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Research Note

Dynamic Compaction Method in Physical Model Tests

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In this paper, physical modeling tests are conducted to study some aspects of the dynamic compaction method. The loose models are prepared with dry sand. Four cylindrical tampers with different weight and cross section areas are used for compaction of the models and dropped from various heights. Strain gage type total stress measuring sensors are placed at different levels inside the model to measure the transferred vertical stresses due to collision of the tamper with the surface of the models. The typical stress time histories are presented. Improvement depth and crater depth and diameter created on the model surface are studied, among the various parameters affecting the phenomena. Using the results of the tests, a relation is proposed for the improvement depth which has good agreement with the measured site results.

INTRODUCTION

Although dynamic compaction has been used for many years, its application as a useful ground improvement method was developed after Menard and Broise [1], around the seventh decade of the last century. At that time, this method was considered mainly for granular grounds. However, today, it is applied also for accelerating the consolidation of saturated fine soils; which, in later cases, will be called the dynamic consolidation method. The method involves the repeated application of high energy impacts on the soil surface using steel or concrete tampers dropped from specific heights. Various parameters could affect the efficiency and applicability of the dynamic compaction, including important ones such as soil type and ground layering, ground water level, compaction equipment and pattern. Real cases and projects could be employed as valuable data for evaluating the method. However, limitation of such data on the one hand and the presence of a large amount of parameters affecting the results of the method on the other hand, cause the need of more fundamental research in this regard.

In addition to the limited and expensive real site tests, another method used by some researchers is the physical model test for studying dynamic compaction. Wetzel and Vey [2] conducted a number of physical model tests and measured the stress and strain in

Ottawa sand models generated due to the impact effect of a tamper on the model surfaces. The test results show that the distribution of vertical stresses in depth, due to the impact, is similar to the Boussinesq solution. Poran and his colleagues [3,4] also conducted a number of physical model tests and studied the effects of different parameters on the dynamic compaction results. They used Boston dry sand for preparation of the $1.22 \times 1.22 \times 1.22$ m^3 models and presented some design curves based on the experimental results. Oshima and Takada [5,6], by using a variety of facts obtained from site tests and centrifuge model tests, studied the effect of the momentum of a tamper and presented some graphs for estimation of the improvement depth during dynamic compaction.

In this paper, the results of some physical model tests for the study of dynamic compaction on dry sand are presented. Stress and acceleration time histories were measured accurately by using the recorded data from deployed miniature sensors at different depths of the models. After explanation of the model preparation details and test procedures, the test results are presented. Improvement depth, induced crater depth and its diameter are considered and some design graphs are presented in the final part of the paper.

MODEL SPECIFICATIONS

The physical models are comprised of a wooden container of $45 \times 35 \times 40$ cm^3 and 0.5 cm thickness soft sheets used for covering its base and side walls. For

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compaction of the models, four cylindrical steel weights are used. These weights were 0.2, 0.5, 1.0 and 2.3 Kgf and their diameters were 2.99, 4.12, 5.06 and 5.70 cm, respectively. PVC guide pipes were used for controlling the weight drops. In order to provide different falling energies, the heights of these guide pipes were different, but their diameters were the same and equal to 6 cm. The soil used for all the models is natural sand, called Babolsar Sand, which was provided from the Caspian Sea Shore close to Babolsar city, Iran. Its grain size distribution is shown in Figure 1. According to this figure, it is uniform sand with a D_{50} of about 0.24 mm and categorized, based on the Unified System, as SP.

According to density tests, the $\gamma_{d \max}$ and $\gamma_{d \min}$ values for this sand are 17.67 and 15.12 KN/m^3, respectively. In Figure 2, a typical section of the model
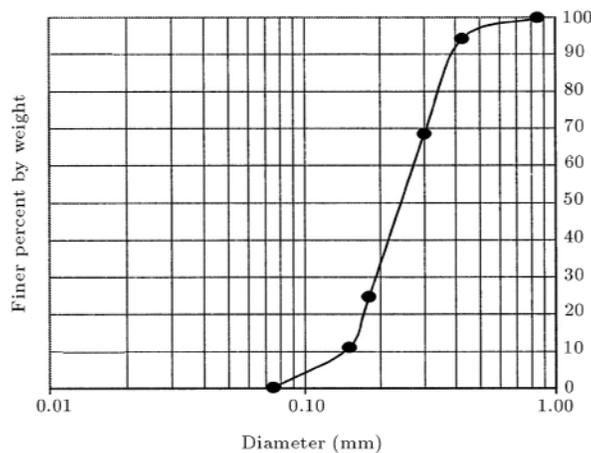
Figure 1. Grain size distribution of Babolsar Sand used for the physical models.
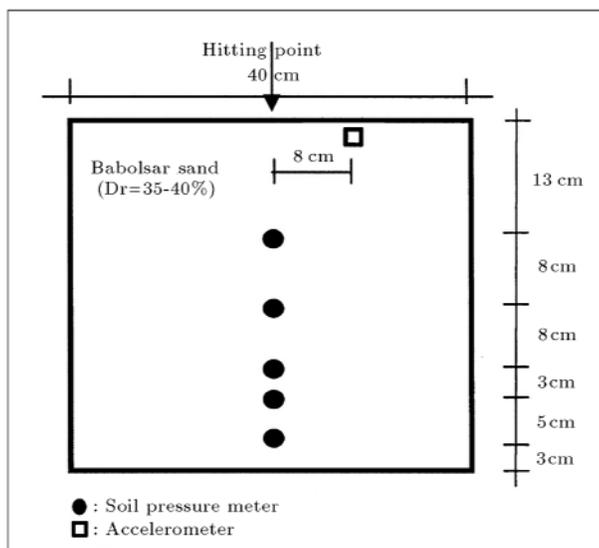
Figure 2. Typical section of the physical models and location of deployed sensors.

container and deployed sensors inside the model are shown.

INSTRUMENTATION

Two types of sensor were installed in the test models: Soil Pressure Meters (SPM) and Accelerometers (ACC) (Figure 2). The SPMs were used for measuring total soil pressure at different locations of the models and for estimating the total stresses, due to the impact of the weights on the surface of the models. They were of a strain gage type with a 2 Kgf/cm^2 capacity, 23 mm diameter and 10 mm thickness, produced by the Kyowa Company. They were placed inside the models horizontally to measure the vertical stresses. The ACCs are also of a strain gage type, cube shaped with 20 mm dimensions and a 5g capacity, supplied by the TML Company. An 8 channel data acquisition system connected to a PC computer was used for collecting and recording the data from various sensors. Due to the nature of the impact tests and in order to have reliable data from the event, it was necessary to use very sensitive sensors with a high data sampler data acquisition system in this research. Therefore, the capacity of the acquisition system was 700 samples per second per channel and was satisfactory. In this paper, the recorded results by SPMs are presented and used to find some correlation between the affecting parameters on the dynamic compaction method.

TEST PROCEDURES

About 50 dynamic compaction tests were performed in this research on physical models and more than 500 acceleration and stress time histories were recorded at different points inside the models [7]. At first, the container was filled with dry sand using an air raining method and its relative density was measured.

All the models produced by the explained method had about 35% to 40% relative densities and were kinds of loose models. The sensors were also placed at specified locations and orientations inside the models. After this stage, the vertical PVC guide pipes were placed on the surface of the models, the weights were dropped from the specified height and the response of the sensors inside the soil was recorded.

Also, the depth and diameter of the induced crater, due to the impact of the weight, were measured carefully. This procedure was repeated after each drop of the weight and, in all cases, the responses were recorded.

TYPICAL TEST RESULTS

In Figure 3, some typical test results are shown. These results correspond to dynamic compaction tests with a
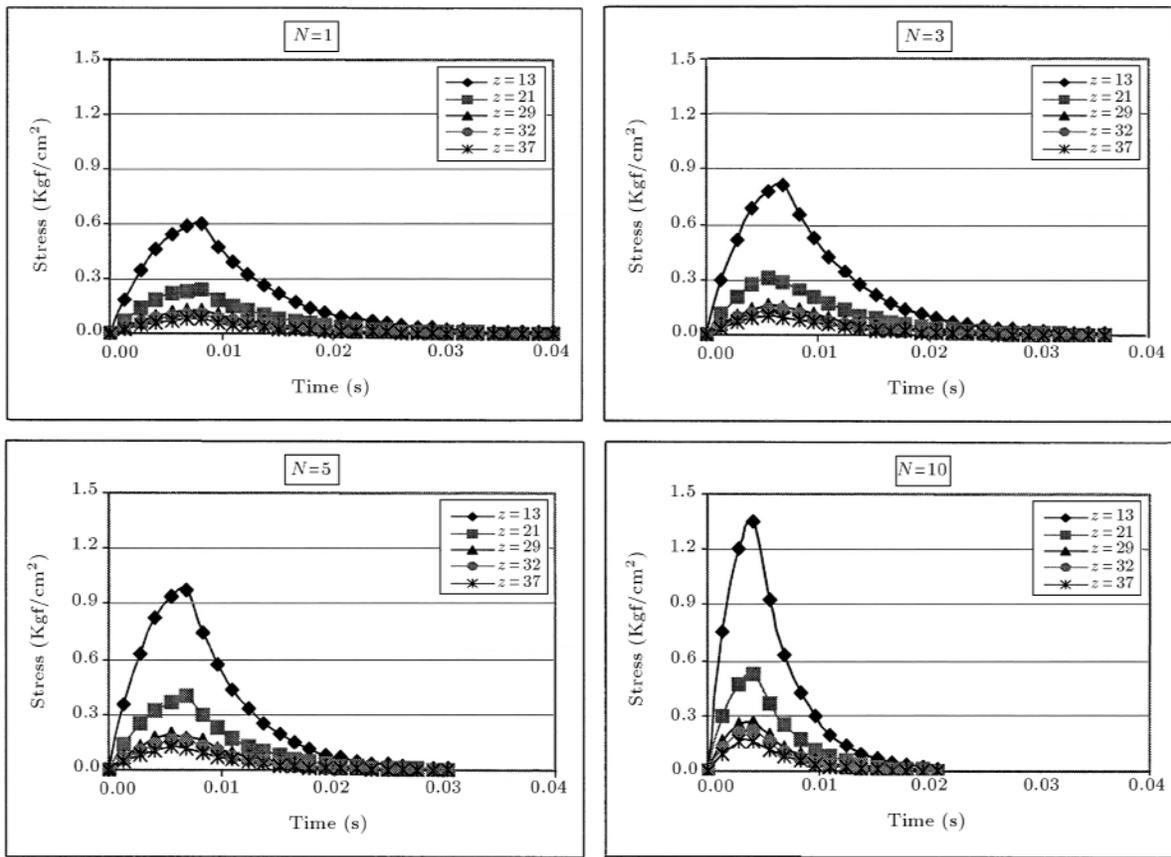
Figure 3. Typical recorded vertical stress time histories for 1 Kgf tamper dropped from 1m height.

tamper of 1 Kgf weight and 5.06 cm diameter dropped from a 1 m height for 1, 3, 5 and 10 times. The stress time histories have been plotted for the sensors placed at 13, 21, 29, 32 and 37 cm depths inside the model. The drop number is shown by N in this figure.

According to this figure, by increasing the drop numbers, the stress amplitude at each depth increases and the peak value occurs sooner. Also, for each specified drop number, the dynamic impact stress decreases by depth.

In Figure 4, typical acceleration time histories are shown at a point located on the surface of the model, 8 cm away from the hitting point of the tamper, due to different tamping numbers. It is clear that by increasing drop numbers, the compaction of the model is increased and the amplitude of the recorded acceleration, which could be related to the compaction energy at a specific point, is also increased.

INFLUENCE AND IMPROVEMENT DEPTH

Influence depth could refer to the depth in the ground or physical model that is affected by the drop energy of the tamper on the ground or model surface. In
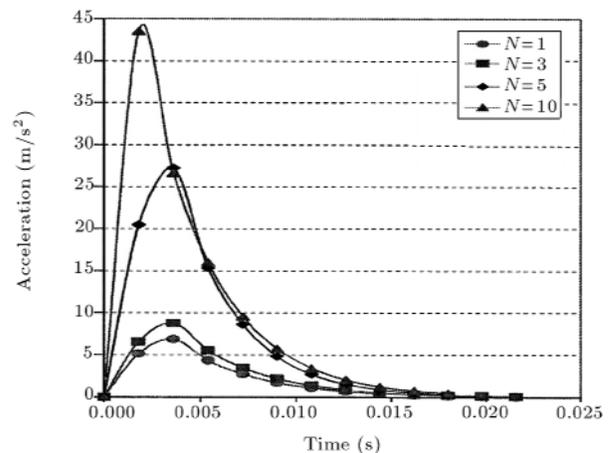

Figure 4. Typical recorded acceleration time histories at model surface (8 cm away from hitting point).

other words, if the stress field at any point were to change due to the impact of tamper at the surface, it could be assumed that the point has received some portion of the compaction energy and its compaction has been affected. It is clear that in order to increase the compaction of any soil element or have a successful dynamic compaction in that element, the impact stress

should have some level. This level is not clear and is under controversy. In this paper, it is assumed to be equal to 0.1 Kgf/cm^2. Therefore, at each test, it is assumed that the Improvement Depth (DI) could be estimated by evaluating the dissipated compaction energy by depth and this energy could be correlated to the impact stress amplitude at each point. Considering that during all tests in this research, the impact stress time histories at various depths have been recorded, the amplitude value could be estimated easily. In Figure 5, typical graphs for the recorded maximum vertical stresses at different depths, due to different drop numbers, are shown. It is clear from this figure that for a specific drop number, the vertical stress decreases by depth sharply. Also, the improvement depth, with the introduced criteria, increases by drop number.

In this research, in order to reduce scale effects, the method proposed by Poran et al. [3] is applied. In the mentioned method, Improvement Depth (DI) is scaled to tamper diameter (D) and a normalized energy index, $N.W.H/A.DI$, is considered. In this phrase, N is the number of drops, W is the weight of the tamper in Kgf, H is the falling height in m and A is the cross area of the tamper in m^2. The above explained method is applied to all tests of this research and the result for the non-dimensional DI/D ratio is shown in Figure 6.

According to this figure, there is a linear correlation between DI/D and $N.W.H/A.DI$ in a semi logarithmic system. In other words, in a test when N, W, H, A and D are known, the improvement depth, DI, could easily be estimated.

CRATER DIMENSIONS

By dropping a tamper on the ground or model surface, a small hole is created. The diameter and depth of this
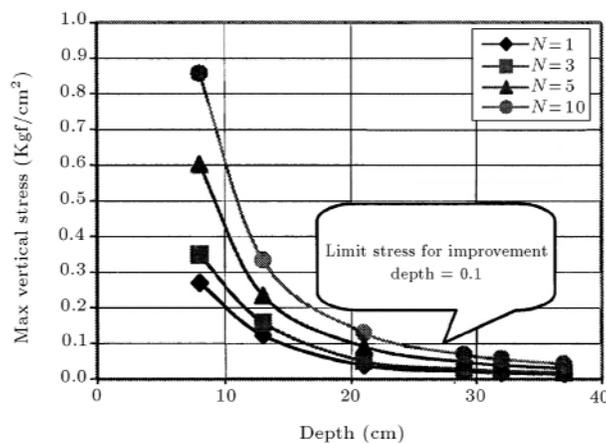
Figure 5. Recorded maximum stresses at different points inside the models for different N values (tamper weight and drop height are constant for all graphs).
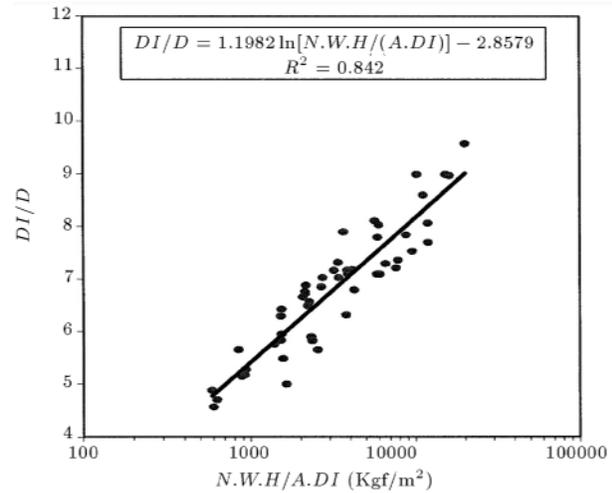
Figure 6. Correlation of improvement depth with normalized compaction energy.

hole could be used for designing a compaction pattern in practice. Usually, the created hole has a semi prolate spheroid geometry. In all tests of this research, the crater dimensions (depth and diameter) are measured precisely after each drop. The results show that the crater depth is increased by the energy level of the compaction. Also, it is found that after about 10 drops of a specific weight from a constant height, the depth of the crater does not change. Takada and Oshima [5,6] proposed the following relation for crater depth, h:

$$h = c.m.v_0(N)^{0.5}/A, \qquad (1)$$

in which m is tamper mass, v_0 is tamper velocity at contact time with the ground surface and c is a constant coefficient assumed equal to 0.0083 m^{2}s/ton. In order to verify the applicability of Equation 1 for this research, the crater depth is normalized to the square root of the applied energy and the results are plotted against the number of drops, N, in Figure 7. Other parameters of Equation 1 are selected based on the physical parameters of this study and test arrangement. It can be seen from this figure that the presented equation by Takada and Oshima predicts low values for a normalized crater depth, compared with the measured data in low compaction energy levels (0.2 and 0.5 Kgf tampers), the situation being opposite for high energy levels (1 and 2.3 Kgf tampers). However, there is good correlation between the measured and estimated values by Equation 1 for low drop numbers.

As explained, after dropping each tamper on the ground surface, a crater is created which has a circular shape in plane.

The diameter of this crater is another parameter that controls the compaction pattern. In this research, after each drop, the diameter is measured accurately. Figure 8 shows a typical measured data for a 0.5 Kgf tamper dropped from various heights. It could be
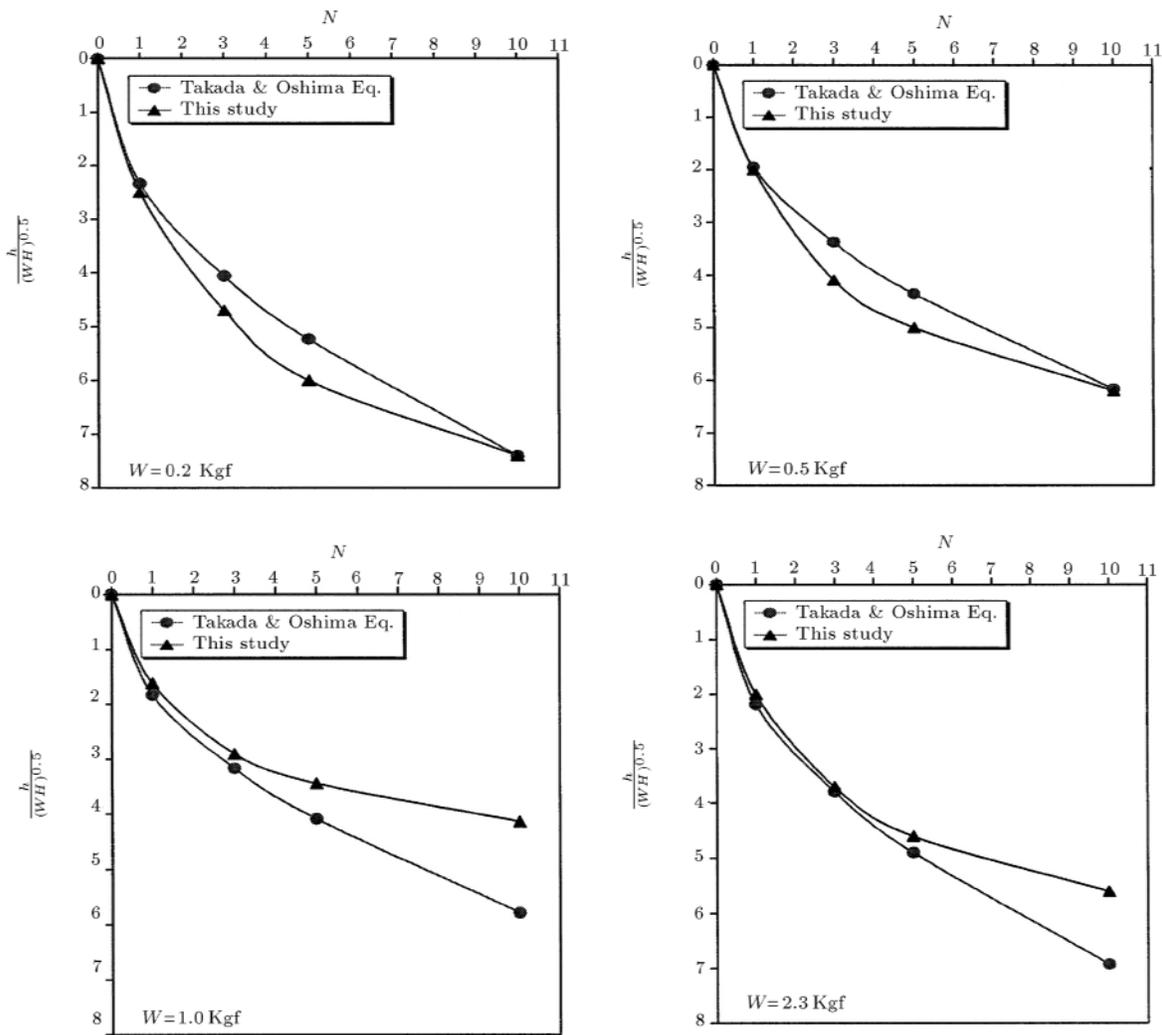
Figure 7. Correlation of normalized crater depth with drop numbers measured from model tests of this study and the Takada and Oshima equation, for different compaction energy levels.
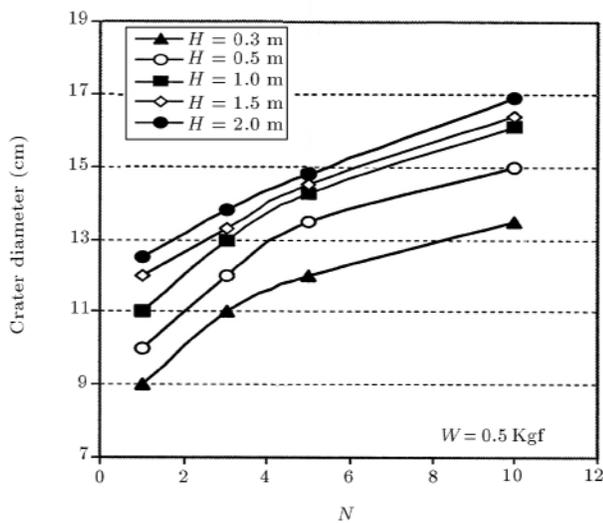

Figure 8. Typical measured crater diameter for 0.5 Kgf tamper, dropped from various heights.

seen that at constant compaction energies, the crater diameter increases by drop number. Also, according to this figure, after about 3 drops, the increasing rate of the crater diameter is reduced. Another point which is clear from this figure is that for a specified number of drops, the crater diameter increases according to the drop height of the tamper or energy level.

CONCLUSION

Dynamic compaction is considered as one of the economic and applicable ground improvement methods. A series of physical model tests were conducted to study the parameters affecting this method. Loose dry sand models instrumented by total stress meters and accelerometers at various points were subjected to the compaction energy of tampers. The compaction energy level was varied by the tamper weight, drop height and drop number. Considering the very short duration

of the collision, a high accuracy data acquisition and recording system, with a sampling capacity of 700 samples per second, are used.

Based on the performed test results, a design curve was presented for estimation of the improvement depth due to dynamic compaction. In this correlation, the effect of important parameters like tamper weight, diameter, cross section, falling height and drop number, are considered. Finally, some comments are presented for evaluating the created crater diameter and depth on the model surfaces and for the applicability of the available equation for crater depth in the literature.

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