Studies to evaluate the impact of tamper on the depth of improvement in dynamic compaction

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ABSTRACT

Ground improvement techniques are widely adopted in geotechnical engineering practices for improving the strength, density, and/or reducing drainage characteristics of the soil. Among the various options available for improving the soil, dynamic compaction (also referred to as impact densification, heavy tamping, and dynamic consolidation) has evolved as a widely accepted method of soil improvement in the past decade for treating poor soils in situ. This method is often an economically attractive alternative for utilizing shallow foundations and preparing subgrade for construction, as compared to other conventional expensive solutions like pile foundations, excavation and replacement, densification etc. Moreover, dynamic compaction has some unique applications, including treatment of reclaimed land, liquefaction mitigation and heterogeneous fill materials, and displacing unsuitable materials such as peat, and collapsing sinkholes. In general, the ultimate goals of dynamic compaction are to increase the bearing capacity of the soil, and decrease the total and differential settlements within a specified depth of improvement. Till date, the effective depth of improvement achieved through this technique has been restricted to about 5m of the soil. To increase the effectiveness of dynamic compaction, the soil condition and the energy configuration (which is decided by the surface area and the shape of the tamper used) has to be taken into account. In the present paper, an attempt has been made to investigate the impact of tamper base area in improving the influence depth during dynamic compaction on sandy soil. For this purpose, an innovative dynamic compaction set-up was developed in the laboratory for carrying out small-scale physical model tests on low energy dynamic compaction using circular steel tampers of three diameters (50 mm, 75 mm and 100 mm). This paper describes details of the dynamic compaction set-up developed, and its advantages over other compaction set-ups developed till date with respect to evaluation of dynamic compaction technique in the laboratory. In general, it was observed that, the width of area influenced by dynamic compaction is proportional to almost 2.5 times the tamper diameter. However, the tamper base area was found to exhibit marginal influence on the depth of improvement, provided the impact energy intensity was kept constant in all the three tests.

Keywords: ground improvement, dynamic compaction, depth of improvement, physical model tests, geopiv.

1 INTRODUCTION

The densification of loose soils by falling weights dates back to antiquity. The first known published reference on the subject involved a site in Germany. Not until 1969, however, was the technique finally promoted by Louis Menard as a routine method of site improvement. During dynamic compaction, repeated impacts are imparted to granular soil by means of a heavy weight hitting the ground surface, causing the soil particles to be rearranged into a denser state. This method is used for different types of civil engineering projects, including building structures, coal facilities, dockyards, highways and airports. In recent years, dynamic compaction has also emerged as an economically attractive method of ground remediation for loose cohesionless soils as a part of liquefaction hazard mitigation technique and densifying municipal solid waste landfills.

Full-scale tests and case studies on the use of dynamic compaction in the field have been reported by researchers like Mayne et al. (1984), Kumar and Puri (2001), Zou et al. (2005), Bo et al. (2009), Feng et al. (2011), and Gupta et al. (2013). However, the design parameters guiding the efficiency of the technique, like, selection of impact spacing, the number of drops per impact point and tamper diameter are yet to be optimized. Laboratory
investigations on low energy compaction process have been carried out by Feng et al. (2000), Arslan et al. (2007), Hajialilue-Bonah and Rezaei (2009), and Bonab and Zare (2014). However, some of these set-ups involve insertion of steel rods into the soil for guiding the mass, which is in contradiction to actual field conditions. Moreover, the tamper is made to fall from a considerable height to impart the required energy to the soil surface, making the overall set-up heavy and cumbersome. Till date, researchers like Chow et al. (1992a,b), Corapcioglu et al. (1993), Chow et al. (1994), Roesset et al. (1994), Gunaratne at al. (1996), Gu and Lee (2002), Thevanayagam et al. (2009), and Nashed et al. (2009a,b) have developed numerical simulation models to analyze the ground response and densification during dynamic compaction. But, they have their inherent assumptions and drawbacks.

In the present paper, low energy dynamic compaction was simulated in the laboratory using circular steel tampers of three diameters (50 mm, 75 mm and 100 mm). The purpose is to determine the effect of tamper base area on dynamic compaction, by keeping the energy intensity (impact energy applied on unit area of affected soil) as constant. Low energy compaction process was chosen keeping in mind the fact that, in the field, studying the process of dynamic compaction is time-consuming, costly and difficult because of the heterogeneous soil encountered and other problems related to instrumentation and data acquisition. An innovative dynamic compaction set-up was developed in the laboratory involving a metallic spring, so as to utilize the potential energy stored by the spring by virtue of its stiffness. The additional potential energy of the spring contributed by a major amount to the total energy required to be imparted to the soil. This, in turn, reduced the height of fall of the tampers, making the developed set-up compact and robust. Details of the dynamic compaction set-up developed, and its advantages over existing set-ups with respect to ground improvement are discussed in subsequent sections along with analyses of model test results using GeoPIV as outlined in White et.al (2003).

2 MODEL SOIL USED IN THE STUDY

The sand used in the present study was found to completely pass through BSS 36 sieve (0.425 mm) and retained in BSS 200 sieve (0.075 mm). The grain size distribution of the sand is classified as SP according to Unified Soil Classification System (USCS). The various properties of sand as determined in the laboratory are tabulated in Table 1.

| Properties                  | Value                  |
|-----------------------------|------------------------|
| Specific gravity            | 2.67                   |
| Sand [0.075-4.75 mm] (%)    | 96.67                  |
| Silt [0.075-0.002 mm] (%)   | 3.33                   |
| Clay [<0.002 mm] (%)        | 0                      |
| USCS                        | SP                     |
| Effective particle size, d<sub>10</sub> (mm) | 0.13                   |
| Average particle size, d<sub>50</sub> (mm) | 0.18                   |
| Co-efficient of uniformity, C_u | 1.57                   |
| Co-efficient of curvature, C_c | 0.93                   |
| Maximum void ratio, e_max | 0.99                   |
| Minimum void ratio, e_min  | 0.70                   |
| Co-efficient of permeability, k (m/sec) | 1.49 x 10^-4 |

3 DETAILS OF DEVELOPED DYNAMIC COMPACTION SET-UP

Figure 1 shows the cross-section of a model test package along with the developed dynamic compaction test set-up. Model tests were conducted in a container having 720 mm in length, 450 mm in breadth and 410 mm in height internally. Front wall is formed with a thick Perspex sheet for enabling view of front elevation of the model during the test. The developed dynamic compaction test setup consists of a ‘spring-mass’ system to guide the tamper mass, as it gets lifted and dropped on the soil with a certain impact velocity. The spring mass system is supported over a C-frame, which was fixed to the top of the container (Figure 1) Figure 2 illustrates different components of the spring mass system, and the three tampers used in the study. The tampers are half circular plates, attached to the square rod (Figure 2), which is made to pass through the hollow guide rod fixed at the base of the bottom plate (Figure 1). The lower part of the spring is welded to the bottom plate and fixed to the C-frame rigidly, while the upper movable part is welded onto the top plate, and guided by providing steel rods. The spring is designed with stiffness (k) of 4423 N/m, wire diameter (d) 6 mm, mean diameter (d<sub>3a</sub>) of 6.6 mm, pitch of 6 mm and number of active coils (n) as 10.

![Schematic view of the dynamic compaction set-up](image)
Figure 3 depicts the working mechanism of the developed dynamic compaction test set-up in the laboratory. As shown in Fig. 3, a steel wire is attached at the end of the rod used for holding the tamper. As it is pulled up by a distance $h'$ vertically, the rod touches the movable top plate of the spring and pushes it upwards. This causes the spring to extend by the same distance $h'$, which the tamper traverses. After attaining $h'$, the steel wire is released, causing the tamper along with square hollow rod to fall under the combined force of gravity ($mg h'$) and with the force induced by the extended spring ($0.5kh'^2$).

The above set-up possesses certain major advantages over other dynamic compaction test setups developed till date. Various researchers like Hajialilue-Bonab and Rezaei (2009), Bonab and Zare (2014) have simulated low energy dynamic compaction in the laboratory by making circular holes on the gravity centre of each quadrant of the tampers, and inserting cylindrical rods passing through these tampers into the soil. These guiding steel rods embedded within the soil impart additional strength to the soil. Hence, the actual gain in strength of the soil at the onset of dynamic compaction cannot be monitored properly. Secondly, these set-ups are designed for dropping tampers by actual drop heights ($h$).

Hence, as the drop height increases, the length of the guiding steel rods increases, making the overall set-up costly and cumbersome. To overcome these difficulties, the metallic spring was introduced in the present set-up to contribute a major share to the overall energy required to be imparted to the soil surface by virtue of its stiffness. The tamper derived a small fraction of its required energy from gravitational potential energy ($mg h'$) and the major fraction is derived (from the potential energy stored in the spring ($0.5kh'^2$), thereby reducing the drop height from $h$ to $h'$. Hence, the present set-up is more compact, robust, and can be used subsequently for small-scale physical model testing at higher gravities also, where constraint space poses a serious issue.

The present set-up can simulate falling of tamper with energy upto 30 N-m. However, by using a spring with higher stiffness, higher energy can be imparted to the soil surface.

4 TEST PROCEDURE

Three tests were performed by raising and dropping the semicircular steel tampers (T1, T2 and T3) 15 times on the surface of the sand deposit in each test. For all the tests, the actual drop height ($h$) was kept constant at 0.55m, while the mass of the tampers were varied such that the energy intensity (impact energy divided by base area of each tamper) was constant in each test. After each impact on the model surface, a digital image was captured of the deformed soil using a Nikon digital camera with an image resolution of 3072 x 2304 pixels. Figure 4 presents the front view of the deformed soil surface captured at different stages of tamping for Test 1. In order to ensure adequate illumination, two no’s of fluorescent lights were placed on the left and right sides of the camera, at a level higher than the optical axis of the camera. Details of tests performed are presented in Table 2.

| Test no | Tamper weight (N) | Drop height, $h'$ (mm) | Actual drop height, $h$ (m) | Tamper dia, D (mm) | Energy intensity (Nm/m²) |
|---------|-------------------|------------------------|-----------------------------|-------------------|--------------------------|
| 1       | 3.00              | 13                     | 0.55                        | 500 (T1)          | 840.33                   |
| 2       | 6.75              | 25                     | 0.55                        | 75 (T2)           | 840.33                   |
| 3       | 12.00             | 37                     | 0.55                        | 100 (T3)          | 840.33                   |
5 RESULTS AND DISCUSSION

A typical image of the deformed soil surface, captured after tamping (for Test 2) is shown in Fig. 5, where heaving of soil along the periphery of the crater is clearly visible. The variation in crater width and depth captured at various stages of tamping for the three tests conducted are presented in Table 3. The variation of crater depth with number of drops of the tamper is presented in Fig. 6, which shows an increasing trend.

Using GeoPIV software, displacement vectors were obtained from the images captured during the test from the plane of the perspex sheet, which were subsequently used for calculating strain contours using the method described in Hajialilue-Bonab and Rezaei (2009).

| Test no | Maximum width of influence area (mm) | Depth of influence area (mm) |
|---------|---------------------------------|----------------------------|
| N = 5   | N = 10                          | N = 15                     |
| 1       | 75                              | 105                        |
| 2       | 101                             | 153                        |
| 3       | 117                             | 189                        |

N = Number of blows delivered

6 CONCLUSIONS

In this paper, the design and development of the various components of a low energy dynamic compaction set up for densification of loose uniformly graded sandy soil is presented. The advantages of the developed set-up over previous dynamic compaction set-ups have been discussed, with special emphasis on the metallic spring incorporated in the design. Based on preliminary tests carried-out, the developed set-up was found to give consistent results. Further, it was used to validate the influence of base area of tampers on dynamic compaction. In general, it was observed that, the width of area influenced by dynamic compaction is
proportional to almost 2.5 times the tamper diameter. However, the tamper base area was found to exhibit marginal influence on the depth of improvement, provided the impact energy intensity was kept constant in all the three tests. However, further tests are warranted in developing this test setup for achieving more quantification of observed test results.

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