Experimental Study on Dynamic Characteristics of Dynamic Drainage Consolidation in Soft Foundation Treatment

DING Jihui, Duan QingSong, Xiong Wei

Abstract—**Based on the field measuring on dynamic characteristics of vibration used by dynamic compaction measuring with 2500kN.m energy-level for reinforced soft soil subgrade in ShanTou is carried out by using the combined method of surcharging and dewatering preloading and dynamic consolidation. The settlement of the rammer, Vibration action time, vibration main frequency, peak acceleration and peak velocity are analyzed. The soil resistance is defined as the unit settlement of the rammer to complete is required single compaction energy on the unit area, which can be reflected the characteristics of the soil layer under the hammer. The cumulative settlement of the point compaction is increased as hyperbolic function with the increase of the number of compaction, and its limit value is equal to the maximum settlement. The acting time of vertical vibration is at 0.19~0.6Sec, and that of horizontal vibration is 0.252~0.854Sec. The horizontal vibration main frequency is at 5.76~14.5Hz, and the vertical vibration frequency is at 7.51~19.26Hz. The vertical peak acceleration is greater than the horizontal peak acceleration, the ratio between the vertical peak acceleration to the horizontal peak acceleration is 1.3~5.0.**

Index Terms—**Dynamic characteristics; Soft soil subgrade; The combined method of surcharging and dewatering preloading and dynamic consolidation; Vibration effects**

I. INTRODUCTION

In recent years, the combined application of the technology of improving the soil water drainage, setting the vertical drainage body and the vacuum preloading or surcharge preloading or precipitation preloading with dynamic consolidation (method combined by static and dynamic drainage consolidation method) in the soft soil and dredger fill soft soil foundation, made the application scope of the dynamic compaction method extended. Combination of static and dynamic drainage consolidation method is by improving the drainage conditions of foundation soil and combined with dynamic compaction method and static drainage consolidation method, which can solve the dredger fill uneven settlement, the settlement amount, the time limit for a strict, the high requirements of the bearing capacity of the foundation. Combination of static and dynamic drainage consolidation method is by improving the drainage conditions of foundation soil and combined with dynamic compaction method and static drainage consolidation method, which can solve the dredger fill uneven settlement, the settlement amount, the time limit for a strict, the high requirements of the bearing capacity of the foundation. The sdudies about dynamic consolidation reinforcement mechanism of the combination of static and dynamic consolidation method belong to qualitative analysis, and lack of objective quantitative analysis. The pore water pressure in the soil, empirical equation of the of stress, strain and seepage are established by Qian Jiahuan, and contact surface stress formula of Scott was revised in the indoor test[1]. Through the improved three axis test, the static and dynamic combination of drainage consolidation of the laboratory test, the pore water pressure and the re-consolidation of the strain has a unique relationship by Bai Bing etc. [2] .The dynamic response of pore water pressure in dynamic compaction process was studied by the large scale test device developed by Wang Shanshan etc. [3]. Zhao Jianhua etc. established the experimental model of silt soft soil reinforcement by using dynamic drainage consolidation method by used a similar ratio of 1:2 indoor experimental apparatus, put forward the determination method of the effective reinforcement depth of the soft soil foundation and evaluation method of the effect of reinforcement of the effective reinforcement depth of the soft soil foundation[4]. Based a dynamic drainage consolidation method for soft soil foundation treatment engineering in Guangzhou indoor model test is designed by Wang AnMing etc., the saturated soft clay pore pressure responses were obtained during inserting plastic drain plate process, dynamic compaction and compaction hit after the completion[5]. The shock stess, soil deformation and pore water pressure during dynamic compaction were studed by really triaxial test by Li Dedi, and the combination of indoor compression shear test, the strength changes of the samples of the samples before and after dynamic consolidation is analysed[6].The action and its dynamic characteristics of the dynamic compaction in the soft foundation treatment process were studed by Ma Na, Ding Jihui and etc. through dynamic compaction combined with preloading dynamic drainage consolidation method the indoor experiment[7]. through of construction site of the dynamic compaction measured data of finishing, analysis of of surface vibration, the tamping pit depth, click tamping is able to hit and dynamic consolidation depth of the relationship between the statistical law. Through the arrangement of measured data to construction site of the dynamic compaction, the dynamic compaction dynamic responses of the dynamic compaction was analysed, and the surface vibration, the tamping pit depth, the relationship of the statistical law between tamping energy and compaction strengthening depth by Zhang JiChao, P. W. Manyne etc. [8]-[9].The results by J.H.Wang etc. show that the duration of vertical vibration in the vibration caused by dynamic

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compaction is shorter than that in the radial direction, and it is pointed out that the higher the dynamic compaction energy level, the greater the amplitude of vibration, the faster the attenuation rate is[10].

However, due to the different engineering properties of various types of foundation soil, domestic and international research on the strengthening mechanism of dynamic consolidation, has not yet achieved satisfactory results. Through a soft foundation engineering reinforced soft soil subgrade by using the combined method of surcharging and dewatering preloading and dynamic consolidation, The relationship between the amount of compaction and the number of compaction, the attenuation law of dynamic compaction energy, the law of dynamic response, evaluation of the effect and influence of the reinforced earth fill foundation with dynamic compaction are studied.

II. FIELD TEST ON DYNAMIC CHARACTERISTICS OF DYNAMIC DRAINAGE CONSOLIDATION

2.1 Engineering background

Table 1 Stratigraphic distribution in the test area

Name	thickness /m	Formation characteristics
①2 fine sand	4.4~6.4	Yellowish gray, wet~saturation, loose~slightly dense, the poor grain and the bad gradation, containing a small amount of clay in local, a small amount of shell fragments, Partial area distribution.
①4 silt (mixed sand)	0.19	Gray, saturated, flow plastic, mixed more fine sand, only local area revealed;
②1 silt (mixed sand)	0.22~0.37	Gray, saturated, flow plastic, mixed more fine sand, only local area revealed;
④1 silt~mucky soil	6.94~11.3	Gray, saturated, flow plastic, the soil is relatively pure, with a small amount of fine sand and shell broken, the formation of a wide range;
④2fine sand	0.27~0.37	Gray, saturated, loose, the poor grain and the bad gradation, with a small amount of fine sand and shell broken, local area distribution;
⑤1 clay	1.56~5.66	Gray, saturated, soft plastic~ plastic, the soil is relatively pure, with more fine sand, the formation of a wide range of distribution;
⑤2 clay ~ silty clay	1.1~9.9	Grayish white, pale yellow, saturation, plasticity, and local hard plastic, the soil is homogeneous, partially with a small amount of fine sand, stratigraphic distribution over a wide range.
⑤4 fine sand	0.33~1.9	Gray, saturated, loose, poor particle size, mixed more muddy soil, local with a small amount of humus, local area distribution;
⑤6 medium coarse sand	0.74~1.7	Gray, saturated, slightly dense, well particle size distribution, subangular, see a small amount of fine gravel, containing more clay, local area distribution;
⑤7 medium coarse sand	1.4	Gray, gray, saturated, mediate-dense~ dense, well particle size distribution, with more local clay, widely distributed;
⑥1 coarse gravel sand		Yellow color, saturation, density, well particle size distribution, subangular, mixed a small amount of clay and a small amount of fine gravel, reveal the local area.

In Shantou Municipal infrastructure construction projects of soft ground treatment engineering test section using the combined method of surcharging and dewatering preloading and dynamic consolidation, the soft soil subgrade was reinforced soft soil subgrade. The main site of formation treatment as shown in Table 1.

Site construction：First leveling, backfill sand; Then the driving plastic drainage plate and the site layout of dewatering wells along the center line and cut-off wells around the field; Then the first stage preloading, two times of universal compaction and two times of point compaction after the first stage preloading, the second stage preloading, the third universal compaction and point compaction and universal compaction after the second stage preloading, finally vibration rolling.

The dynamic characteristics test of dynamic compaction is carried out after the construction of the first stage preloading (surcharged 2.5m) of the site. Rammer diameter is 2.4m, Rammer weight is18.76t. The falling distance is 13.35m. The tamping energy is 2500kN.m. Rammer points are arranged by square with spacing4.5×4.5m.

2.2 Dynamic performance test of dynamic drainage consolidation

The test area is transformed into the grid of 4.5m×4.5m according to the dynamic compaction spacing, the grid node is the tamping point, and the acceleration vibration pickups are placed on the surface of the soil and the different depth of the ground surface. Main contents of field test for dynamic characteristic test are as followed:

(1) Test and law analysis of the settlement of the dynamic compaction points during dynamic compaction.

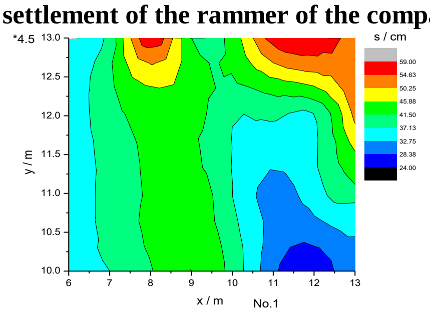
(2) The measurement of the acceleration time history curves: the vibration frequency is obtained by analysis of spectra, the significant influence range of the horizontal and vertical direction is obtained by time history curve analysis during the period of dynamic consolidation.

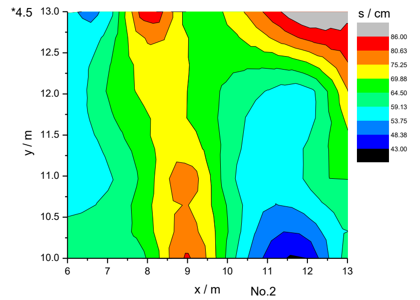
2.3 Test implementation

There is an acceleration sensor in horizontal and vertical direction, as shown in Fig. 8.3. According to the energy of dynamic compaction method, measurement range of the acceleration sensors is 20g and 50g, which is made in Qinhuangdao science and technology limited company. Signal gathering system G01USB32 is made in engineering mechanics research institute of earthquake bureau.

2.4 Dynamic Measuring Results analyses of dynamic compaction

2.4.1 The settlement of the rammer of the compaction





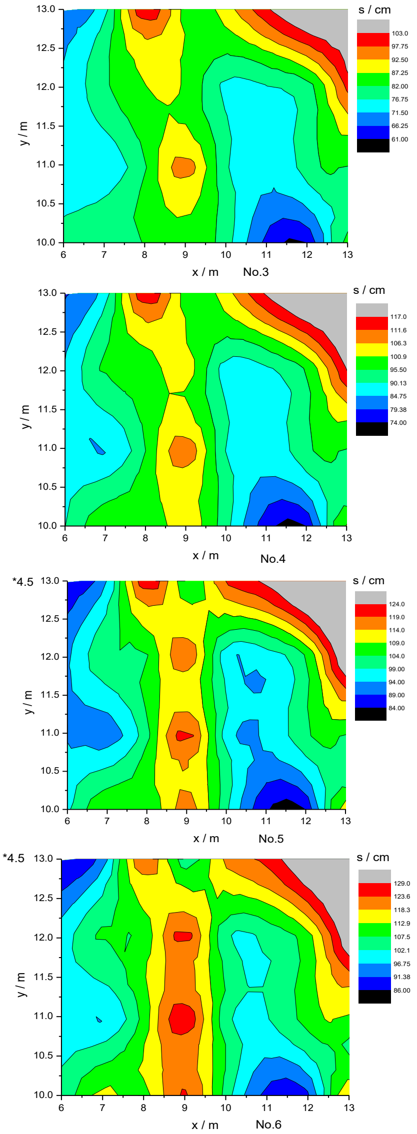


Fig. 1 The Cloud Picture between the accumulated settlement of the rammer s (cm) and the number of compaction(x)

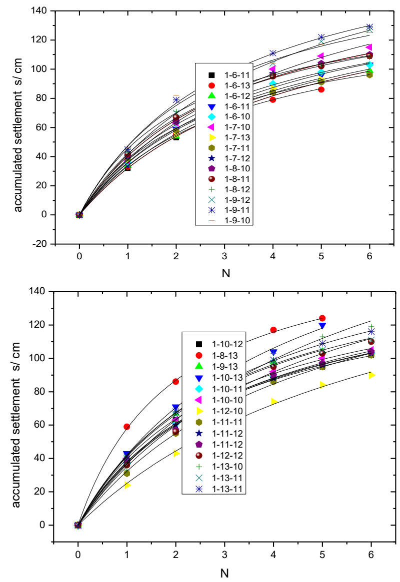


Fig. 2 The Fitting Curve between the accumulated settlement of the rammer s (cm) and the number of compaction(x)

Fig.1 is the Cloud Picture between the settlement of the rammer s (cm) and the number of compaction(x), and Fig.2 is the Fitting Curve between the accumulated settlement of the rammer s (cm) and the number of compaction(x). The fitting function is a hyperbolic function through the origin:

$$s = \frac{P_1 x}{P_2 + x} \tag{1}$$

In where, s is the accumulated settlement of the rammer, cm; x is the number of compaction; P_1、P_2 are the fitting parameters.

The correlation coefficient of the fitting curve except for the individual measurement points is greater than 0.99. The fitting degree of the measured point and the fitting curve is very good. The accumulated settlement of the measured point is increased with the tamping number as the form of the hyperbolic function. The limit value of fitting curve (P_1) of each measuring point is between 158.8- 231.2, and P_2 is between 1.99- 6.82.

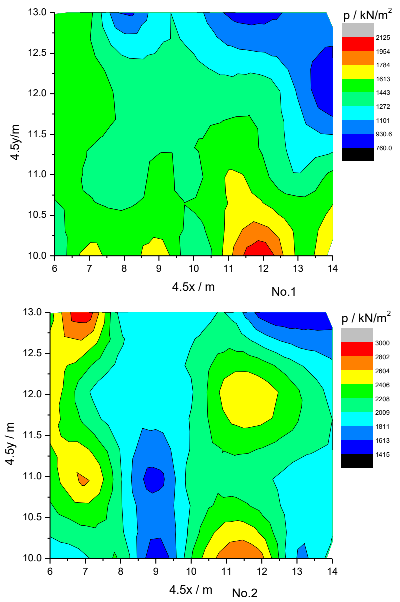
2.4.2 The resistance of soil layer

The soil resistance is the ability of the soil layer to resist deformation, which defined as the unit settlement of the rammer to complete is required single compaction energy on the unit area. Unit: kN/m^2.

$$p = \frac{E}{AS} \tag{2}$$

where, p is resistance to deformation of soil layer, kN/m^2; E is single compaction energy, kN.m; A is the bottom area of Rammer, m^2; S is the accumulated settlement of the rammer, m.

Fig. 3 is the Cloud Picture of the resistance of soil in the test area. The greater the resistance value p of the soil layer, the greater the ability of the soil layer to resist deformation; and of the soil layer is compacted under the hammer, the ability to resist deformation of the soil layer is strengthened. The uniformity of the soil layer can be measured by using the soil resistance parameters of the last hammering. is between 760.5-2123.2 in No. 1; p is between 1498.7- 2830.6 in No. 2; p is between 2123.142- 6369.427 in No. 3; p is between 2547.771- 6369.427 in No. 4; p is between 2316.155- 8492.5697 in No. 5; p is between 7279.345- 10191.087 in No. 6. The resistance of the soil layer increased gradually with the increase of the number of compaction.



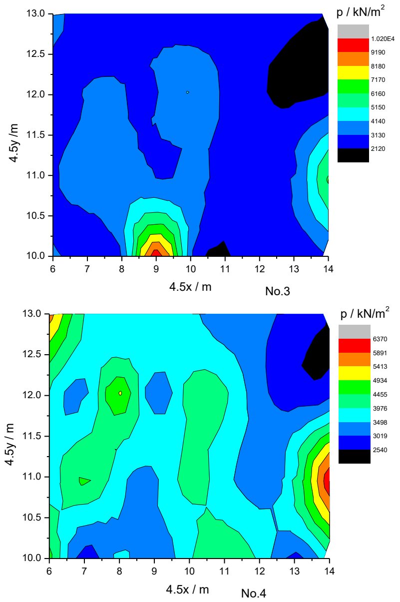


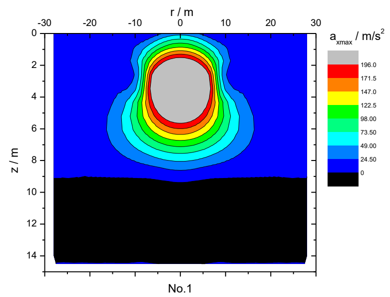
Fig. 3 The Cloud Picture of the resistance of soil in the test area

2.4.3 Vibration Acting Time and Main Frequency Caused by Dynamic Compaction

When energy level is 2500kN•m, the vibration caused by the dynamic consolidation of soft ground is similar to the blasting vibration. The vibration acting time lasts very short. Vibration acting time depends on the distance between rammer point and measuring point, soil properties. The horizontal vibration acting time out of the individual measuring points is greater than the vertical vibration. The vibration acting time increases with distance between rammer points and measuring, but the increasing amplitude is not large. The acting time of vertical vibration is at 0.19-0.6Sec, and that of horizontal vibration is 0.252-0.854Sec.

The frequency of vibration is mainly determined by the soil property between the measuring point and the tamping point, the horizontal vibration frequency and the vertical vibration frequency have no obvious rule. The average frequency of vertical vibration is greater than the average value of the horizontal vibration frequency. When z=0m, the horizontal vibration frequency is 8.74-14.503Hz and its mean value is10.72Hz, the vertical vibration frequency is 7.51-19.17Hz and its mean value is 12.81Hz measured, and the average value of the vertical vibration is greater 19.5% than the horizontal vibration. When z=3.0m, the horizontal vibration frequency is 6.51-16.84Hz and its mean value is 9.96Hz, the vertical vibration frequency is 5.85-13.73H and its mean value is10.13Hz, and the average value of the vertical vibration is greater1.7% than the horizontal vibration. When z=9.0m, the vibration frequency is 6.77-19.5Hz and its mean value is 12.61Hz. When z=14.5m, the vibration frequency is 8.22-14.5Hz and its mean value is 11.88Hz.

2.4.5 Peak Acceleration Results



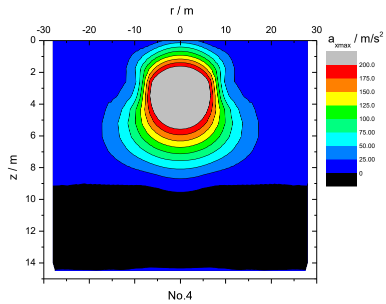


Fig.4 The cloud images of the horizontal peak acceleration in the test area (plane rz)

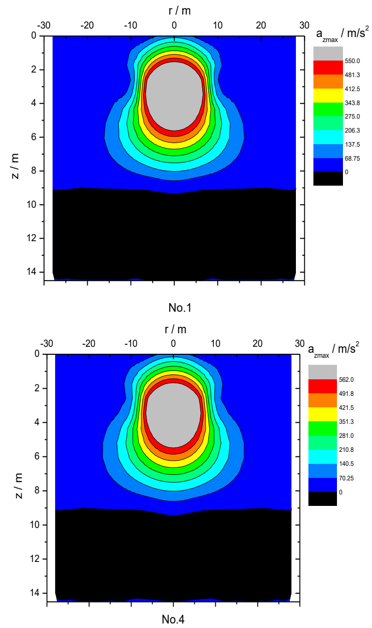


Fig.5 The cloud images of the vertical peak acceleration in the test area (plane rz)

Fig.4 and Fig.5 are the cloud images of the peak acceleration at the different depth in the test area. From Fig.4 and Fig.5, the vertical peak acceleration is greater than the horizontal peak acceleration, the ratio between the vertical peak acceleration to the horizontal peak acceleration is 1.3-5.0. Since the measuring point is not below the bottom of the Rammer, the acceleration peak value of the ground surface is not the maximum value, and the peak value at 3m of the earth's surface reaches the maximum value. When the distance between measuring point and tamping point is 7.4m, the measured maximum horizontal acceleration is 199.9m/s^2, and vertical acceleration is 561.0 m/s^2, the ratio of the vertical acceleration to horizontal acceleration is for 2.81.When the distance between measuring point and tamping point at 3m of the earth's surface is 27m, the measured maximum horizontal acceleration is less than1.9m/s^2. When the distance between measuring point and tamping point at 9m of the earth's surface is 7.4m, the measured maximum horizontal acceleration is 2.0m/s^2, and the distance is 27m, the measured maximum horizontal acceleration is less than 2.0m/s^2.When the distance between measuring point and tamping point at 14.5m of the earth's surface is 7.4m, the measured maximum horizontal acceleration is 1.90m/s^2, and the distance is 27m, the measured maximum horizontal acceleration is less than 0.4m/s^2.

From Fig.4 and Fig.5, it is clear that the attenuation of the peak acceleration of the soil layer to the depth of the soil layer. The effect of dynamic compaction is equivalent to that of a large dynamic load produced in the soil layer, and the load is a body force, its value is the product of the density of the soil mass and acceleration of the soil mass, the acting time of dynamic loading is very short. Under the dynamic load, the excess pore water pressure is generated in the soil layer, the excess pore water pressure is dissipated, and the consolidation of the soil layer is made.

III. CONCLUSION

The effect of dynamic compaction is equivalent to that of a large instantaneous body force in the soil layer. Under the dynamic load, the excess pore water pressure is generated in the soil layer, the excess pore water pressure is dissipated, and the consolidation of the soil layer is made. The dynamic performance test of dynamic compaction is made in this field, and the following conclusions are obtained.

(1) The cumulative settlement of the point compaction is increased as hyperbolic function $s = P_1 x / (P_2 + x)$ with the increase of the number of compaction, and its limit value is equal to the maximum settlement. Fitting parameter P_1 in the test site is at 158.8-231.2, and P_2 is at 1.99-6.82.

(2) The soil resistance is defined as the unit settlement of the rammer to complete is required single compaction energy on the unit area. The greater the soil resist, the greater the ability to resist deformation. With the increase of the tamping number, the compaction of the soil layer under the hammer, the ability to resist deformation of the soil layer is enhanced. The uniformity of the soil layer can be measured by using the soil resistance parameters of the last Rammer.

(3) When energy level is constant, vibration acting time depends on the distance between rammer point and measuring point, and soil properties. The horizontal vibration acting time is greater than the vertical vibration. The acting time of vertical vibration is at 0.19-0.6Sec, and that of horizontal vibration is 0.252-0.854Sec.Vibration main frequency depends on the soil properties between the measuring point and the tamping point, the horizontal vibration main frequency is less than the vertical vibration frequency. The horizontal vibration main frequency is at 5.76-14.5Hz, and the vertical vibration frequency is at 7.51-19.26Hz.

(4) The vertical peak acceleration is greater than the horizontal peak acceleration, the ratio between the vertical peak acceleration to the horizontal peak acceleration is 1.3-5.0. The peak value at 3m of the earth's surface reaches the maximum value. When the distance between measuring point and tamping point is 7.4m, the measured maximum horizontal acceleration is 199.9m/s^2, and vertical acceleration is 561.0 m/s^2, the ratio of the vertical acceleration to horizontal acceleration is for 2.81.

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