 2009b; Indraratna *et al.*, 2011; Seah, 2006). However, one difficulty of using vacuum preloading is that the top surface of the newly pumped clay is too soft for machines to rest on and perform soil improvement work. One solution to this problem is the use of a working platform formed by first treating the top few metres of soil (Chu *et al.*, 2012, 2013).

Chu *et al.* (2012, 2013) summarised the methods used to create a working platform on the top of soft soil. These methods include (a) sun drying, (b) capping the soil with sand or other good soil (Chu *et al.*, 2000; Yan and Chu, 2005), (c) the use of geotextiles (Arulrajah *et al.*, 2009; Broms, 1987; Chu *et al.*, 2009a, 2009b; Terashi and Katagiri, 2005), (d) cement mixing (Burgos *et al.*, 2007; Chu *et al.*, 2005) and (e) dewatering using drainage. The principle of dewatering using drainage is to dewater or consolidate a layer of soil at the top surface to form a working platform; this is a relatively inexpensive and quick method. As the clay is soft, it is possible to install prefabricated vertical drains (PVDs) manually into the top few metres of the clay and improve it using vacuum preloading. The conventional vacuum preloading (CNVC) method requires a sand blanket layer of approximately 40 cm thickness in which to wholly embed the vacuum pipes and protect them from damage or destruction during construction. However, for sand-scarce regions such as Tianjin, China, the construction of a sand blanket layer is expensive and time consuming. Furthermore, the site to be improved using CNVC is often limited by the size of the membrane and has to be divided into many subzones.

In the work reported here, pilot tests were conducted to investigate three methods of using vacuum preloading combined with short PVDs to form a working platform. The three methods investigated were as follows.

- Conventional vacuum preloading (CNVC), which uses short PVDs, horizontal vacuum pipes, a sand blanket layer, a membrane layer and vacuum pumps.
- Fish-bone vacuum preloading (FBVC), which uses a fish-bone shaped connector to connect drainage pipes and short PVDs together with a vacuum pump. In this method, the sand blanket layer and the membrane layer are not required.
- Pipe-embedded vacuum preloading (PEVC), which involves wrapping the ends of the PVDs onto horizontal drainage pipes and embedding them into soft clay to create an airtight condition.

The ground surface settlement and pore water pressure (PWP) in the soil were monitored during the pilot tests. The undrained shear strength, unit weight and water content of soil in the subzones were measured at the specific period of the vacuum preloading. The average degrees of consolidation (DoCs) were calculated based on the records of settlement and PWP. The advantages and disadvantages of the three proposed methods are discussed in this paper.

2. Pilot tests

To investigate the effects of the three methods, pilot tests were conducted at a land reclamation site in Tianjin, China. As shown in Figure 1, the site area was 1800 m² and was divided into six subzones. The working platforms in subzones B1 and B3 were constructed using the CNVC method. Subzones D1 and D2 were used to investigate the performance of the FBVC method. The performance of the PEVC method was tested in subzones E1 and E2. The dimensions of the six subzones are shown in Figure 1. The site investigation for the land reclamation site included borehole sampling and vane shear tests, which were conducted at the specific period of the vacuum preloading. The field instruments included PWP transducers and surface settlement plates. Data were recorded during the entire vacuum preloading process. The layout of the instruments and site investigation tests are also shown in Figure 1.

2.1 Subsoil conditions

The soil profile consisted of a 4.0 m thick newly pumped soft clay layer and a 15 m thick accumulated soft marine clay layer overlying a stiff silty clay layer. The basic engineering properties of the newly pumped soft clay layer in the six subzones are shown in Table 1. It can be seen that the water contents of the top layer of soils in the six subzones were about twice their liquid limits and the undrained shear strength of the soils was only 0.7–2.7 kPa. The unit weight and void ratio of the top two soft clay layers had similar magnitudes of 15 kN/m³ and 2.3, respectively. The specific gravity of the clay layers was 2.75.

2.2 Conventional vacuum preloading (CNVC)

The method of using CNVC combined with short PVDs to form the working platform was tested in subzones B1 and B3. As shown in Figure 1, the areas of subzones B1 and B3 were 272 m² and 268 m², respectively. To investigate the influence of PVD spacing, the PVDs in zone B1 were installed in square grids with a spacing of 0.6 m while in zone B3 they were installed in a square grid with a spacing of 0.4 m. Before manual installation, the open-ends of the PVDs were sealed to prevent the entry of clay particles. A hole was usually pre-drilled into the soft clay to reduce the resistance when penetrating the short PVDs. The short PVDs were installed manually into 3.5 m deep holes in the soft dredge clay. Two layers of lightweight non-woven geotextiles were laid onto the surface of the dredged clay to protect and support the workers (see

Figure 1. Site information of the land reclamation project in Tianjin, China (dimensions in m)

Table 1. Soil properties in the test site before and after vacuum preloading

Subzone	Before vacuum preloading						After vacuum preloading					
	w : %	s_u : kPa	γ : kN/m ³	e	w_L : %	w_p : %	s_u : kPa			w : %		
							10 d	30 d	60 d	10 d	30 d	60 d
B1	83.0	2.3	15.3	2.31	45	22	4.8	7.1	13.1	55.0	48.5	46.2
D1	87.8	2.3	15.1	2.43	45	22	2.6	3.8	5.4	77.9	64.0	57.1
E1	82.9	1.1	15.1	2.29	43	21	2.9	6.5	11.1	60.8	53.3	48.1
B3	85.0	2.5	15.2	2.31	44	21	13.8	21.4	26.4	46.5	44.2	43.4
D2	83.8	2.7	15.2	2.32	45	22	10.1	15.3	20.5	59.5	52.5	48.0
E2	82.1	0.7	15.3	2.30	45	22	10.1	19.5	23.6	45.5	45.5	43.7

Figure 2(a)). The two geotextile layers could also prevent clay particles flowing into the sand layer and help to prevent uneven settlement of the sand blanket layer. The ends of the short PVDs were left approximately 0.5 m long and then tied directly onto the horizontal vacuum pipes (of diameter 40 cm), as shown in Figures 2(a) and 2(b). A 30 cm thick sand blanket layer was used to embed the horizontal vacuum pipe, as shown in Figure 2(c). To protect the membrane from being destroyed during the construction period, another layer of geotextile was laid on the surface of the sand blanket. Then, two layers of membranes were used to cover the entire area to create airtight conditions for the vacuum preloading. The edges of the membranes were embedded into four 0.5 m deep trenches. The trenches were backfilled with slurry. One jet vacuum pump was

used to pump the vacuum pipes in subzones B1 and B3 for approximately 80 d.

2.3 Fish-bone vacuum preloading (FBVC)

The FBVC method – using vacuum preloading combined with short PVDs linked using a fish-bone connector – was investigated in subzones D1 and D2. The dimensions of subzones D1 and D2 were 15 m × 20 m. To investigate the influence of PVD spacing, the PVDs in zone D1 and D2 were installed in square grids with 0.6 m and 0.4 m spacing, respectively. The penetration depth of the PVDs in the two subzones was 2.5 m. The short PVDs were connected to the drainage pipes and the vacuum pump using a specially designed fish-bone connector (Figure 3(b)) with the arrangement shown in

Figure 2. Conventional vacuum preloading combined with short PVDs to form a working platform: (a) sketch of the method; (b) installation short PVDs; (c) laying the sand blanket layer

Figure 3. Using fish-bone connectors to connect drainage pipes and short PVDs to form a working platform: (a) sketch of the method; (b) plan view of the arrangement of fish-bone system; (c) installation of the PVDs (dimensions in mm)

Figure 3(c). Each fish-bone connector could connect 12 drainage pipes. The drainage pipes connected to the PVDs were embedded to 10 cm depth in the soft clay to prevent air leakage (Figure 3(a)). One jet vacuum pump was used to pump the vacuum pipes in subzones D1 and D2 for approximately 80 d.

2.4 Pipe-embedded vacuum preloading (PEVC)

Vacuum preloading combined with short PVDs connected using embedded vacuum pipes (the PEVC method) and a slurry cap was tested in subzones E1 and E2. The dimensions of subzones E1 and E2 were 15 m × 20 m. The PVDs in zone E1 and E2 were also installed in square grids with spacings of 60 cm and 40 cm, respectively, at a depth of 2.5 m. The horizontal vacuum pipes were placed in the middle of the two

adjacent rows of PVDs, as shown in Figures 4(a) and 4(c). Each PVD was then connected to the horizontal vacuum pipes using a plastic tie, as shown in Figures 4(b) and 4(c). A 0.5 m deep trench was excavated to embed and seal the horizontal vacuum pipe (Figures 4(a) and 4(d)). After connecting all the PVDs with the horizontal vacuum pipes, clay slurry of approximately 0.3 m thickness was pumped on top to cover all the horizontal pipes (Figure 4(e)). Again, one jet vacuum pump was used in subzones E1 and E2.

3. Results and data analysis

3.1 Pore water pressure in soil

Figure 5 shows the soil PWPs measured in the six subzones plotted against the duration of vacuum preloading. The vacuum pressures in the soil were maintained during vacuum

Figure 4. Vacuum preloading using embedded vacuum pipes and short PVDs to form a working platform: (a) sketch of the method; (b) sketch of embedded vacuum pipes; (c) arrangement of PVDs and vacuum pipes; (d) installing PVDs; (e) the site after installation of PVDs

Figure 5. Measured pore water pressure at a depth of 1 m in the six subzones

preloading. The sudden reductions of soil PWP were due to the vane shear test and soil sampling when the vacuum pumps were switched off. The applied vacuum pressure in the six subzones was approximately 80 kPa.

The spacing of the PVDs heavily influenced the PWP in the soil. After 60 d of vacuum preloading, the PWP reductions in subzones B1, D1 and E1, where short PVDs were installed in a square grid with a spacing of 0.6 m, were 20.1 kPa, 8.59 kPa

and 13.6 kPa, respectively. However, the maximum PWP reductions in subzones B3, D2 and E2, where PVDs were installed with spacing of 0.4 m, were 73.7 kPa, 63.7 kPa and 68.1 kPa, respectively. These results suggest that, for a consolidation time of 60 d, PVDs installed with a spacing of 0.4 m are preferable for constructing a working platform on the surface of very soft dredged clay.

The vacuum preloading method also influenced the pore water distribution in soils. As shown in Figure 5, the PWP in soil improved using the CNVC method (subzone B1) showed the greatest reduction, followed by that using the PEVC method in subzone E1 and that using the FBVC method in subzone D1 when the PVDs were installed at a spacing of 0.6 m. Similar phenomena were observed for the cases where the PVDs were installed at a spacing of 0.4 m. This is because airtight conditions in the CNVC method were provided by the membrane layer, but in the PEVC and the FBVC method they were supplied by the slurry and the fish-bone connectors. The fish-bone connectors were not effective because of the gaps generated between regions on the soil surface and the drilled drainage pipes that may have caused leakage after a certain period of vacuum preloading.

3.2 Ground settlement

The installation of the PVDs induced additional settlements because the installed PVDs shortened the drainage path of the soft clay, inducing more DoC under the self-weight of the soil. The average settlements of the ground surface in each subzone are summarised in Table 2. It can be seen that installation of the PVDs with a spacing of 0.4 m induced more settlement than those with a spacing of 0.6 m. This is because the smaller spacing of the PVDs lessened the drainage path of the soft clay and thus induced more settlement at a specific consolidation period.

Further settlements were developed after the application of vacuum preloading. Five surface settlement plates were installed in each subzone (Figure 1) to measure the surface settlements. The average surface settlements in each subzone are plotted against vacuum preloading duration in Figure 6. It

can be seen that the surface settlements in subzones B3, D2 and E2 developed more quickly than those in the other subzones. For example, the settlements in subzones B3, D2 and E2 were about double those in the other three subzones at a consolidation time of 20 d. Towards the end of the vacuum preloading period, the settlement curves in subzones B3, D2 and E2 tended to converge. The final surface settlements in the six subzones are summarised in Table 2.

3.3 Water content variations

Soil samples at different depths were taken to measure the water contents after vacuum preloading. The average water contents of the soil at different durations and subzones after vacuum preloading are summarised in Table 1. For the PVDs installed at spacing of 0.6 m (subzones B1, D1 and E1), the average water content of the soil in subzone B1 showed the largest reduction, from 83% initially to 55%, 48.5% and 46.2% after 10 d, 30 d and 60 d of vacuum preloading, respectively. The average water content in subzone D1 showed the smallest reduction, 9.9%, 23.8% and 30.7% after 10 d, 30 d and 60 d of vacuum preloading, respectively. Similar phenomena were observed for the average water content reduction for the PVDs installed at spacing of 0.4 m (subzones B3, D2 and E2). After 60 d of vacuum preloading, the average water content reductions in subzones B3, D2 and E2 were 41.6%, 35.8% and 38.4%, respectively.

The spacing of the PVDs influenced the average water content of the soil. The average water content reduction for PVDs installed at a spacing of 0.6 m in subzone B1 was 34.5% after 30 d of vacuum preloading. However, a similar water content reduction (38.5%) only required 10 d of vacuum preloading when the short PVDs were installed at a spacing of 0.4 m (subzone B3). Similar phenomena were also found when comparing the measured average water contents in subzones D1, D2, E1 and E2.

3.4 Vane shear strength variations

Field vane shear tests were conducted on each subzone after 10, 30 and 60 d of vacuum preloading. The results are summarised in Table 1. For PVDs installed at a spacing of

Table 2. Calculation of DoC using measured settlement and PWP data

Subzone	DoC based on settlement data						DoC based on PWP data (Yan and Chu, 2005)		
	S_{PVD} : mm	$S_{t=60}$: mm	Asaoka's method (Asaoka, 1978)		Hyperbolic method (Tan 1995)		$\Delta u_{t=60}$: kPa	u_s : kPa	$U_{h=1.0 \text{ m}}$: %
			S_{∞} : mm	U : %	S_{∞} : mm	U : %			
B1	134.0	524.3	737.0	89.3	774.0	85.1	20.1	80	25.1
D1	123.3	447.2	814.0	70.1	877.7	65.0	8.59	80	10.7
E1	73.5	445.6	621.1	83.6	639.8	81.1	13.6	80	17.0
B3	312.0	570.7	938.6	94.0	917.2	96.2	73.7	80	92.1
D2	141.6	588.3	873.7	83.5	816.8	89.4	63.7	80	79.6
E2	132.0	540.4	731.4	91.9	711.4	94.5	68.1	80	85.1

Figure 6. Average surface settlements in the six subzones

0.6 m (subzones B1, D1 and E1), the average vane shear strength of the soil in subzone E1 showed the largest percentage of increase, from 1.1 kPa before vacuum preloading to 2.9 kPa, 6.5 kPa and 11.1 kPa after 10 d, 30 d and 60 d of vacuum preloading, respectively. The soils in subzone B1 had the largest undrained shear strengths, with magnitudes of 4.8 kPa, 7.1 kPa and 13.1 kPa after 10 d, 30 d and 60 d of vacuum preloading, respectively. The vane shear strengths in subzone D1 slightly increased from an initial 2.3 kPa to 5.4 kPa after 60 d of vacuum preloading. Similar phenomena were observed for the PVDs installed at a spacing of 0.4 m (subzones B3, D2 and E2). After 60 d of vacuum preloading, the average vane shear strength in subzones B3, D2 and E2 was 26.4 kPa, 20.5 kPa and 23.6 kPa, respectively. As all the vane shear strengths were greater than 20 kPa, the requirements of the working platform were met in all cases.

The spacing of the PVDs also influenced the vane shear strength of the soils. The average vane shear strength for PVDs installed at a spacing of 0.6 m in subzone B1 was 13.1 kPa after 60 d of vacuum preloading, but this strength was reached in 10 d for the PVDs installed at 0.4 m in subzone B3. Similar phenomena were observed when comparing the measured vane shear strengths in subzones D1, D2, E1 and E2.

3.5 Degree of consolidation (DoC)

The effectiveness of soil improvement can be estimated using the average DoC, which is calculated as the ratio of current ground settlement (S_t) to the ultimate ground settlement (S_∞). Asaoka's method (Asaoka, 1978) was adopted to estimate the ultimate ground settlement using the ground surface settlement data shown in Figure 7. As the vacuum surcharge was fully applied at 13.6 d, the plot of settlement data S_n ($n=0, 1, 2, \dots$) versus S_{n-1} starts from this point. An example of using

Asaoka's method to estimate the ultimate preliminary consolidation settlement at subzone B1 is shown in Figure 7(a). The constant time interval in this calculation is $t_n - t_{n-1} = \Delta t = 1.2$ d. The estimated ultimate preliminary consolidation settlement is 0.737 m. As shown in Figure 6, the average ground surface settlement in subzone B1 was 0.524 m, excluding the settlement of 0.134 m during PVD installation. The DoC based on surface settlement in subzone B1 after 60 d of vacuum preloading was calculated as 89.3% (see Table 2). The estimated ultimate preliminary consolidation settlements in subzones B3, D1, D2, E1 and E2 and their DoCs were also calculated and the values are shown in Table 2. Apart from subzone D1, the DoCs in all the subzones were higher than 80% after 60 d of vacuum preloading. The DoCs were slightly higher in the subzones where PVDs were installed at spacing of 0.4 m rather than 0.6 m.

The hyperbolic method is another method used to predict the ultimate preliminary settlement of soil (Sridharan and Sreepada Rao, 1981; Tan, 1995; Tan and Chew, 1996; Tan *et al.*, 1991). To calculate the settlement, this method uses the slope of the linear relationship between the $t/S-t$ curve, where t is consolidation time and S is the measured settlement. More details of the method and its application in case records can be found in the literature (Narasimha Rao *et al.*, 1981; Sridharan and Sreepada Rao, 1981; Tan, 1995; Tan and Chew, 1996). An example of using the hyperbolic method to estimate the ultimate preliminary consolidation settlement in subzone B1 is shown in Figure 7(b). In the calculation, the drainage depth $H=3.5$ m, spacing $s=0.6$ m, the equivalent diameter of the PVD $d=67.5$ mm, the equivalent diameter of soil influenced by PVDs $D=1.05$ m, the drain spacing ratio $n=9.3$ and $H/D=5.6$. As the soft clay was newly dredged under-consolidated marine clay and its engineering properties were quite

Figure 7. Estimate of ultimate settlement of soil in subzone B1 using (a) Asaoka's method and (b) the hyperbolic method

uniform, the ratio of the vertical to horizontal coefficient of consolidation was assumed as $c_v/c_h = 1.0$. The calculated ultimate settlement is 0.774 m, which is slightly higher than that predicted by Asaoka's method. The DoC based on the ultimate settlement predicted by the hyperbolic method in subzone B1 after 60 d of vacuum preloading was calculated to be 85.1%. Similarly, the estimated ultimate preliminary consolidation settlements in subzones B3, D1, D2, E1 and E2 and their DoCs were calculated and are summarised in Table 2. The results show that the DoCs calculated using ultimate

settlements predicted by Asaoka's method and the hyperbolic method are well matched.

The DoC can also be estimated using the PWP distribution profiles (Yan and Chu, 2005). In this method, the average DoC is estimated as the ratio between the area covered by the PWP distribution curve at a given time and the suction line, and the area covered by the initial PWP line, and the suction line. However, as only one PWP transducer was installed at a depth of 1.0 m in each subzone, the calculation using PWP data in this method only provides the DoC at a specific location (i.e. depth of 1.0 m). Table 2 shows that the DoCs at a depth of 1.0 m after 60 d of vacuum preloading in subzones B1, D1 and E1 were only 10.7–25.1%. These results are much lower than those calculated using surface settlement data. In subzones B3, D2 and E2, the DoCs calculated using PWP data match the DoCs calculated using surface settlement data. The DoC results also indicate that CNVC is the most effective method, followed by PEVC and then FBVC. It should be noted that the DoCs calculated using the PWP data (see Table 2) are only the DoCs of the soil at a depth of 1.0 m, which does not consider the effect of vacuum preloading along the depth of the subsoil nor in the soil beneath the improved layer.

4. Discussion and comparisons

4.1 Spacing of PVDs

In the pilot tests using vacuum preloading combined with short PVDs to form a working platform, short PVDs were installed in a square grid at spacings of 0.4 m and 0.6 m, which are much less than the spacing normally used in the CNVC method (0.7–1.3 m). The spacing used in the CNVC method is because smear zones will influence the performance of PVDs if the spacing is less than 0.7 m. However, for the methods investigated here, the smear zone effect is limited because the clay under study was very soft remoulded clay. For example, the site soil properties included a water content of 85%, or double that of the liquid limit.

In practice, the construction time for a working platform is usually around one month. The pilot tests indicated that vacuum preloading combined with short PVDs installed at a spacing of 0.4 m was much more effective than PVDs installed at a spacing of 0.6 m. The undrained shear strengths of the soil after 60 d of vacuum preloading in subzones where PVDs were installed with a spacing of 0.4 m were more than 20 kPa, meeting the requirements for a working platform. However, the undrained shear strengths of the soil in subzones where the PVDs were installed with a spacing of 0.6 m were only approximately 10 kPa. This means that vacuum preloading requires a longer duration or other construction methods are required to further treat the top layer of the soil. Therefore, a spacing of 0.4 m is suggested when using the proposed method to form a working platform on the surface of dredged clay.

4.2 Treatment effects

The CNVC method uses short PVDs, horizontal vacuum pipes, a sand blanket layer, a membrane layer and vacuum pumps. The FBVC method uses a fish-bone shape connector to connect all the drainage pipes and short PVDs; a sand blanket layer and a membrane layer are not required in this system. The PEVC method uses a layer of clay slurry to embed and seal the horizontal drainage pipes to create an airtight system.

The subzones consolidated using the CNVC method were found to have higher DoCs and undrained shear strengths because the membrane system provided airtight conditions. However, this method is more expensive because a sand blanket layer is required. A further drawback of the method is that sites have to be divided into many small subzones due to the limit on the size of the membranes.

The FBVC method is time consuming because more labour is required to connect each drainage pipe to the fish-bone connector and then to the vacuum pump. Furthermore, this method can also induce vacuum leakage problems because too many connections are involved. The contact area between the drainage pipe and the ground surface generates many cracks that can break the airtight condition, as demonstrated by the lowest DoC and undrained shear strength of soil treated using by this method.

The PEVC method is the most effective technique in terms of cost and time. In this method, slurry is placed on the surface of the horizontal drainage pipes to seal the whole system and supply airtight conditions. The soils treated in this way soil had a DoC and undrained shear strength similar to those treated by the CNVC method, and therefore the PEVC method is the preferred method for constructing a working platform on the surface of newly dredged soft soil.

5. Conclusions

Pilot tests were conducted to investigate three methods of using vacuum preloading combined with short prefabricated vertical drains (PVDs) to form a working platform on the surface of very soft dredged clay. The first method used conventional vacuum preloading (CNVC) combined with short PVDs. The second method required no sand blanket layer or membrane layer because fish-bone connectors were used to connect the short PVDs directly (FBVC). The third method involved wrapping the PVDs around horizontal drainage pipes and embedding them in soft clay (PEVC). The influence of the spacing of the short PVDs was also investigated in the pilot tests. The ground settlement, the applied vacuum pressure and the pore water pressure in the soil were also monitored during the vacuum preloading.

The pilot tests indicate that the PEVC method is the best method for using vacuum preloading combined with short PVDs to form a working platform on the surface of very soft

dredged clay. This method yielded substantial savings in construction cost and time, but also produced efficiencies similar to those of the CNVC method. When using the PEVC method, short PVDs installed at a spacing of 0.4 m were considerably more effective than those installed at 0.6 m. The undrained shear strength and degree of consolidation of the soil after 60 d of vacuum preloading were more than 23.6 kPa and 85.1%, respectively, meeting the requirements of a working platform.

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