The 2016 World Congress on
Advances in Civil, Environmental, and Materials Research (ACEM16)
Jeju Island, Korea, August 28-September 1, 2016

Research on High Filled Foundation Compaction Method in Mountainous Airport

*Yan-peng Zhu[1)], Zhan-bin Shi[2)] and Xiao-hui Yang[3)]

[1), 2), 3)] *Key Laboratory of Disaster Prevention and Mitigation in Civil Engineering of Gansu Province, Lanzhou University of Technology*

ABSTRACT

Recent years, the airport construction in Western China has entered a peak period, thus many high filled foundation treatment issues appeared due to the terrain constraints. In order to obtain the optimal tamping times and reinforcement depthand evaluate the effect of the reinforcement with the method of dynamic compaction in the aspect of foundation reinforcement in the area ofmountainous airport, three energy levels of the tests with 2000kN·m, 3000kN·m and 4000kN·m have been carried out.The results showed that the optimal number of dynamic compaction of the original ground with 2000kN.m, 3000kN·m, 4000kN·m compaction tamping are 10, 13 and 15 respectivelyand the effective reinforcement depth were 4 m, 6 m and 8 m, respectively. For the fill area: the compaction level should be 2000kN·m when the thickness of silty clay is less than 2m;the compaction level should be 3000kN·m when the thickness of silty clay is 4~6m;and if the thickness of silty clay is greater than 6m, the compaction level of 4000 kN·m should be selected. Dynamic compaction method is the most common and effective method for foundation treatment in mountainous areas, which is better and more practical in construction.

1. INTRODUCTION

The method of dealing with high filled foundation soil is mainly in the means of dynamic compaction and rolling compaction (impact roller compaction and vibration roller compaction).The dynamic compaction method in foundation reinforcement settlement deformation control is the mostcommonly used and economical method in Chinaat present.Dynamic compaction method is often used to reinforce the gravel, sandy soil, cohesive soil, miscellaneous fill soil, collapsible loess and other kinds of foundation soil,whichhas the advantages of simple equipments, fast construction speed, wide applicable scopeand alsois economically feasibleand effective.

From different point of view ,many domestic and foreign scholars analyze the mechanism of dynamic compaction (especially the development to fdynamic

[1)] Professor, mail: [1)] zhuyp@lut.cn
[2), 3)] Graduate Student

compaction and dynamic compaction vibration and its impact on environment).Some useful conclusions and suggestions is formed in that way. Zhou Jian etc.(2007).Put forward a method that can determine parameters such as the spacing of tamping points, tamping times, effective reinforcement depth, interval of twicecompaction by using the experiment.

Cai Yuan-jiang.etc.(2006) analyzed consolidation mechanism and vibration impact on the environment by usinglarge deformation geometrical nonlinear finite element method.

According to successful implementation of the ground vibration real-time acceleration monitoring and analysis in a coastal gravel field dynamic compaction construction, He Li-jun.etc.(2006), obtained the acceleration attenuation of the gravel soil and propagation characteristics of dynamic compaction construction, and realized the dynamic design and information-based construction to ensure the smooth progress of the project. Ding Zhen-zhou.etc.(2006)based on the imbalance filler particles,poor graduation and large pore characteristics of the backfill subgrade in mountainous areas through theory and practices analysis, conclude that block gravel filling foundation dynamic compaction shock wave is asymmetric, scattering and time varying of its boundary, etc.

In combination with gravel backfill foundation reinforcement construction examples in southwest mountainous aeras, GuoWei-lin.etc.(2005) analyzed the feasibility of the dynamic compaction method in foundation treatment under this complex geology condition, and alsoanalyzed some problems such as the soft soil improvement of original groundin the mountains foundation treatment engineering, yard drainage and lap and isolation measures between dynamic compaction filling body and artificial slope.Huang Tao etc.(2007)analyzed mechanism of using dynamic compaction to control high fill settlement and deformation in amountain airport ground foundation treatment construction, which pointed out that using dynamic compaction method, fill layer of consolidation pressure can be accelerated, and the time for preloading can be shorten

Previous studies of dynamic compaction construction mainly focused on the impact on the surrounding environment, characteristics of dynamic compaction wave, the single packingeffect, the determination of the distance between the tamping points andother parameters, such as the determination. But comparison of the reinforcement effect of dynamic compaction under different impact energy level is relatively rare.

In the article, based on a mountain airport construction project, by adopting three kinds of dynamic compaction energy (2000 kN • m, 3000kN • m and 4000kN • m) to compare trial tamping, the author get the optimal number of tamping times and reinforcement depth and effect assessment under different energy levels

2.Experimental study on the method

2.1Geological conditions

According to geological exploration report, the engineering geological conditions r from top to bottom as shown in Tab.1:

Tab.1 Geological conditions of the test area

Name of soil layer	Depth of soil layer （m）	Thickness of soil layer （m）	Soil characteristics
The filling layer	0 ~ 2.30	0.10 ~ 2.30	Yellow brown ,Uneven, mainly composed of cultivated soil, containing a lot of humus and plant roots in the surface, small amount of ginger lithogenic particles and rock debris in part ,slightly wet, slightly dense
Silty clay layer	0.10 ~ 2.30	0.20 ~ 29.40	Brown-red brown, Uniform, slightly shiny, Moderate dry strength and toughness, plasticity and hard plastic, soft plastic with rich groundwater
Strongly weathered bedrock layer	0.10 ~ 30.20	3.00 ~ 5.80	Mud calcium cementation, huge thick layered structure of rock mass, clastic structure and massive texture of rock, microfissureand weathering fracture more development .Easy to soften contact with water, dense, The basic quality grade of rock mass is V
Medium weathered rock	4.00 ~ 34.00	1.20 ~ 46.80	Mud calcium cementation, huge thick layered structure of rock mass,clastic structure and massive texture of rock,microfissure, intermediary weathered sandstone , Easy to soften contact with water, dense, more rigid, The basic quality grade of rock mass is IV

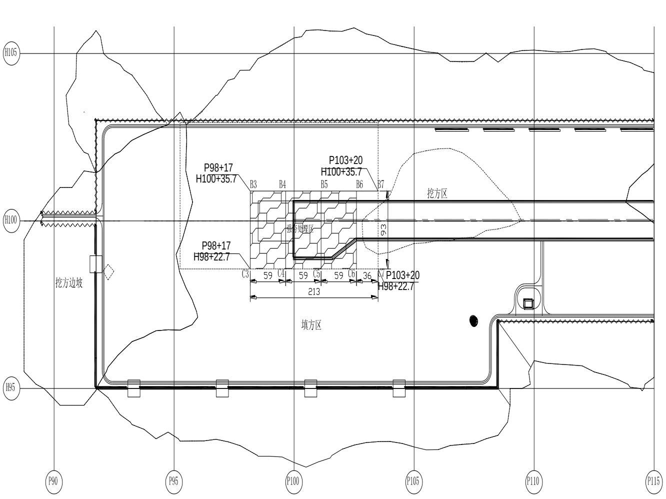
During investigation period (from February 2013 to March 2013), the buried depth of groundwater is 0.70 ~ 0.70 m Level elevation is between 1055.64 ~ 1119.66 m. Groundwater type is loose quaternary pore water distributedinthe low areas of the valley so both sides of the mountain ridge runway have distribution.

2.2testing program

Thedynamic compaction test area is located in the west side of channel slot and the blast pad.

According to silty clay thickness and its dry density from the detailed survey report and due to the original foundation treatment for channel slot area and soil surface area require different compaction degrees and treated separately, the foundation treatment test range is divided into three zones (T1: B3B4C3C4 is 2000 kN•m energy level dynamic compaction area; T2: B4B5C4C5 is 3000 kN•m energy level dynamic compaction area; T3: B5B6C5C6 is 3000 kN•m energy level dynamic compaction area), as shown inFig.1.

When dealing with dynamic compaction, it needs twice point compaction and one full compaction. For the first time and second time, compaction points should be staggered, and the space between the compaction points is 4×4m. Tamping timesare greater than 10. The final average damp subsidenceis differentaccording to the different partitions. The specific parameters are shown in Tab.2. Every time after tamping, the soil samples are got from the pit to test its compaction effect. After the completion is accomplished, soil samples are got under the pit and from exploratory well between tamping pits to test its compaction effect. Single tamping observation spot for land uplift is shown in Fig. 2.



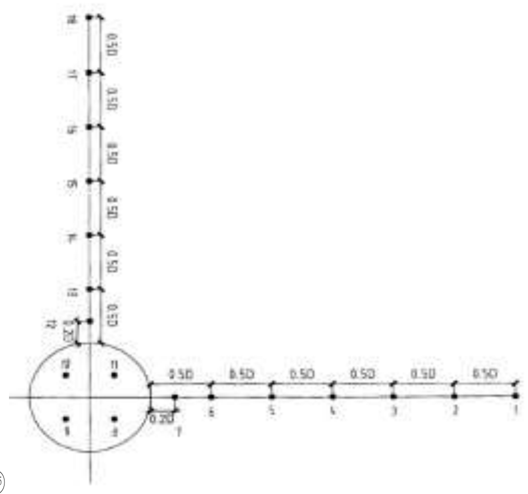


Fig.1 Test partitionFig.2The arrangement of surface uplift observation point

Tab.2 Dynamic compaction process parameter list

Test partition		area T1	area T2	area T3
Main tamping	Single point compaction energy	2000kN•m	3000kN•m	4000kN•m
	Tamping point spacing	4m		
	Number of times of compaction	2		
	Form of dynamic compaction	Grid layout		
	Number of compaction	≥10	≥13	≥15
Full tamping	Dynamic compaction energy	1000kN•m		
	Tamping point spacing	1/3Hammer seal lap		
	Number of times of compaction	1		
	Number of compaction	2~3		

Close compaction standard	The average of the last two strikes	≤5cm	≤7cm	≤9cm

3.Test and effect assessment

3.1 Field trial ramming test section

Before construction, in order to ensure the rationality and feasibility of the test program, in combination with the actual situation and geological survey report, three experimental plots are chosento carry out the trial ramming test in turn. The tamping energy are respectively, 2000, 3000, and 4000 kN•m. After the first two tamping are completed, the samples are taken from ram pits.

Researching on construction and analysis of dynamic compaction test of three partitions in turn, and make sure filling water content is the optimal water content during the construction of the. Padding is processed withpoint tamping optimal water content and full tamping once. For point tamping, each energy level of tamping points, tamping times, the subsidence quantity of each time, subsidence of pit, uplift of surrounding soil and data from buried measured pointsare record. Besides, the scope and degree of tamping vibration should be paid attention.

After completion of local compaction, full compaction should be carried out.

1) after local compaction construction completed, till pore water dissipates to the design requirements, full compaction should be carried out; 2) the full compaction construction main reinforce the soilbetween the tamping rammer up above the bottom part of the rammer earth; 3) full compaction construction generally uses 1/3 full diameter hammer two-way overlap, the tamping times, clicks of per pointshould be ensured and not be leaked.At last,considering rebound quantity around the pitsunder different tamping energy and the changes of damp subsidence, the result are analyzed.

(1)T1 area 2000 kN·m compaction test

In the region, the tamping points distance is 4 m, weight of rammer is 26.8 T and the drop distance is 8.5 m. Two spring back uplift observation point is set in this area. The tamping times are 10 ~ 13 times. The springback quantity issmaller of those observationpoints, and the maximum uplift quantity is 6 cm and 6.5 cm. The total sedimentation volumeof1sttamping point is 174 cm. The total sedimentation volumeof1sttamping point is 194 cm. Details are shown in the chart below:

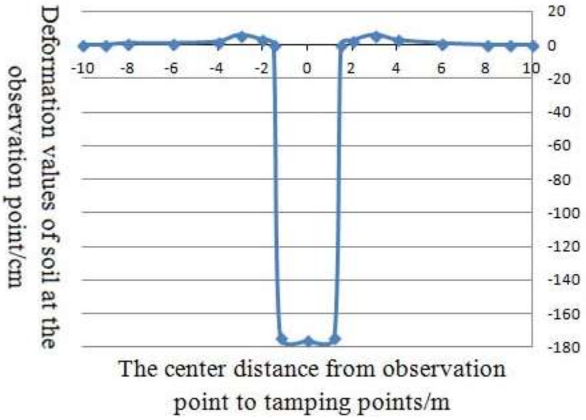


Fig.3 The curve of the ground soil uplift at tamping point 1

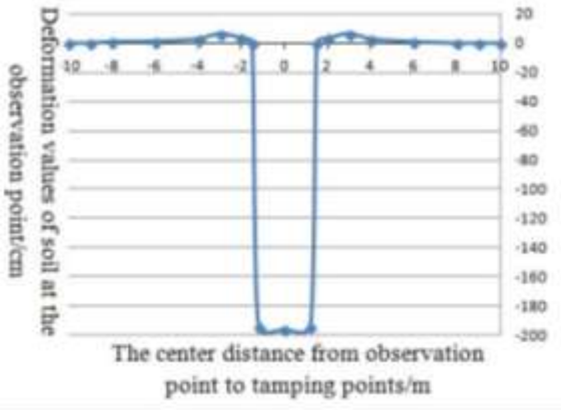


Fig.4 The curve of the ground soil uplift at tamping point 2

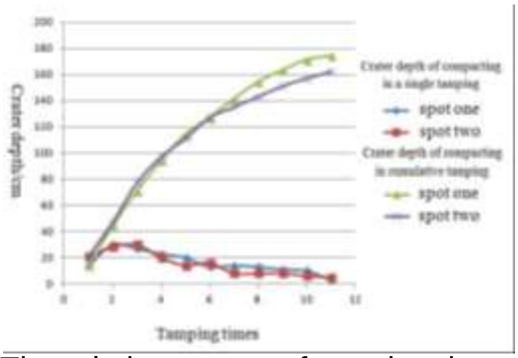


Fig.5 The relation curves of tamping times and settlement of dynamic compaction

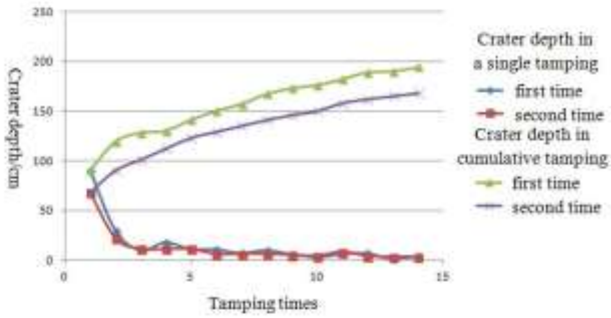


Fig.6 The relation curves of tamping times and settlement of dynamic compaction under 2000kN·m

What shown above is relation curve of tamping points and damp subsidence quantity of those two tamping point. After analysis and data processing, post-statistic relation curve of tamping points and damp subsidence quantity is given in 2000kN tamping test.

Through the experimentsabove, it is concluded that the ideal tamping number of 2000kN • m is 11 ~ 13 times and the soil around tamper pit has small springbackvale as well as small cracks. For the last two tamping, average damp subsidence is control to 5 cm.

(2) T2 area 3000kN·m compaction test

Two spring back uplift observation point are still set. The tamping times is control to 14 ~ 16 times. The spring back around pit and cracks is obvious. The maximum uplift valueis10 cm and 10.5 cm.

The total sedimentation volumeof1sttamping point is 174 cm. The total sedimentation volumeof1sttamping point is 194 cm. Details are shown in the chart below:

When 3000kN•m level trial tamping, for the last three tamping of 14 ~ 16 times tamping set, the tamping subsidence value is less than 7 cm. the rammer is slant (pit wall is incomplete).For the first time, average dry density of the pit soil sample is about 1.75 g/cm3 and average compaction coefficient is 0.92; For the secondtime, average dry density of the pit soil sample is about 1.80g/cm3 and average compaction coefficient is 0.94.

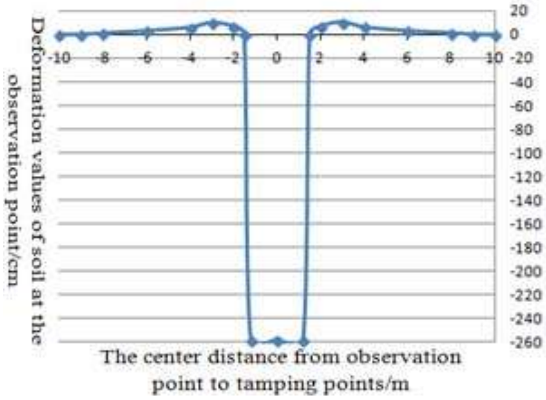


Fig.7 The curve of uplift around the pit at tamping point 1 inarea T2

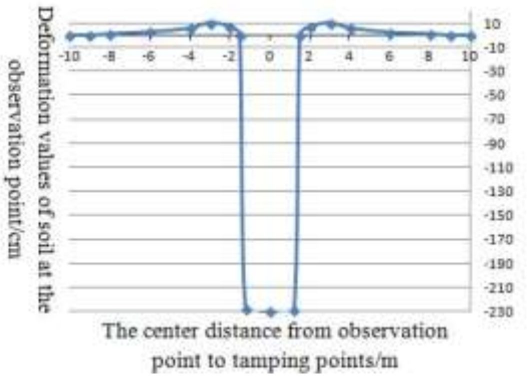


Fig.8 The curve of uplift around the pit at tamping point 2 in area T2

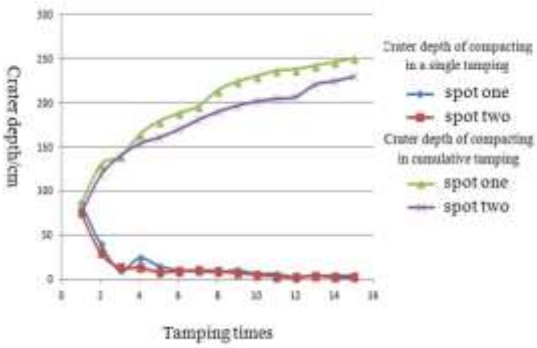


Fig.9 The relation curves of tampingtimes and settlement of dynamic compaction

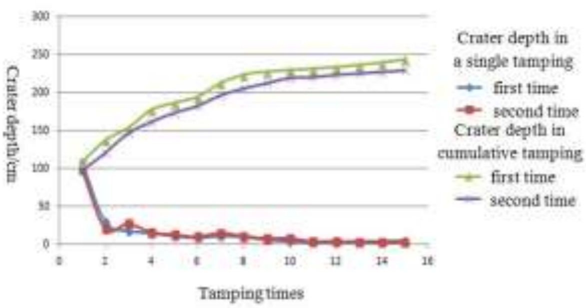


Fig.10 The relation curves of tamping times and settlement of dynamic compaction under 3000kN·m

(3)T3 area 4000 kN·m compaction test

Two spring back uplift observation point are still set. The tamping times iscontrol to 17 ~ 19times.Thespringback around pit and cracks is obvious.The maximum uplift valueis13 cm and 12.5 cm.

The total sedimentation volumeof1sttamping point is 190 cm. The total sedimentation volumeof1sttamping point is 194 cm.

Details are shown in the chart below:

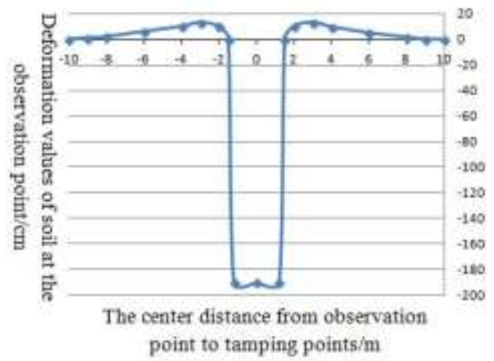


Fig.11 The curve of uplift around the pit at tamping point 1(The first time

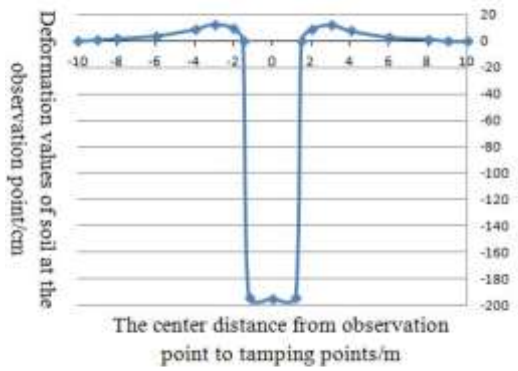


Fig.12 The curve of uplift around)the pit at tamping point 2(The first time)

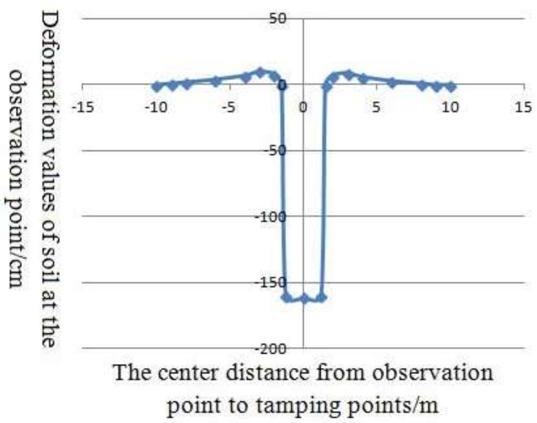


Fig.13 The curve of uplift around the pit at tamping point 1(The second time)

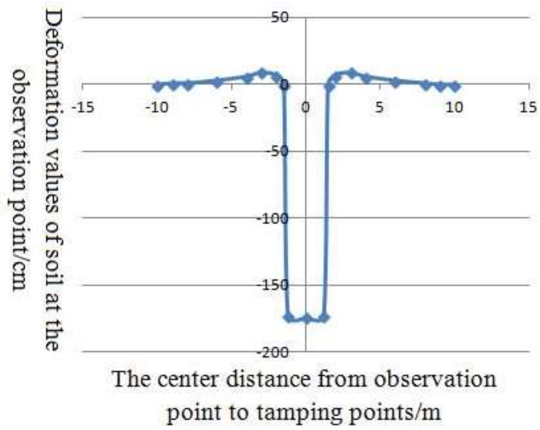


Fig.14 The curve of uplift around the pit at tamping point 2(The second time)

As shown in picture, after secondary backfill dynamic compaction, the uplift of the soil around the pit has been reduced and there is no obvious abnormal phenomenon. Tamping times should be controlled during the construction reasonablyto complete the projectmore efficiently. What is given below is the 4000 kN•m energy level ration curve of the tamping subsidence and tamping times,

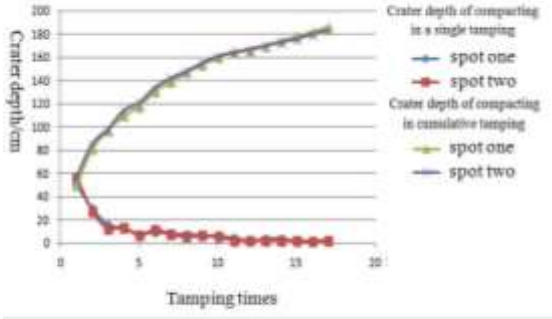


Fig.15 The relation curves of tamping times and settlement of dynamic compaction

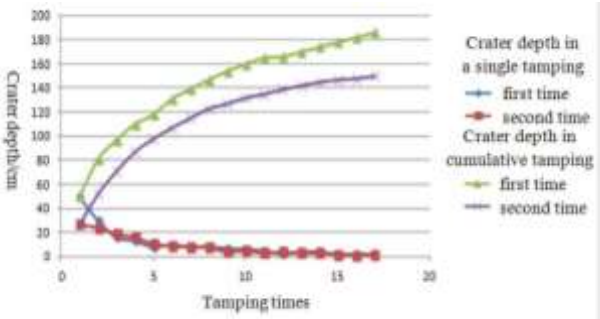


Fig.16 The relation curves of tamping times and settlement of dynamic compaction under 4000kN·m

When4000kN•m level trial tamping,forthe last three tampingof 17~19times tampingset, the tamping subsidence value is less than 9 cm. The averagecompacting factor is 0.94.

The results show that for the original foundation, the best tamping compaction times of 2000 kN•m, 3000 kN•m and 4000 kN•mis 10, 13, 15 respectively.

3. CONCLUSIONS

3.1 Trial ramming effect assessment

Through relation curve of the number of single tamping and the tampingsettlement,the rammer curve almost have the same shape in all the experimental zones. In the early stage of dynamic compaction, settlement is bigger, but with the compaction continuing, gradually the curve become smooth.For the last three strikes, the settlement value barely changes.

Through the detailed observation and analysis of the experimental zone at both rammer points, experimental designed ram-stop standard is consistent with point tamping ram-stop standard average ram sink in the last two strike, which also suggests that ram-stop standard of dynamic compaction follows also meets the requirements.

Spring back and uplift values by observation around the pit in all experimental zones are under control and there is no obvious abnormal situation, whichalso suggests that within the required ramming times, tamping effect is good.

Overall, the dynamic compaction test has guiding .According to the specific construction condition, if it has anyproblems,itshould be discussedin time.

After the completion of the final trial ramming, exploratory well should be set in ram pit and between the pits in order to test compaction effect of the soil samples, test results are shown in Tab.3 to Tab.5.

Tab.3 The original foundation compaction contrast list before and after dynamic compaction under 2000kN·m

direction	depth (m)	Before tamping		After tamping: Hammer Center		After tamping: The hammer between	
		Moisture content (%)	Compaction factor	Moisture content (%)	Compaction factor	Moisture content (%)	Compaction factor
N	1	17.18	0.88	16.11	0.98	19.88	0.89
	2	21.26	0.84	19.76	0.90	21.04	0.91
	3	18.9	0.86	20.34	0.91	18.87	0.93
	4	19.18	0.86	21.12	0.90	23.44	0.89
	5	22.53	0.86	22.76	0.86	22.85	0.86
S	1	16.51	0.91	15.66	0.98	18.53	0.86
	2	21.46	0.82	19.22	0.93	20.31	0.92
	3	16.47	0.90	19.58	0.93	19.18	0.94
	4	19.35	0.87	21.43	0.88	22.23	0.87
	5	23.00	0.85	23.36	0.85	23.71	0.85

Tab.4 The original foundation compaction contrast list before and after dynamic compaction under 3000kN·m

direction	depth (m)	Before tamping		After tamping: Hammer Center		After tamping	
		Moisture content (%)	Compaction factor	Moisture content (%)	Compaction factor	Moisture content (%)	Compaction factor
N	1	11.78	0.92	16.99	0.83	17.44	0.96
	2	19.33	0.88	17.45	0.97	18.90	0.93
	3	19.30	0.87	22.04	0.90	19.65	0.93
	4	21.96	0.86	19.54	0.93	29.69	0.78
	5	20.19	0.87	22.34	0.89	24.99	0.86
	6	21.01	0.87	21.36	0.87	22.32	0.86
S	1	14.96	0.88	16.24	0.84	17.95	0.95
	2	20.46	0.87	18.22	0.95	19.84	0.93
	3	20.50	0.88	13.33	0.98	20.1	0.91
	4	22.62	0.85	21.88	0.89	30.14	0.79
	5	20.66	0.86	22.88	0.91	24.73	0.87
	6	20.45	0.87	21.35	0.87	22.59	0.87

Tab.5 The original foundation compaction contrast list before and after dynamic compaction under 4000kN·m

direction	depth (m)	Before tamping		After tamping			
				Hammer Center			
		Moisture content (%)	Compaction factor	Moisture content (%)	Compaction factor	Moisture content (%)	Compaction factor
N	1	12.63	0.91	17.29	0.84	17.86	0.96
	2	18.31	0.88	16.53	0.96	18.92	0.94
	3	18.27	0.87	21.34	0.91	19.83	0.92
	4	20.76	0.86	19.17	0.95	28.11	0.77
	5	20.09	0.87	22.54	0.93	25.13	0.86
	6	21.01	0.87	22.62	0.91	24.12	0.86
	7	21.41	0.87	22.78	0.90	23.59	0.85
	8	21.32	0.86	21.59	0.87	21.92	0.85
S	1	14.96	0.88	12.76	0.86	18.33	0.95
	2	20.21	0.87	18.01	0.96	18.95	0.93
	3	20.33	0.87	14.13	0.97	20.16	0.91
	4	21.62	0.86	21.92	0.90	30.06	0.82
	5	20.48	0.87	22.98	0.91	24.93	0.88
	6	20.45	0.87	21.69	0.90	23.62	0.89
	7	20.36	0.86	21.03	0.90	22.74	0.88
	8	20.41	0.87	20.56	0.88	20.61	0.87

By analyzing of the data above we can see, after treating foundation soil with dynamic compaction,the void ratio and dry density increased. The shallow soil of foundation changes obviously, and it is getting wake gradually with depth. Compression moduli of foundation soil after processing has a larger degree of increase--from high compressibility into low compressibility and the foundation bearing capacity have been improved obviously. The ground surface moisture of soil that rammedspreads significantly and decreases, which leads to the moisture content of the soil between ram location sincreased. While with increasing depth, soil moisture content changes before and after tamping gradually decrease. For the original foundation, effective reinforced depth of dynamic compaction of 2000kN·m, 3000 kN·m and 4000kN·mis respectively 4 m, 6 m, 8 m. To the fill zone: silty clay thickness which is less than 4 m, dynamic compaction level should choose 2000 kN·m, the silty clay thickness which is 4 ~ 6 m, dynamic compaction level should choose3000kN·m, thickness of silty clay is more than 6 m, dynamic compaction level should choose4000kN·m.

4. Numerical simulationverification

Tab.6 Physico-mechanical properties of soil

Deformation modulus E_0（MPa）	Natural weight（kN/m^3）	Poisson ratiov	Cohesion C(kPa)	internal friction angle
10	17.2	0.30	10	15
40	18.7	0.25	15	24

For further research on the effect of dynamic compaction, with the aid of the finite element software MIDAS, three-dimensional analysis model is established. The soil constitutive model adopts the mohr-coulomb model and the concentrated load is transformed. Model size is 15 m x 15 m x 15 m. The soil parameters are shown in Tab.6. The boundary conditions is groundsupporting. 215 hexahedron unitsis formed. Deformation analysis is under nonlinear static.The influence of initial stress is not eliminated and basic parameters of soil are shown inTab.4.

The cloud picture of MIDAS software simulation is shown below. As the Fig.17 shows, when the tamping energy is 2000kN·m, the obvious boundary caused by tamping in the ground horizontal direction is about 5 m from rammer central point. The settlement of rammer heart point is about 2m, which is consistent with the test results inFig.3.

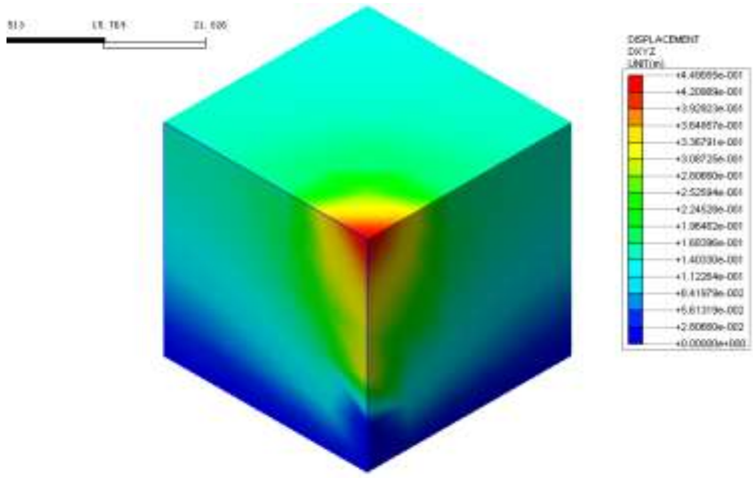


Fig.17 The strain contour of tamping soil under 2000kN·m

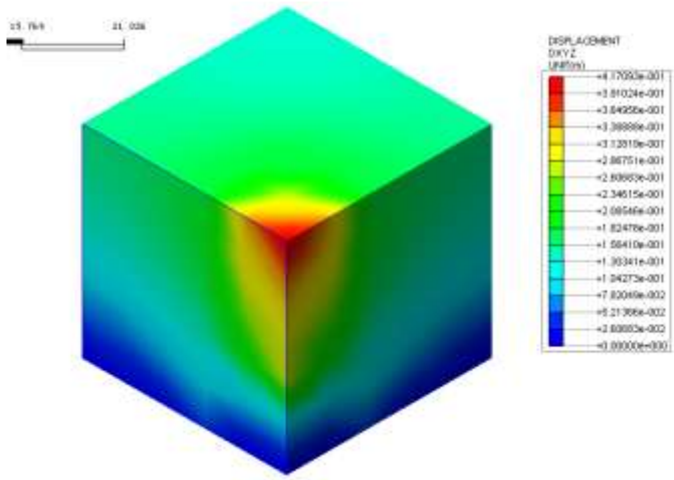


Fig.18 The strain contour of tamping soil under 3000kN·m

AsFig.18 shows, when the tamping energy is 3000 kN·m, the obvious boundary caused by tamping in the ground horizontal direction is about 8m from rammer central point. The settlement of rammer heart point is about 2.5 m,which is consistent with the test results in Fig.7..

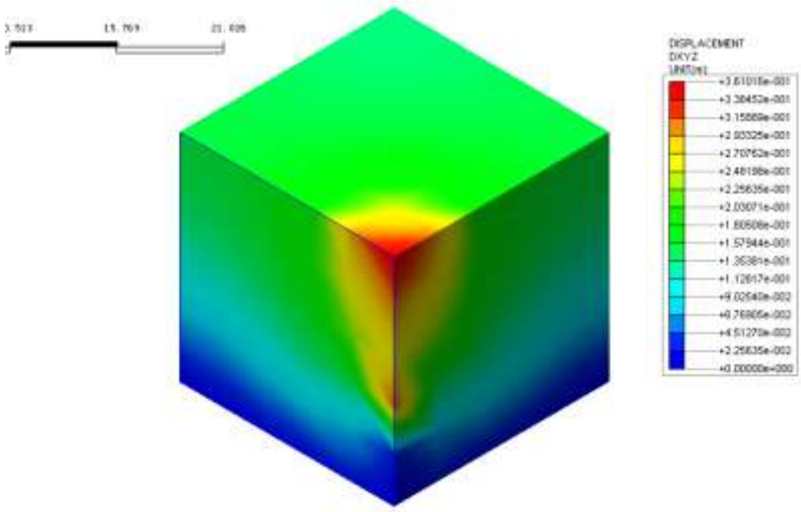


Fig.19 The strain contour of tamping soil under 4000kN·m

AsFig.19 shows, when the tamping energy is 4000 kN·m, the obvious boundary caused by tamping in the ground horizontal direction isclose to the top of the cloud picture, which means that is, the border is close to unit boundaries and it is about 15 m from rammer central point. While in the field test, the uplift boundary is 10 m from the rammer central point. It is seen that when the tamping energy is larger, the accuracy of the numerical simulation will be reduced.

5. Conclusion

(1)To fill zone, when the thickness of the silty clay is less than 4 m, dynamic compaction level is 2000 kN • m, the thickness of the silty clay 4 ~ 6 m, dynamic compaction is level 3000 kN • m, thickness of silty clay is more than 6 m, dynamic compaction is level 4000 kN, m. Compression modulus of foundation soil is improved largely.

(2)The single-point tamping test results show that for the original foundation, the best tamping timesis 10, 13, 15 for 2000 kN·m,3000kN·m,4000kN·mrespectively. Effective reinforcement depth is 4 m, 6 m, 8 m respectively.

(3) According to the result of trial ramming, with the improvement of dynamic compaction energy levels, although the effective processing depth increase,the required compactness or the number of stroke control standards in last three rammer heavy volume increases,resilience value and crack of pit increases accordingly, and it is go against the control of coefficient of consolidation of foundation soil.

(4) The MIDAS software numerical simulation is consistent of the field test results. It is capable to simulate deformationof the soil in the deflection of the horizontaland vertical direction more accurately and show the actual impact on the surrounding soil.

REFERENCES

Journal articles:

CaiYuan-qiang, Wang Da-li. and XuChang-jie. (2005), “Numerical analysis of dynamic compaction and environmentaleffect caused by the impacting vibration”,*J.Rock and Soil Mechanics*(26), 159-162.

GuoWei-linand An Ming.(2005), “Dynamic Compaction Treating Hight Backing Foundation Under the Conditionsof Hight Lands Complex Geomorphic Geologic Engineering”, *J.ConstructionTechology*.132-136.

HeLi-jun, ShuiWei-hou.andLiu Bo. (2006), “Monitoring and analysis of environmental vibration caused by dynamic compaction”, *J.Geotechnical engineering community.***9**(7), 87-90.

Huang Tao and Liu Hui.(2007), “Study on Mechanism of High Fill Settlement Controlled by Dynamic Compaction and Bedded-Earth Rolling”,*J.Journal of Southwest Jiaotong University,* **42**(2), 158-163.

Zhang Ping-cang,WangNian. (2000), “A study of dynamic consolidation depth in engineering practice”,*J.Rock and SoilMechanics*.**21**(1), 76-78.

Zhou Jian, Shi Da-dan,JiaMing-cai and Cui Ji-hong.(2007), “In-situ test study on low-energy dynamic consolidationmethod to improve a silty clay ground”, *Rock and Soil Mechanics*.**28**(11), 2359-2364.

Books:

Code for investigation of geotechnical engineering(GB/5O021-2001).

GanHou-yi,(1998), “On the foundation treatment of high fill engineering in Mountainous Areas”, *Building Science*.**14**(6), 16-22.

Wang Cheng-hua, (1991), “A review of methods for estimating the depth of reinforced foundation with dynamic compaction”, *J.FoundationTreatment.***2**(3), 20-24.

XuZhi-jun, (2004), “Strengthening foundation by dynamic compaction and dynamic consolidation replacement method”, 1-274.

Ye Guan-bao, Chen Wang-chun.andXuChao. (2003), “Analysisand Research on the effectivereinforcement depth of dynamicconsolidation method in foundation treatment”, *Shanghai Land & Resources.* (3), 22-25.

Journal articles:

Ding Zhen-zhou, Lu Xin. andZhengYin-ren. (2003), “Study on strengthening mechanism of dynamic consolidation in mountainous area”, *Proceedings of the Ninth Conference on soil mechanics and geotechnical engineering of China Civil Engineering Society ,*25-28.

Wang Zhong-qi and Deng Xiang-lin, (1983), “Mechanism of dynamic compaction and its environmental impact”, *The Fourth National Conference on soil mechanics and Foundation Engineering Symposium,Beijing*.