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ABSTRACT

Under the condition of tamping energy 975～1125 kN.m per blow with four kinds of typical tampers including the shock absorbed and assembled tamper (SAAT) designed by the first author, the tests of vibration acceleration and relative tamping settlement are carried out in situ during the improvement of mud ground with high water content and great void ratio by use of the static-dynamic drainage consolidation method (SDDCM); the synthetic safety distances satisfying the requirement of relative code (under seismic intensity grade 7) are obtained under the condition. The test results show that SAAT enhances the effect of SDDCM in evidence and diminishes vibration influence on surrounding environment obviously. Besides, the laws on initial contact between the tampers and ground, tamper rebound, impact secondary action and transmission of vibration acceleration produced by impacting are analyzed.

INTRODUCTION

Dynamic consolidation and the gradually developed Method of Static-dynamic Drainage Consolidation are getting wider application due to easy construction and comprehensive advantages in terms of effects, economy and time saving.[1-5] However, a task should be addressed before the method could gain wider application---massive stress wave occurred in soil during impacting will definitely cause the surrounding soil to vibrate, thus it will affect structures and environment in the vicinity of the site. A certain horizontal of effects will render this method unsuitable due to safety consideration. Therefore, it's of vital importance to effectively lower vibration impacts to periphery so that the method will gain further recognition and application.

A soft soil improvement site is located on Guangzhou petrochemical storage area. The total Area treated in the project No.1 is 186,000 m^2, the soft soil improvement area exclusive of public site is 149,000 m^2. Geological prospecting indicates that the site geological condition is very poor, with wide distribution of muck layer. The layer average thickness is 12.0 m; average water content is 75.0%, maximum 114%; average void ratio is 2.087, maximum 2.992. Top filling soil layer distribute unevenly, its thickness ranges between 0.0~0.2m, with heavy muck content. Also, this soft soil improvement has to be undertaken in rainy seasons in line with the urgent construction progress requirement. Method of Static-dynamic Drainage Consolidation is adopted to ensure project quality, progress and low price. This method organically combines fill static force (coverage load), dynamic load, residual force (caused by the previous loads and hetero-sphere of soils) and rapid drainage system to consolidate soft soil foundation, while process quality controlling, and impact point (space) quality controlling are emphasized. It will be discussed in detail in another paper for limited space here.

This paper describes work on the above soft soil improvement field with static-dynamic drainage consolidation method, which adopts moving tamping point i.e. shock source and measuring point to exam vibration acceleration of surroundings in tamping process, in an attempt to obtain horizontal and vertical vibration acceleration in various distance when various tampers impact the ground. Considering the above project background, using definition of seismic intensity and description of the relation between seismic intensity and corresponding horizontal and vertical acceleration in "Construction Anti-earthquake Design Codes of China" （GBJ-11-89）, relation between horizontal & vertical acceleration and tamping point (shock source) interval, and minimum safety distance can be obtained; Besides, tamper features to improve tamping effectiveness and reduce vibration effects to surroundings can also be sorted out by tests comparison.

TEST CONDITION

Equipment And Its Work Principle

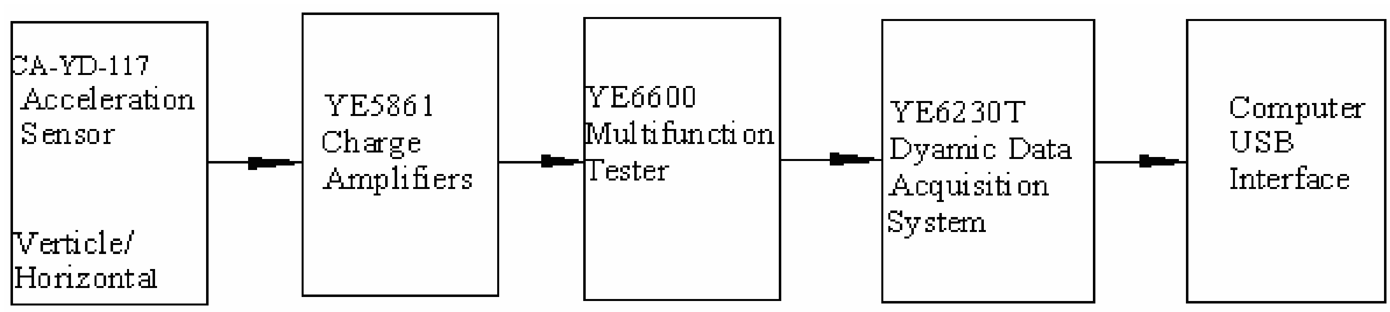


Fig.1 Test apparatus schematics

As is shown in Fig.1, the test system consists of Dynamic Data Collector (DDC) and a computer. The DDC is composed of CA-YD-117 Acceleration sensor (calibrated), YE5861 Programmable charge amplifier, YE6600 Multifunction Tester, and YE6230TCA-YD-117. Piezoelectric Accelerometer has a limit impact of 150g, frequency response of 0.2~3000 Hz, axial sensitivity of 50 PC/ms^{-2} (500 PC/g) , size at$\Phi 28\times 20$ (mm) . YE6230T Dynamic Data Acquisition System has 12 bit resolution, 8 channels, sample rate 100kHz/8CH (single channel maximum 20 kHz).

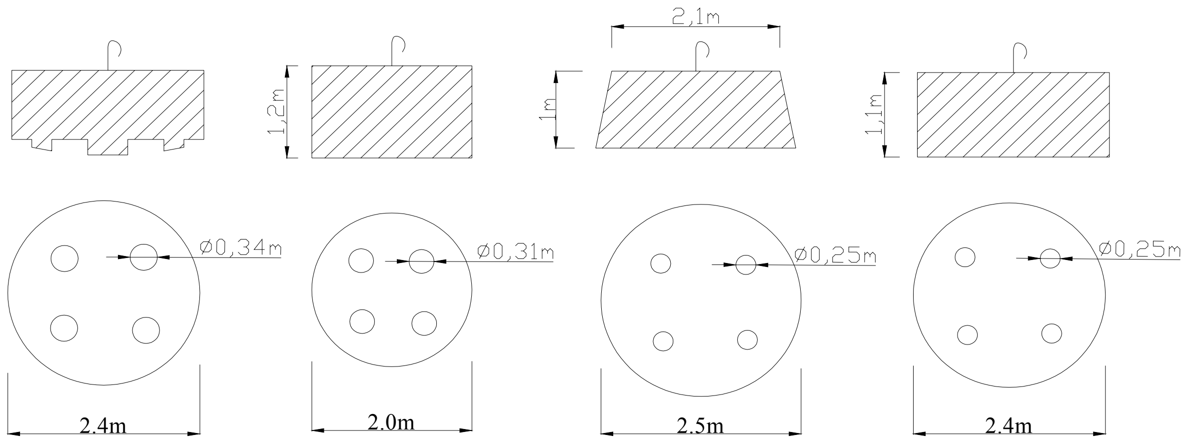
The test system works on the following principle: signals of the acceleration sensor get enlarged via YE5861 Programmable Charge Amplifiers, and then converted into voltage signal by YE6600 Multifunction Tester's automatic identification; YE6230T dynamic data collector, which is connected to a computer with USB interface, acquires data at a high speed. The data is then stored by collecting software under Windows system. Acceleration sensor is required to be fixed 10cm underground.

Related Project Condition At Test Site

Tank District 4 of a Guangzhou Petrochemical storage area Period I is selected as the test site. The district boasts of uniform geologic condition, with total area of 10370 m^2 (i.g.122 m × 85 m), muck layer average thickness at 11.5 m, other major physical nature are stated as above; The muck layer is topped with filling soil added 2~3 months ago, the average thickness of the filling soil is 1.5m; 1m sand cushion and 1m thick earth (the surface of which is 20cm powder layer) are covered up before tampering. The upper muck layer is set with blind ditches and catchments wells. After laying the sand cushion (before covering the thick earth), set plastic drainage board at a depth of 15.0m, with surface spacing at 1.4m. For the convenience of laying wire, it takes square layout. Tamping point spacing is 5.5m, square layout. Four types of tamper (Type A, B, C, D, specific parameters see Table 1) are used in the test.

Table 1: Parameters of the tampers

Tamper (Rammer)/ Type	Weight /T	Size /m	Holes	Drop height /m	Tamping energy /kN.m	blow number
A	15	Φ2.40, H1.10	4Φ340 mm	7.5	1125	2
B	13	Φ2.00, H1.20	4Φ310 mm	7.5	975	3
C	16	TopΦ2.1, BottomΦ2.5, H1.10	4Φ250 mm	6.5	1040	3
D	15	Φ2.40, H1.00	4Φ250 mm	6.5	975	3



tamper A **tamper** B **tamper** C **tamper** D

Fig. 2 Geometry characteristic of the tampers

Tamper A[7] (shock absorbed and assembled tamper(SAAT) invented by First Author of this paper, which has been licensed National Patent in Dec. 2003) consists of handle and hammer, with ventilation holes in it. At the center ground of the hammer there is a projected cylinder, surrounded by evenly distributed small projected cylinders at a height between the cylinder and center ground; nut and bolt are placed on top of the tamper to adjust weight.

TEST RESULTS AND ANALYSES

<u>Acceleration-Time Curve</u>

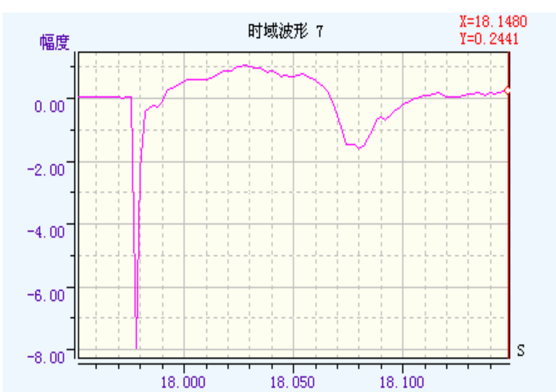


Fig. 3 Vertical acceleration-time curve (1st impact)

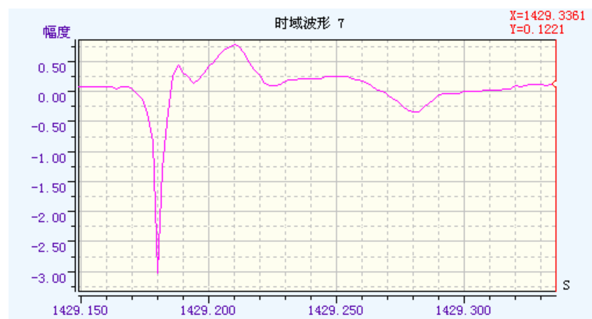


Fig. 4 Horizontal acceleration-time curve (1st impact)

Typical relationship between vertical/ horizontal acceleration and time at first blow of Tamper A in first tamping are shown in Figure 3 and 4. As is shown in the figures, shock and counteractive at the tamping moment lasts about 130ms, and the response can be divided into 3 stages:

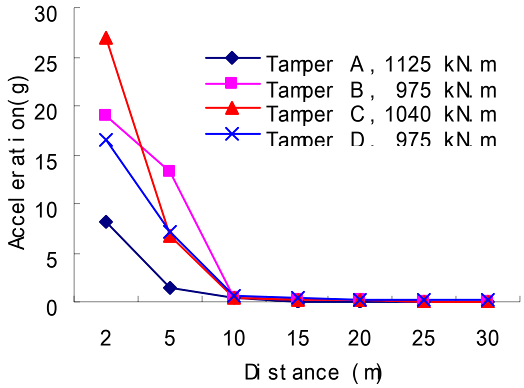
(1) First blow stage: During this stage, massive instant impact (amplitude far exceeds that of stage 2 and 3), vertical and horizontal acceleration times are 3ms and 10ms (less than 1/10 of total time) respectively, acceleration increases rapidly and reaches its peak, and the vertical value is about 2.67 times of the horizontal value; thereafter, due to resistance of the muck, tamper and muck still contact, but acceleration drops to the original value zero; the entire stage lasts about 15ms.

(2) Bounce back stage: Foundation vibrates vertically and horizontally, the tamper bounce back; this period is about 80ms, and the acceleration various slightly.

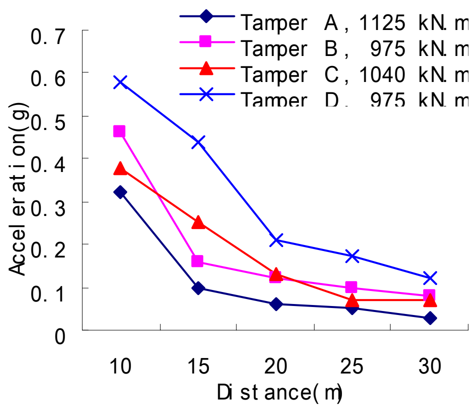
(3) Secondary impact of tamper: The tamper blows secondly to the foundation with about 35ms.

After the above 3 stages, very small amplitude vibration takes place.

Acceleration-Distance Changes

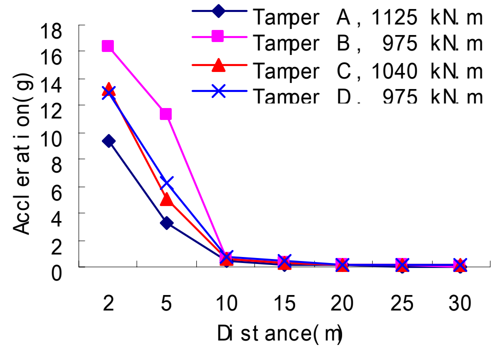


(a) Total (Complete) curve

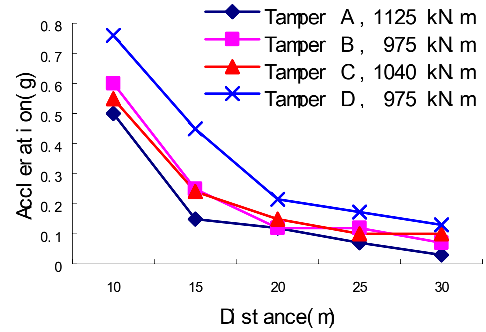


(b) 10-30 m curve

Fig. 5 Vertical acceleration-distance curve (1st impact)

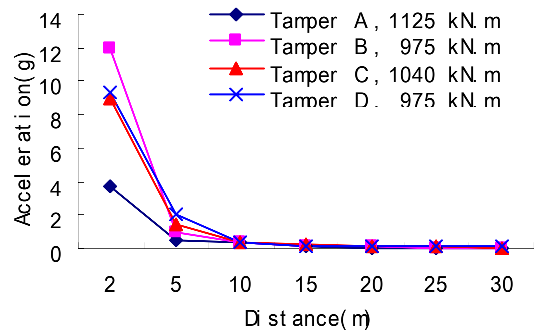


(a) Total curve

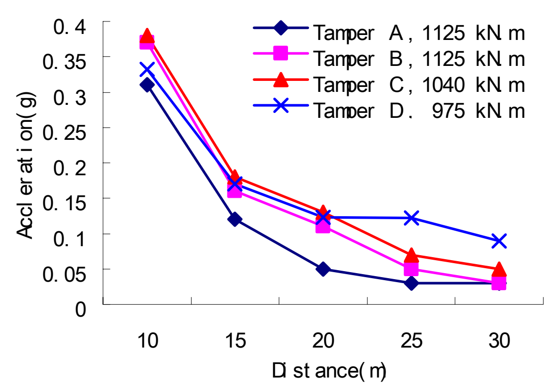


(b) 10-30 m curve

Fig. 6 Vertical acceleration-distance curve (2nd impact)

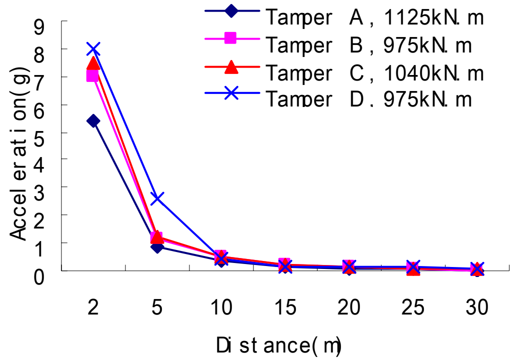


(a) Total curve

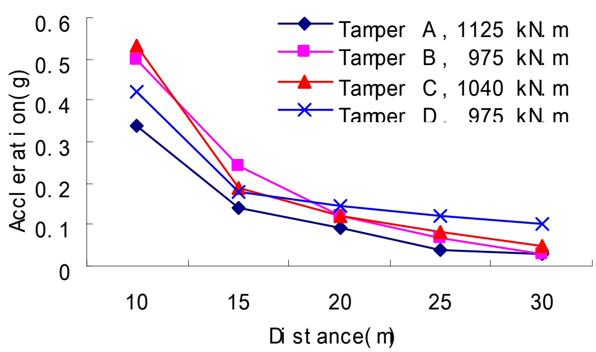


(b) 10-30 m curve

Fig. 7 Horizontal acceleration-distance curve (1st impact)



(a) Total curve



(b) 10-30 m curve

Fig. 8 Horizontal acceleration-distance curve (2nd impact)

As is indicated in the vertical and horizontal acceleration changes curves (according to tamping point distance) under impacts of different tampers in figure 5~ figure 8: There's a sharp decrease of vertical acceleration within 0~10m, and a slow decrease within 10~30m; as of horizontal acceleration, the respective distances are 0~5m and 5~30m. According to definitions in 《Construction Anti-earthquake Design Codes》 (GBJ 11-89), seismic intensity has the following connection with vertical and horizontal acceleration, see Table 2.

Table 2: Relation between seismic intensity and horizontal & vertical acceleration

Earthquake intensity	Horizontal acceleration /g	Vertical acceleration / g
9	0.4	0.8
8	0.2	0.4
7	0.1	0.2
6	0.05	0.1
5	0.025	0.05

Security distance should be identified by the protected structure's requirements. In terms of references [6 and 8], general industrial and civil buildings should resist 7 degree of earthquake, therefore corresponding substructures should withstand the same degree of earthquake, which is to say the tamping security boundary standard should be: horizontal acceleration less than 0.1g, vertical acceleration less than 0.2g.

Table 3 :Safety distance of impact for the tampers according to the code (under magnitude 7)

Tamper Type	Tamper Weight /T	Drop height /m	Tamping Energy per blow /kN.m	Distance between tamping point and position of horizontal acceleration <0.1g /m	Distance between tamping point and position of Vertical acceleration <0.2g /m	Minimum synthetic safe distance / m
A	15	7.5	1125	20	15	20
B	13	7.5	975	25	20	25
C	16	6.5	1040	25	20	25
D	15	6.5	975	30	25	30

As shown in Table 3, Tamper A can best absorb shock. It has the biggest tamping energy but the lowest horizontal and vertical accelerations under the same condition. Tamper A can satisfy safety standard by greatly reducing horizontal and vertical acceleration within 20m and 15m. On the other hand, Tamper D is most inefficient in shock absorbing, with tamping energy only 975kN.m, but accelerations reduce slowly, respectively require distances longer than 30m and 25m to satisfy the safety standard horizontally and vertically. Tamper B and C are in the middle, horizontal and vertical vibration acceleration can decrease within 25m and 20m to reach the security standard.

Tamping Effects

Obtained by site investigations, settlements per blow and total settlements are shown in Table 4. Speaking of tamping times, tamper B, C and D require 3 blows to achieve ideal settlement amount and effects (foundation soil continue to compact in tamping, instead of corrupting and up-heaving around tamping spots); Tamper A, by contrast, can reach the same settlement amount and effects by 2 blows, thus save energy and reduce costs.

Table 4: Settlements impacted

Tamper type	Tamper weight /T	Dropheight /m	Energy per blow /kN.m	blow number	Settlement per blow /cm			Total blow
					1st blow	2nd blow	3rd blow	Settlement /cm
A	15	7.5	1125	2	34	13	--	47
B	13	7.5	975	3	17	12	11	40
C	16	6.5	1040	3	18	13	10	41
D	15	6.5	975	3	20	14	10	44

Comprehensive Appraisal

To sum up, tamper A is obviously superior to the rest in shock absorbing and compacting, followed by B, C and D; the explanations are as below:

The bottom shape of tamper A with multi-stage millisecond delay contact enables the each bottom part get down to the soil successively; while total energy remains the same, vibration and energy dissipation effect decrease visibly, impact noise is small, and a larger portion of total energy can be transmitted to the deep so better reinforcement result can be achieved. In addition, the many small projected cylinders on the tamper possess strong bite force with the soil, thus enhance tamping stability, and reduce the possibility of the case which tamper tilt over to the ground (inclined hit will reduce the energy of body wave).

Tamper B also ensure low air cushion effect due to large spiracles in it, and tamping energy could be effectively transmitted to the deep. But blows and height should be increased to attain satisfying the requirements of tamping settlement and effects, because the tamper is quite light and the influenced area is correspondingly limited. Considering muck ground (sludge or muddy soil) using the method of Static-dynamic Drainage Consolidation, this type of tamper is likely to penetrate surface soil plus sand cushion, then get buried, and are therefore not conductive to form residual stress, neither conformed to the ”step by step, deeper each step” technological requirements.

Tamper C is forged in a circle shape, ensuring a lower focus and higher tamping stability. But the pore section is relatively small compared to the tamper bottom, tamping settlement is therefore lacking under fixed rammer will. It can only be enlarged by increasing blow times, still, the tamping energy can be hardly sent down; when the crane is high, tamping will cause strong vibration on the surface, and seriously disturb soil structure.

Tamper D is flat, its ratio of height to diameter is rather short, and the ratio of spiracle to bottom area is too small. Air cushion and lateral extrusion in tamping cause severe vibration on surrounding land and huge noise. The settlement per blow is quite small, for the energy has dissipated in top soil vibration, and again it can be enlarged by increasing blow times or energy. Moreover, the focus of such tamper (compared to its height H) is relatively high, it means poor stability, and the tamper is likely to tilt over to the ground upon tamping.

CONCLUSIONS

(1) The contact between Tamper A and ground is divided into 3 stages: first blow stage, bounce back stage and tamper power secondary impact; among which the first contact period takes a fraction of time, but vibration amplitude far exceeds those of other stages, so improving the way tamper contact the ground can greatly reduce tamping vibration. In sum, it is feasible and effective to lower surface wave energy and shock by meliorating tamper shape and spiracle area (which could boost foundation dense wave energy).

(2) Adoption of shock absorbed and assembled tamper (Tamper A) can reduce vibration influences to the environment nearby, and lower particle velocity by 20~60 percent. As to those vulnerable areas, using of Tamper A and damping ditch can greatly minimize disturbance to them, attain environment protection effects, and ultimately promote the application of static-dynamic drainage consolidation and dynamic drainage consolidation (dynamic compaction).

(3) Besides vibration absorbing, adoption of shock absorbed and assembled tamper (Tamper A) can also achieve obvious reinforcement result; make construction of high efficiency; save energy and money. Application shows that this tamper enables static-dynamic drainage consolidation more suitable for muck and muddy soft soil.

ACKNOWLEDGMENTS

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