HVDM METHOD APPLICATION IN A SANDY CLAY GROUND

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ABSTRACT: For Traditional Dynamic Compaction (DC) method, there are some limit for application to sand with allowable silty content. A new soil improvement technique- high vacuum densification method (HVDM) is introduced in this paper, which will enlarge the scope of DC method application for more soil conditions. Based on a soil improvement project in Ningbo (China) where ground consists of a silty sand layer in surface and underlying a sandy silt layer, in-situ test study on the applicability of HVDM is done. By analyzing the variation of excess pore water pressure with depth, distance and the impact number, and considering the increasing and dissipation regularity of excess pore water pressure in different soil layers, the construction parameters for HVDM by experimental means is proposed. At the same time, field tests are given to evaluate the effectiveness of improvement, and the results indicate the validity of HVDM to treat the silty clay ground and also further broaden the application range of HVDM.

Keywords: Hydraulic reclamation; low-energy dynamic consolidation; vacuum dewatering; excess pore water pressure.

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1 INTRODUCTION

Dynamic compaction(DC) technique is one of the ground improvement methods which has been proven very effective in densification of loose soil within certain depth[1] (Menard and Broise 1975), which has also been successfully utilized on a wide variety of soil types and conditions, such as gravel, sand, collapsible loess, and miscellaneous fill with low water content. But for the soft clayed soil, specially for the saturated soft clay and mucky soil, the improvement results by dynamic compaction method are far from satisfaction [2]. The main problems for traditional dynamic compaction method to improve saturated soft clay are: 1) the saturated soft clay has features with high water content, big void ratio, low permeability, the excess pore water pressure caused by dynamic compaction can not dissipate rapidly and the "spring soil" will be formed easily; 2) extreme high compaction energy is easy to damage the structure of soft soil, and hardly recover in the short time; 3) most of compaction energy is absorbed by the pore water between soil, while not applied to soil mass, so the soft soil can not be improved.

For the above three points, many scholars have embarked the study on DC mechanism and practical technique of saturated soft clay, and brought forth solutions as followings: increasing the drainage path by prefabricated vertical drain to solve the problem of excess pore water pressure dissipation; choosing low-energy DC method instead of traditional DC to avoid excessive destroy of soft soil structure, and achieved good results [3,4].

High Vacuum Densification Method (HVDM) is an innovative technique based on the traditional DC method, it combines vacuum dewater technique and low-energy DC method to improve saturated soft fine clay. HVDM method enlarges the scope of traditional DC application, the treatment effect for soft sandy clay or silty sand is greatly improved than the later. Up to now, this technique has been applied successfully in many projects[5,6].

This paper presents the mechanism and construction procedure of HVDM method, and a successful project applied in silty clay ground is given as a case study. Through the analysis of in-situ test data, the improvement effect of HVDM is analysized and some suggestions are given for similar engineering projects.

2 HVDM MECHANISMS AND CONSTRUCTION PROCEDURE

2.1 HVDM MECHANISMS

In specification, a "high vacuum densification method"(HVDM) is to create "pressure gradient" ('positive pressure' of pore water pressure generated by compaction, and 'negative pressure' caused by high vacuum pressure) in the soil, and make use of the "pressure gradient" to dissipate rapidly the excess pore water pressure during the course of dynamic compaction procedure, so the water in the soil can be drained out easily, shown in Fig 2.1. At the same time, due to the high vacuum drainage, most of compaction energy will be put on the soil skeleton, the effect of compaction will be greatly enhanced, and a "hard shell" layer with a certain thickness of over-consolidated soil will be formed at the top of soil layer. As "hard shell" layer exists, surface load can be effectively diffused, the differential settlement caused by uneven load is reduced. In addition, there are no drainage paths in the "hard shell" layer, so the post-construction settlement rate is under control.

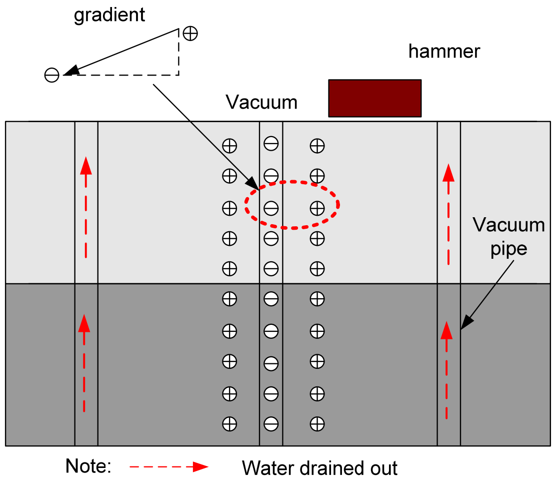

Fig 2.1 the primary mechanic of HVDM method

2.2 HVDM CONSTRUCTION PROCEDURE

Comparing with the conventional dynamic compaction method, there is one more procedure-vacuum dewatering before dynamic compaction. In this procedure, as a vertical drainage path, vacuum pipes with holes are installed into the soil with different depths (6-8m). Then, horizontal PVC pipes without any holes are connected with the vacuum pipes, and under the vacuum pressure from the vacuum pump, the water can be drained out through vertical and horizontal drainage system, just as shown in Fig. 2.2-2.4.

During the dynamic compaction, the vacuum pipes are not removed, while vacuum pressure and dynamic compaction energy act on the soil at the same time, under the "pressure gradient" caused by them, the soil can be improved greatly, the construction procedure is shown in Fig 2.5.

Fig 2.2 Vacuum pipe installation by hydraumatic method

Fig 2.3 vacuum drainage system layout

Fig 2.4 Vacuum pumps

Fig 2.5 Dynamic compaction

3. A CASE STUDY OF HVDM

3.1 GEOLOGY AND SUBSOIL CONDITIONS

The proposed site is estuarine, river mouth area, groundwater level in the site is 0.5 ~0.7m. Geological investigation report exposes soil from the top to bottom as followings: Filling soil, silty sand at the top layer, loose ~ slight dense, with thickness of 0.1 ~ 0.5m; ① with fine sand and silt, saturated, plastic flow, high compressibility, with fine sand content of 10-30%, this layer can be divided into: ①-1: 0~3 m, sand mixed with silt, mainly silty sand or fine sand, silt content of 20 to 30%, slightly dense, saturated ; ①-2: 3~6 m, silt mixed with sand, mainly silt, sand existing as sandwich or mixed form; ①-3: below 6 m, silt mixed with sand, fine sand content of 20%, stream plastic. ② mud, blue gray, gray, saturated, plastic flow, high compressibility, with a small amount of fine sand and shell debris and semi-carbonized materials (organic matter), 13.20 ~ 14.50m thick.

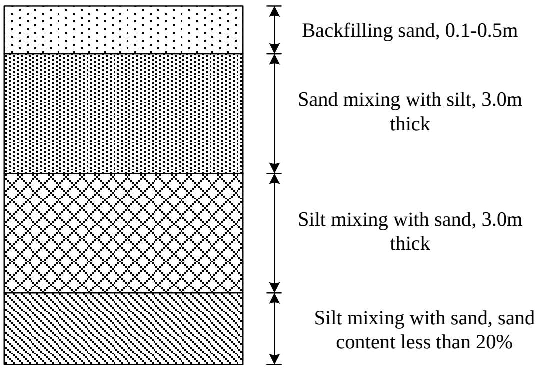

Fig 3.1 soil condition section

3.2 Improvement Requirements

After soil improvement by HVDM method, the bearing capacity of soil shall be over 80 kPa, and the effect depth should be over 6m, to reduce the post-construction settlement and differential settlement.

3.3 Design Scheme

For the dynamic compaction method design, site trial is a necessary to modify and determine the construction parameters for large-area construction. For this project, 3 typical test plots of 7500 m2 is chosen for the site trial.

The total test area is divided into A,B,C test plot, each 50mx50m area. In each zone, two cycles of vacuum dewatering and dynamic compaction will be applied following design. The construction parameters of each zone are shown in table 3.1.

Single point ramming is executed in each zone, and according to different distance from the tamping point center, 7 sets of pore water pressure measurement gauges are set up in different depths, test arrangement is shown in Fig.3.2. Based on the analysis of pore water pressure, the optimal compacting numbers of single point ramming, the effect depth and width of compaction energy, effects of HVDM on different kinds of soil are determined.

Test plot	Compaction energy		Compaction number	
	1st	2nd	1st	2nd
	kN·m		blow	
A	800	1200	5	5
B	1000	1400	5	5
C	1200	1600	6	6

Table 3.1 Parameters of single point impact of every section

section

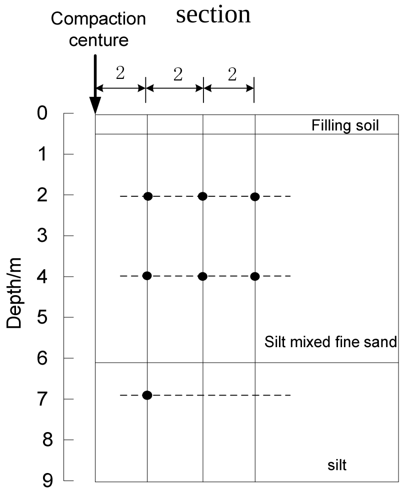

Fig 3.2 Arrangement of the pore water pressure gauges in the location of single point impact

3.4 Analysis of Excess Pore Water Pressure

3.4.1 Variation of Excess Pore Water Pressure with Time

The pore water pressure is measured by vibrating wire pressure gauge. During the course of HVDM, the pore water pressure is measured successively to get its development character in different soil layers. Fig.3.3 shows the pore water pressure growth and dissipation of ramming point one and two during the dynamic compaction (point one lies in layer ①-1 fine sand mixed mud, point two lies in the layer ①-2 silt with fine sand interlayer), the specific location is shown in Fig.3.2.

From Fig.3.3, after each drop of hammer, the excess pore water pressure in layer ①-1 (fine sand mixed mud) reaches the peak value immediately, and began to dissipate at once. With the increase of the compaction number, the amplitude of pore pressure vary decreases. But for the layer ①-2 (silt with fine sand interlayer), there are obvious hysteresis for increase of pore water pressure caused by dynamic compaction, the peak value of excess pore water pressure does not appear immediately after each ramming, while increases slowly with time.

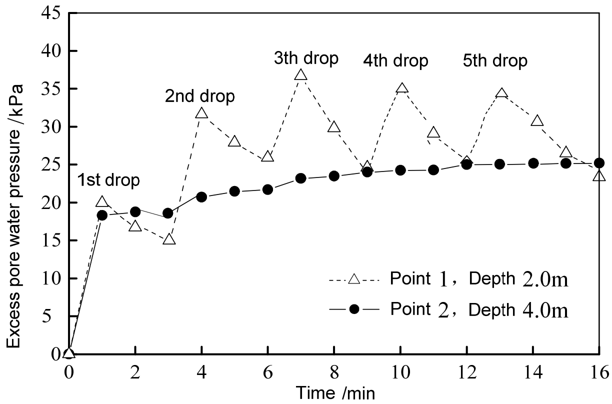

Fig. 3.3 The increasing curves of excess pore water pressure of single point impact

According to the "pressure gradient" theory, HVDM method can make rapid dissipation of pore water pressure and speed up the consolidation of soil. The value and speed of growth and dissipation of pore water pressure can reflect the improvement result of soft soil and the effective influence scope, so it is an important parameter in the design of HVDM.

The pore water pressure in different depth at point one(2m far from the ramming point) are shown in Fig.3.4 and Fig.3.5. Dynamic compaction is carried out in clay and the peak of excess pore water pressure will appear "lag phenomenon", mainly due to the permeability of clay, impact energy and other ramming factors.

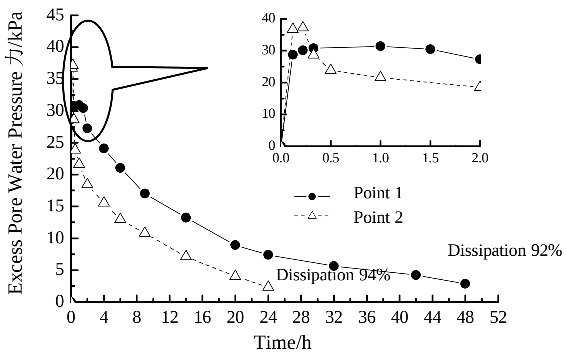

Fig 3.4 Dissipation curves of excess pore water pressure of single point impact (1st pass)

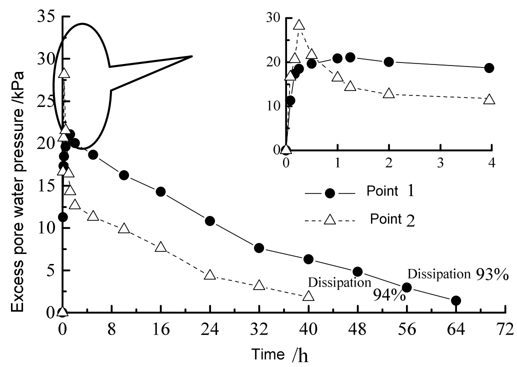

Fig 3.5 Dissipation curves of excess pore water pressure of single point impact (2nd pass)

From Fig.3.4, at the time of 6-7 days after each ramming, the excess pore water pressure dissipation rate has reached over 85%, that means the interval of every ramming determined as 7 days is reasonable in HVDM construction procedure for the ①-1 (fine sand mixed mud). In addition, from the enlarged map of pore water pressure peak value, the peak value appears immediately after each ramming in the upper layer, and then began to dissipate at once. But for the lower layer ①-2 (silt with sand interlayer), the peak value does not appear immediately but has an obvious "lag phenomena", it grows slowly with time, which is the characteristics of pore pressure of clay soil.

From Fig.3.5 we can see, the peak value of excess pore water pressure in second pass is slightly less than that in first pass. That is because of increase of tamping number and tamping energy, the density of soil increases gradually and a certain thickness of hard shell is formed at the surface layer. Due to the "isolation effect" of hard shell, the structure destruction of lower clay by tamping is small and excess pore water pressure is relatively low.

3.4.2 Variation of excess pore water pressure with drops

Fig.3.6 shows the relation between increment of excess pore water pressure and the tamping number of each drop. With the increase of tamping number, the increment of excess pore water pressure of continuous drop decreases rapidly. The maximum value of increment of excess pore water pressure appears in the first drop, then significantly decreased in the following drops, and reaches zero at the end. For different tamping energy, the tamping number for increment of excess pore water pressure decreasing to zero is different.

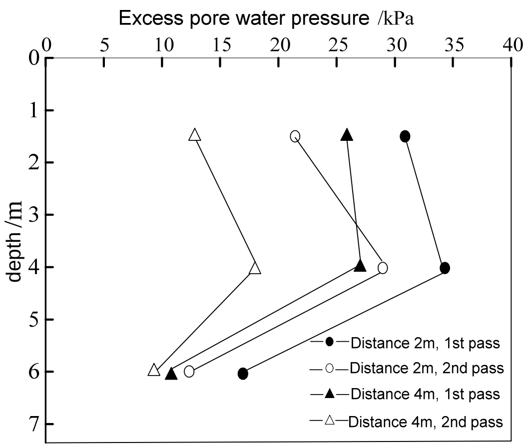

Fig 3.6 Variation of the increment of excess pore water pressure with the impact number

3.4.3 Variation of excess pore water pressure with horizontal distance

Fig.3.7 shows the variation of excess pore water pressure with horizontal distance. From it we can find that with the increase of horizontal distance, the peak value of excess pore water pressure decreases gradually, this is in accordance with the law that impact energy decreases with distance. From Fig.3.7, at the depth of 6m and horizontal distance of 4m, the peak value of excess pore water pressure is 5~12kPa, so the horizontal effect distance of applied impact energy is 4m, which will be used in the HVDM design.

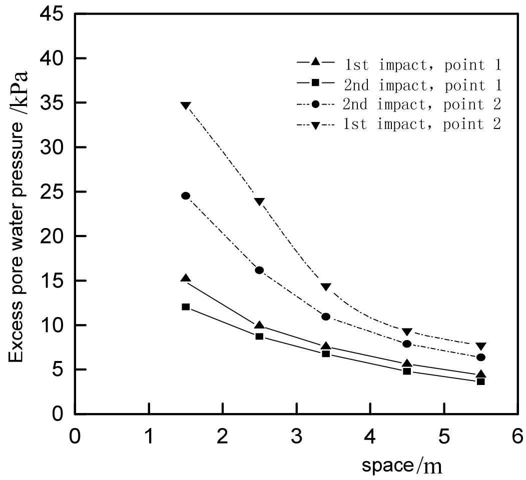

Fig 3.7 Variation of the peak value of excess pore water pressure with horizontal distance

3.4.3 Variation of excess pore water pressure with depth

Fig.3.8 shows the relationship between excess pore water pressure with depth, from it we can find that at the same distance from the impact point, the excess pore water pressure at depth of 1.5m is less than that at the depth of 3m, that is due to vacuum dewatering measurements before dynamic compaction, the saturation degree of fine clay is reduced.

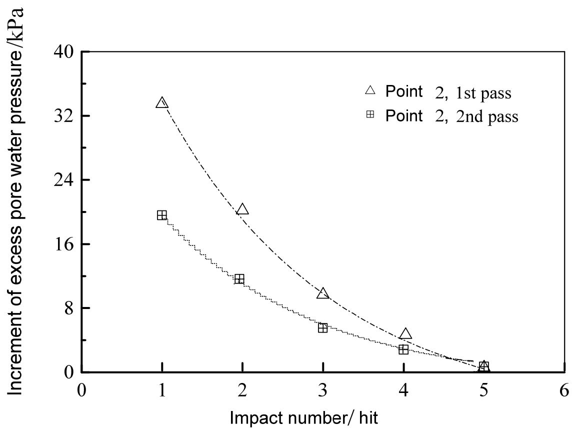

Fig 3.8 Variation of the peak value of excess pore water pressure with depth

Fig.3.8 also shows that at the depth of 6m, the peak value of excess pore water pressure is 7~18 kPa, which means the effect depth of applied impact energy is about 6m.

3.5 Analysis of improvement results

In order to test the HVDM results, before and after HVDM, on-site cone penetration test (CPT) and standard penetration test(SPT) was carried out, the test results are the base of large-area construction parameters and process. For the silt mixed fine sand, considering the lag effect of strength increase by HVDM, the time for SPT test is chosen at the time of 7d, 14d after HVDM, the time for CPT test is chosen at the time of 14d after HVDM.

3.5.1 CPT test results

Fig.3.9 shows the CPT results of the site before, 1st pass and 2nd pass of HVDM, from the analysis of the test data, we come to conclusions as followings:

After soil improvement by HVDM, the Ps values of CPT in the range from 0m to 6m depth increases greatly. For the silt mixed with fine sand layer, the average value of Ps improved from 0.94Mpa to 4.31Mpa, for the fine sand mixed with silt layer, the average value of Ps improved from 4.33Mpa to 6.91Mpa, which overrun the design requirements.

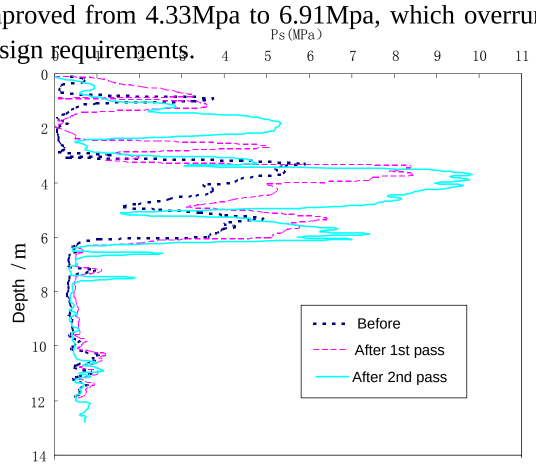

Fig 3.9 CPT test results between before and after soil improvement

For the different layer soils, the law of strength increase is different. Comparing with the state of no improvement, at the 3rd day, the strength of silty mixed sand layer increase 35~40%, but for the fine sand mixed with silt layer, the strength increase 70~100%. That is mainly due to the thixotropic solidifying character of the clay.

3.5.2 SPT test results

Fig.3.10 shows the SPT results of the site before, 1st pass and 2nd pass of HVDM, the test data also show the great improvement of soft soil by HVDM. For the silt mixed with fine sand layer, the average value of N improved from 3.5 to 6.5, for the fine sand mixed with silt layer, the average value of N improved from 7 to 10.5.

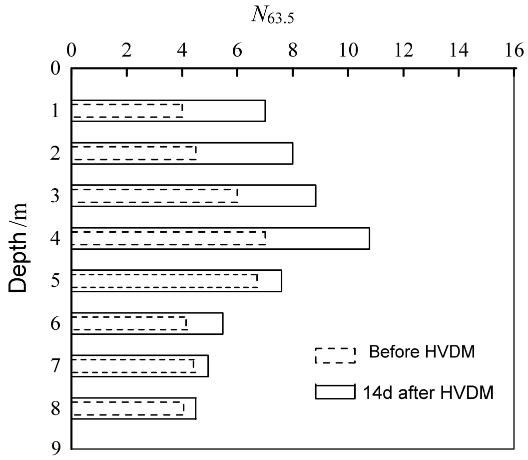

Fig.3.10 SPT test results between before and after soil improvement

4 CONCLUSIONS

The HVDM method is one technique by combining dynamic compaction method with vacuum dewatering method, the highlighted advantage is to reduce the dissipate time of pore water pressure caused by dynamic compaction, then save the construction duration greatly. A successful case is studied in this paper, the feasibility of HVDM for large-area application is discussed, the application range of conventional dynamic compaction method is enlarged.

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