International Geotechnical Symposium on Theory and Practice of Earth Reinforcement / Fukuoka Japan / 5-7 October 1988
 ISBN 90 6191 820 0

Improvement of very soft ground

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ABSTRACT: The treatment of very soft ground consisting of hydraulic fill combined with vertical drainage at a jetty construction is presented. On the basis of the field study, a suitable method consisting of fascine sand cushion plus preloading by vacuum was suggested. This method was successful in treatment of 700,000 m^2 area at the jetty with cost saving, easy construction and proven performence. The function of geotextile and fascine sand cushion as well as preloading by vacuum in combination with packed sand drain or PVC drain is analysed and discussed.

1 INTRODUCTION

With development of national economy and opening of coastal cities to the outside world more wharves are in urgent need, some of which would be constructed on reclaimed land due to the lack of suitable sites. At present, it is economical and efficient to reclaim land from the surrounding sea with hydraulic mud filling. The mud having a high water content and almost zero strength is referred to as very soft ground. A jetty in China was constructed on such fill. The soft ground had to be improved immediately after hydraulically filling so that twelve berths scheduled to be completed at the jetty before 1992 will be put into service in time. Therefore, certain conditions must be met so that construction equipments can enter the site. In our case, this problem was dealt with using surface treatment and then using preloading by vacuum, sometimes in combination with PVC drains, which was the first application in China. This method was successful in treatment of 700,000 m^2 area of ground at the jetty.

2 TECHNIQUE FOR IMPROVEMENT OF VERY SOFT GROUND

In order to make the very soft ground suitable for construction as early as possible, the following techniques have been adopted in China and abroad:

2.1 Natural evaporation

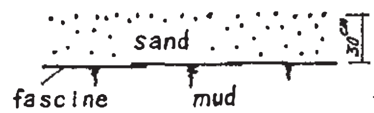
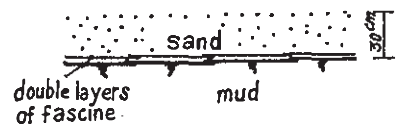
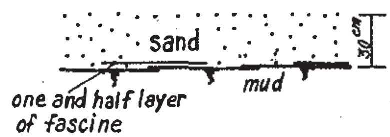
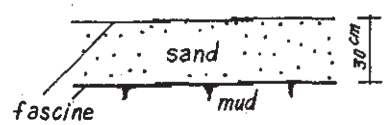
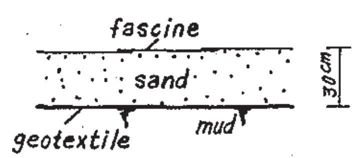
At the end of pumping the hydraulic fill is left for a certain period of time, allowing water to evaporate and to consolidate. According to the information available, after a duration of three months, the variation of water content with depth was close to that at complete consolidation under gravity. After a duration of two years, the water content at surface layer reduced considerably, resulting in the formation of soil layer where one could walk on it. After a duration of three years, the water content at depth of 0.5 to 2.0 m from the surface was about 80 %, resulting in the formation of a crust soil layer(Watari et al,1983). The method was used in Tianjin and Shanghai (Hu, 1982).

2.2 Drainage

Provision of a horizontal thin layer of permeable material between sedimented clays, such as sand, geotextile, and bagged sand will shorten drainage passage to accelerate drainage. A sand dredger was built in Japan for the purpose of construction

When the hydraulic fill is rather thick, sand drain, packed sand drain and PVC drains etc., are installed to form ver-

Table 1 Six proposed methods for surface treatment

Item	Description	Section	Remarks
1	A single layer of fascine mattress plus sand cushion; the subsoil was laid first with a layer of fascine mattress, then with a 30-cm-thick layer of sand		overlap: 20 cm
2	Two layers of fascine mattress plus sand cushion: The subsoil was laid first with two layers of fascine mattress, then with a 30-cm-thick layer of sand.		ditto
3	One and half layer of fascine mattress plus sand cushion; The subsoil was laid first with one and half layers of fascine mattress, then with a 30-cm-thick layer of sand.		ditto
4	Two layers of fascine mattress with sand between: The subsoil was laid first with one layer of fascine mattress, then with one 30-cm-thick layer of sand.		ditto
5	Ditto	ditto	overlap: 40 cm
6	Geotextile and fascine sand cushion: The subsoil was laid first with a layer of geotextile, then with a layer of 30-cm-thick layer of sand, finally with a layer of fascine.		overlap: 20 cm

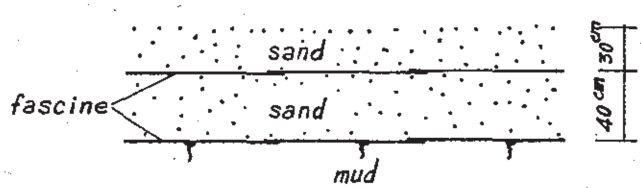


Fig.1 The final section adopted

tical drains. This method has been widely used because of economy and efficiency. For example, these methods have been already used in Lianyungang, Tianjin and Shanghai(Ye,1983; Gao, 1987) as well as in Osaka in Japan(Sasaki, 1982).

2.3 Surface treatment

Surface layer of the soft ground can be improved into the rigid plate by means of cement or lime stabilization. This method has been used in Tokanton, Japan (Nishio .,1981).

Geotextile or fascine sand mattress is placed on top of the subsoil in order to change stress distribution under loading. This method has been used to construct a highway at the port of Kanda in Japan(Yasuhara, 1982), a highway in the south-eastern part in Mexico(Olivera,1982) and a breakwater in Tianjin, China(Li,1984).

3 SITE DESCRIPTION

The original ground at the jetty sloped down from west to east with an average elevation of +1.5 m, which was designed to construct to an elevation of +6.5 m by hydraulic filling. The field tests were carried out when the fill reached the elevation of +3.5 m. The test site consisted of 2 m hydraulically filled mud (W= 85-90 %, e = 2.2, γ=16 KN/m^3) underlying natural mud and silty loam (W=45-55 %, e = 1.1-1.4, γ= 16.5-17.5 KN/m^3).

4 SURFACE TREATMENT AND RETENTION EMBANKMENT CONSTRUCTION

With the principle of using locally available and inexpensive material, six surface treatment methods were proposed as shown in Table 1. They can be divided into two types. Type I, consisting of the first three methods, was to place sand on the fascine mattress. Type II comprising the remaining ones was to place sand between two fascine mattresses or between fabric and fascine mattress. Comparision of the results showed that Type II was superior to Type I because the working surface built using Type II had better rigidity. The 4th, 5th and 6th methods all had similiar effectiveness and could meet the requirements of the project. However, the geotextile suffered large deformation, and was difficult to construct and expensive although its tensile strength was larger than that of the fascine. Finally, the 4th method was selected because it needed less fascine. In view of heavy construction equipment and requirements of preloading by vacuum an additional 30-cm-thick layer of sand was placed on the top of the upper fascine mattress and the sand cushion was increased from 30 to 40 cm. The final section adopted is shown in Fig.1. The practice showed that the working surface after treatment allowed construction equipment with wheel pressure of 30 KN and dumper truck with wheel pressure of 45 KN to perform normal operation on it.

5 FUNCTION OF GEOTEXTILE IN EMBANKMENT

During the last decade many researchers around the world have been studying the theory of the geotextile or fascine reinforced embankment but only a few have studied burried geotextile sand cushion. The researchers in China, based on laboratory model test in combination with case history, have analysized its behaviour(Zhang, 1987). A new fabric element was designed. A mathematical model of soil-geotextile interaction using finite deformation theory and relative movement method was derived as elaborated in a large computer program GNFT(Geotechnical Non-linear Finite Element Analysis Program). It was also found that the function of the reinforced soil layer is to reduce average stress, deviator stress and shear stress of the main bearing zone of the ground, and to distribute high strain along the narrow and deep zone just below the center line of the embankment, resulting in higher stability. It was also learned that, in order to keep the embankment and reinforced cushion as one unit, a suitable geotextile should be selected. Model and centrifuge tests indicated that, due to placement of geotextile, the slip circle moves a little deeper so the stability can be checked by using modified Miga Kawa method(Zhang, 1987) as shown in Fig.2. Let the tensile force of fabric be $N = m\tau_0 L$, where L is length of slip circle,and m is dimensionless coefficient. The following results were obtained.

When the soft soil is thick, the shear strength of the subsoil can be considered to increase linearly with depth, that is, $\tau=\tau_0+\lambda Z$ where Z is the depth as shown in Fig.2. λ is the slope of shear strength versus depth curve as shown in Fig.2. The factor of safety for slip circle can be expressed by

$$K=\frac{\frac{2\lambda g^3}{\sin^2\theta}\left(1-\frac{\theta\cos\theta}{\sin\theta}\right)+2(1+m)\tau_0 g^2\frac{\theta}{\sin^2\theta}}{P(g-f)} \qquad (1)$$

Where g and θ can be obtained by the following equations

$$g=\frac{(1+m)\tau_0}{\lambda}\cdot\frac{2\theta\,ctg\theta-1}{\theta-3ctg\theta+3\theta\,ctg^2\theta} \qquad (2)$$

$$\frac{g(2g-3f)}{(2f-g)}=\frac{(1+m)\tau_0}{\lambda}\cdot\frac{\theta}{1-\theta\,ctg\theta} \qquad (3)$$

The definition of notation is explained in Fig.2.

When m = 0 the above equations are applicable to embankment without geotextile. For homogenous subsoil, $\lambda = 0$, resulting in g = 2f and $\theta = 66^\circ 47'$.

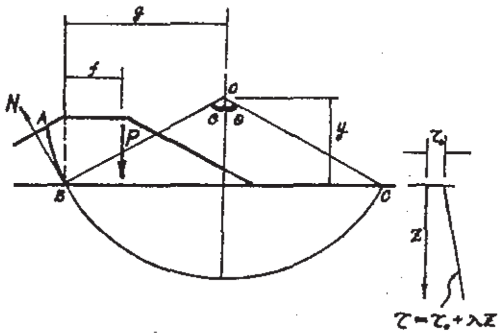


Fig.2 Schematic illustration of stability check

6 TREATMENT OF SOFT SOIL

The test site was divided into two zones: one was treated by preloading by vacuum in combination with packed sand drain; the other by that in combination with PVC drain in order to examine the effectiveness through comparisons.

Packed sand drains, 7 cm diameter, were installed to depth of 15 m in a 1.3 m square grid. PVC drain, 100 mm wide by 3.5 mm thick, were installed in the same pattern with the same spacing and depth. The latter is manufactured by Nanjing Plastic Development Factory which produces three products, that is, SPB-1, SPB-1B, SPB-1C. Their properties and dimensions are summarized in Table 2.

The two test sites, 42 m x 40 m each, 4 m apart, were evacuated using two vacuum systems. Around the zones drainage channels were provided. The results obtained are as follows:

6.1 Settlement of surface layer

Settlements occuring at different stages are shown in Table 3. From Table 3 it can be seen that the settlements of the two test zones were very close.

Table 4 shows consolidation at various time. From Table 4, it can be seen that the rate of consolidation at the two zones was almost the same, indicating that the two kinds of drainage material had the same effectiveness. Settlement during a period of 65 days after normal pumping was equal to 80 %.

6.2 Vane shear strength

Table 5 shows increase of vane shear strength. From Table 5 it can be seen that the strength of soil treated by preloading by vacuum increased considerably and the increase rate reduced gradually from the surface to bottom. The two zones had similiar increase.

Table 2 SPB series of PVC drain

Width mm	Thickness mm	Weight g/m	Length m/roll	Vertical flow capacity m^3/s (1)	Transverse permeability m/s	Tensile strength KN/10cm	Extension % (3)
100±2	> 3.5	90-120	200	15-40x10^{-6}	5x10^{-6}	> 1.0((2)	< 10

Note: 1) lateral pressure, 350 KN/m^2; 2) at extension of 10 %; 3) tensile force, 1 KN/10 cm.

Table 3 Settlements at various stages(in centimeters)

	Installation of vertical drain	Preloading by vacuum		Total
		centre	mean	
	1	2		1 + 2
Packed sand drain	24.2	100.4	87.21	124.6
PVC drain	23.2	101.0	88.07	124.2

Table 4 Degree of consolidation, U, at various time after pumping

Zone	S_∞ cm		U_{60} %		U_{65} %		U_{99} %	
	centre	mean	centre	mean	centre	mean	centre	mean
Sand drain	143.0	127.03	79.86	78.88	80.10	80.45	87.10	88.70
PVC drain	141.1	127.04	78.95	78.09	81.08	80.05	88.02	88.37

Note: Subscript 60, 65, 99 refer to days after pumping

Table 5 Variation of vane shear strength with depth

Depth	Strength at sand drain zone			Strength at PVC drain zone			Strength at area between two zones		
	before treatment	after treatment	increase	before treatment	after treatment	increase	before treatment	after treatment	increase
	KN/m^2		%	KN/m^2		%	KN/m^2		%
0-2.0	0.2	18.4	9100	0.2	18.3	9050	0.2	11.2	5500
2.0-10.0	14.2	32.0	125	14.2	30.4	114	14.2	29.3	126
10-13.0	17.6	25.5	44.9	17.6	26.1	48.3	17.6	24.7	40.3

Table 6 Soil properties before and after treatment

	Water content %	Unit weight KN/m^3	Void ratio
Before treatment	90	16	2.2
After treatment	55	17	1.5

6.3 Physical properties of hydraulic fill

The physical properties of the hydraulic fill are shown in Table 6. From Table 6 the improvement is obvious.

7 CONCLUSION

Fascine sand cushion and geotextile sand cushion both were successfully used in surface treatment. The former was cheaper, more efficient, easy to construct and abundantly available. So it was adopted in the project.

Preloading by vacuum in combination with packed sand drain or PVC drain was successfully used in treatment of very soft ground. Which one is to be adopted depends on such factors as cost, efficiency, supply of materials and construction equipment. In this project PVC drains produced by Nanjing Plastic Development Factory were used in great quantities because of excellent properties, low price less weight and less hard labour.

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