Effects of Vibrating Frequency of a Plate Compactor on Soil Density

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ABSTRACT: This paper presents experimental data on the change of density in a cohesionless fill due to vibratory compaction at different vibration frequencies. A variable-frequency plate compactor with a frequency range of 10 ~ 100 Hz was designed and constructed. Air-dry Ottawa sand was used as fill material. The initial relative density of the uncompacted fill was about 33 %. Vibratory compaction was applied on the surface of a 1.5 m-thick lift. The cyclic normal stress applied on the surface of the fill was kept a constant (σ_{cyc} = 30 kN/m^2) under the compaction frequencies of 45, 58, 64, 74, 83, 89 and 100 Hz. Test results indicated that within the depth of 0.3 m, which was the width of the compaction plate, the density increase was most significant. The density increase effect reduced with increasing depth. The effective compaction depth varied from 0.43 to 0.54 m, which was deeper than the maximum permissible lift thickness 0.15 ~ 0.30 m suggested by NAVFAC DM-7.2 (1982). Under the same amplitude of cyclic normal stress, both the peak relative density of the fill and the effective compaction depth were not significantly influenced by the applied compaction frequency.
Keywords: Compaction, Frequency, Relative density, Plate compactor, Sand.

1. INTRODUCTION

In the construction of highway embankments, earth dams, and many other engineering structures, engineers are often required to compact loose soils to increase their densities. The purpose of compaction operation is to improve the engineering properties of soil such as increasing shear strength, reducing permeability and compressibility. Various soil improvement techniques had been used in the past.

Vibration is especially effective to compact granular soils. Typical vibrational methods included hand temper compaction, roller compaction, vibroflotation, dynamic compaction, and compaction sand pile. However, in the literature, there were few research regarding the relationship between vibration frequency and soil density change. Limited laboratory and field studies were made, and no explicit conclusion was drawn. The objective of this study was to investigate how does the vibratory frequency affects the compaction results.

Baidya and Krishna (2001) conducted experiments to investigate the effects of loading frequency and amplitude of a vibrating footing on a layered soil system. It was concluded that, the frequency corresponding to maximum surface displacement amplitude from the response curve was considered as resonant frequency. For the layered soil system, the observed natural frequencies varied from 8.3 to 31.3 Hz. Wersäll and Larsson (2013) conducted small-scale tests to investigate the influence of loading frequency on compaction effects. For the test with large-amplitude the resonant frequency was about 48 Hz, and for small-amplitude tests the resonant frequency was about 68 Hz.

2. EXPERIMENTAL FACILITY

2.1 Soil Bin

The soil bin was designed to minimize the lateral deformation of soil specimen during testing. In Figure 1, the soil bin was fabricated of steel plates with inside dimensions of 1,500 mm × 1,500 mm × 1,600 mm. In Figure 1 the model wall is 45 mm-thick, and the sidewalls are 35 mm-thick. To achieve an at-rest condition, the wall material should be nearly rigid.

In Figure 1, twenty-four 20 mm-thick steel columns were welded to the four sidewalls to reduce any lateral deformation during loading. In addition, twelve C-shaped steel beams were also welded horizontally around the box to further increase the stiffness of the box. For more information regarding the soil bin, the reader is referred to Chen and Fang (2008).

2.2 Variable-Frequency Plate Compactor

This section introduces the design of the NCTU variable-frequency hand tamper used in this study (Lin, 2015). To design the

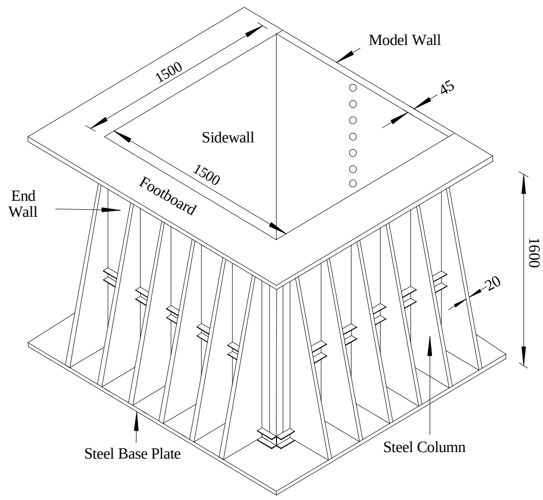


Figure 1 NCTU non-yielding model retaining wall and soil bin (after Chen and Fang, 2008)

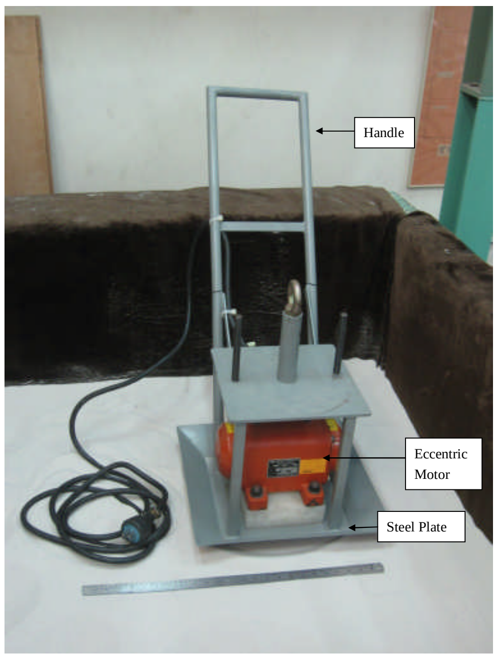
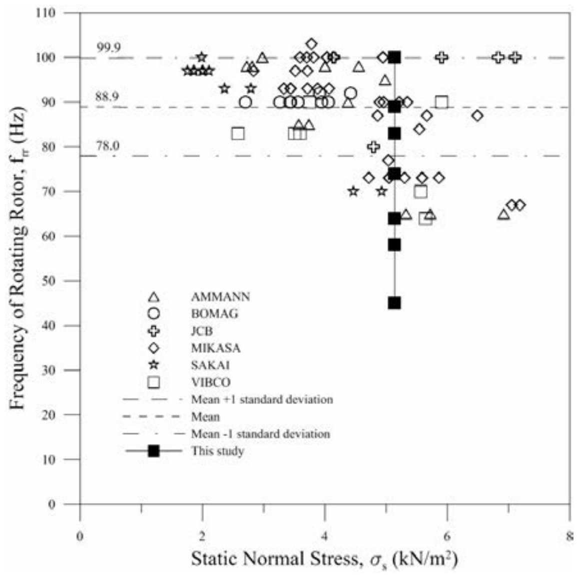
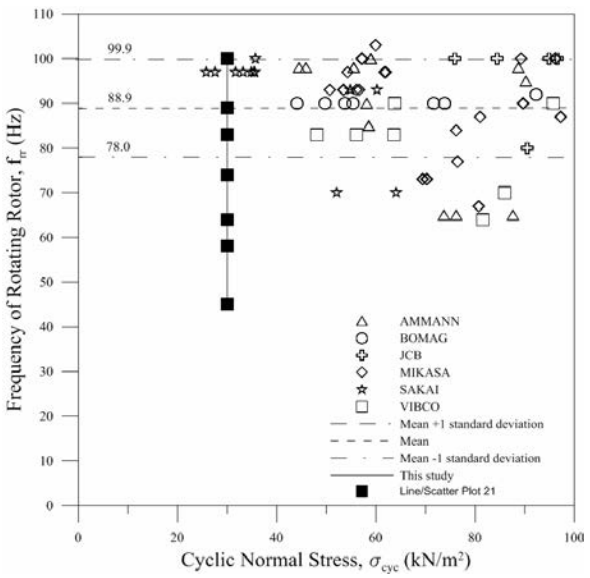


Figure 2 NCTU vibrating plate compactor (after Lin, 2015)



(a) Frequency of vibratory compaction vs. static normal stress



(b) Frequency of vibratory compaction vs. cyclic normal stress

Figure 3 Distribution of vibration frequency for commercial vibratory tampers

experimental compactor, 83 commercial compactors on the market were collected and investigated. Four main factors considered for the design of the experimental hand tamper were: (1) compacting plate area; (2) applied static pressure; (3) cyclic normal stress; and (4) vibration frequency. Figure 2 shows the vibrating plate compactor used for all experiments in this paper. The distribution of vibration frequency as a function of static and cyclic normal stresses for the 83 commercial hand tampers are illustrated in Figure 3 (a) and (b).

For this study, since the area of the soil bin for testing was only 1.5 m × 1.5 m, therefore a small plate size 0.30 m × 0.30 m was selected. The area of the compaction plate was 0.09 m^2. The mass of the compactor was 47 kg, and the applied static stress was 5.12 kN/m^2.

2.3 Constant cyclic normal Stress

The amplitude of cyclic normal stress was kept to be σ_{cyc} = 30 kN/m^2 for all experiments in this investigation. The cyclic normal load applied could be described as follows:

$$Q(t) = Q_o \sin \omega t \quad (1)$$

Q(t) was produced by the eccentric motor with rotating mass. The force amplitude applied was:

$$Q_o = m_e \, e \, \omega^2 \quad (2)$$

where m_e was the eccentric mass, e was the eccentricity, and ω was the angular frequency. The amplitude of cyclic normal stress applied from the plate compactor to the fill was $\sigma_{cyc} = Q_o/A$, where A was the area of the loading plate. To keep the cyclic normal stress a constant with increasing frequency, the rotating mass was decreased by remove the rotating eccentric plate attached to the central axis of the motor shown in Figure 4.

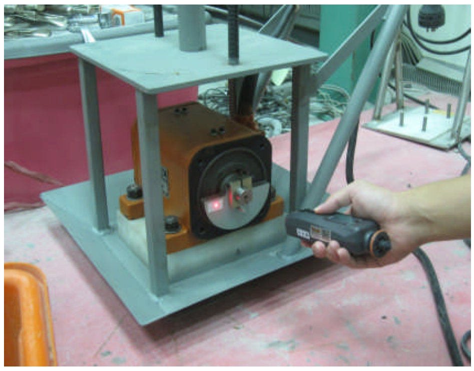
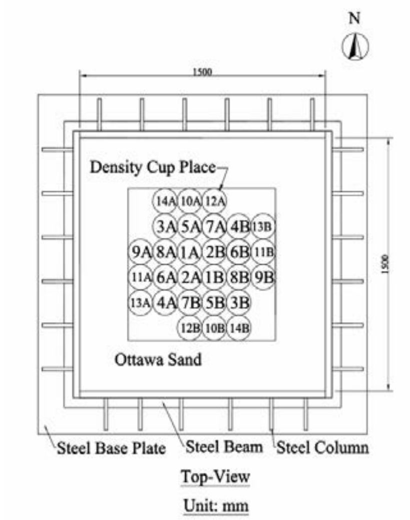
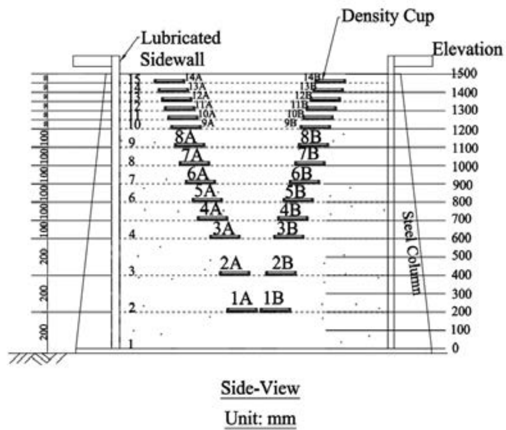


Figure 4 Measurement of revolution speed of rotor plate with photo tachometer



(a)



(b)

Figure 5 Soil density molds buried at different elevations

3. BACKFILL CHARACTERISTICS

3.1 Specimen Preparation

Air-dry Ottawa sand (ASTM C-778) was used throughout this investigation. Physical properties of the soil include G_s = 2.65, e_{max} = 0.76, e_{min} = 0.50, D_{60} = 0.39 mm, and D_{10} = 0.26 mm. To observe the distribution of soil density in the bin, soil density molds were made. During the preparation of the 1.5 m x 1.5 m x 1.5 m soil specimen, density cups were buried in the soil mass at different elevations and different locations in the fill as indicated in Figure 5. After the soil had been filled up to 1.5 m from the bottom of the soil bin by air-pluviation, density molds were dug out from the soil mass and soil density was measured carefully.

3.2 Testing Procedure

Figure 5 shows the soil density cups were placed at spread locations to avoid hindering the propagation of vibratory waves to reach the lower-elevation locations. For a 1.5 m-thick air-pluviated Ottawa sand layer, the distribution of soil density with depth is shown in Figure 6. For the sand specimen, the mean unit weight γ is 15.5 kN/m^3, the mean relative density is D_r = 33.3% with the standard deviation of 1.8%. Das (2010) suggested that for the granular soil deposit with a relative density between 15% and 50% is defined as loose sand. Figure 6 shows the relative density D_r = 33.3 % achieved by the air-pluviation method was quite loose and uniform with depth.

The fill surface was divided into five lanes as indicated in Figure 7. Each 0.3 m-wide 1.5 m-long lane was compacted with the vibratory compactor for 35 seconds for each pass. For the travel distance of 1.2 m, the speed of the compactor movement was 34 mm/s.

4. DENSITY INCREASE DUE TO VIBRATORY COMPACTION

4.1 Density Distributions at Low Vibration Frequency

Figure 8 shows the density distribution with depth after two passes of the vibratory plate compactor at the loading frequency of 45 Hz. In the figure, for the uncompacted fill, the relative density was 33.3 ± 1.8 %. After 2 passes of the compactor with the rotating rotor frequency of 45 Hz, the relative density increased up to the peak relative density of about 116 %. For the upper 0.53 m of fill, the relative density of the compacted fill was greater than the D_r = 75 % which was required by the US Navy Design Manual 7.2 (1982).

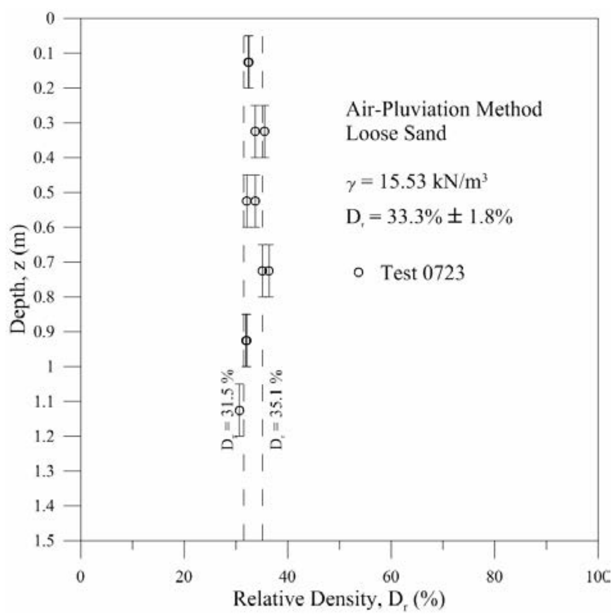


Figure 6 Distribution of relative density of soil with depth

4.2 Density Distributions at Different Vibration Frequencies

Figure 9 summarized the relative density distributions after 2 passes with the compaction frequencies of 45, 58, 64, 74, 83, 89 and 100 Hz. Within the depth of 0.3 m, which was the width of the compaction plate, the density increase was most significant. The density increase effect was reduced with increasing depth.

Figure 10 shows the peak relative densities $D_{r,peak}$ induced after 2 passes of the tamper at different compaction frequencies. The relative density for the uncompacted fill was 33.3 ± 1.8 %. After compaction with the cyclic normal stress σ_{cyc} = 30 kN/m^2, the peak relative densities increased to 114 ~ 119 %. However, test data indicated that the peak density of the fill was not significantly affected by compaction frequency.

4.3 Effective Compaction Depth

Figure 11 illustrates the effective compaction depths obtained at different compaction frequencies. In the figure, the effective compaction depths varied from 0.43 to 0.54 m, which was deeper than the maximum permissible lift thickness 0.15 ~ 0.30 m (6 ~ 12 inch) suggested by the US Navy Design Manual 7.2 (1982). From these experimental data, it may be concluded that the effective compaction depth was not significantly influenced by the compaction frequency.

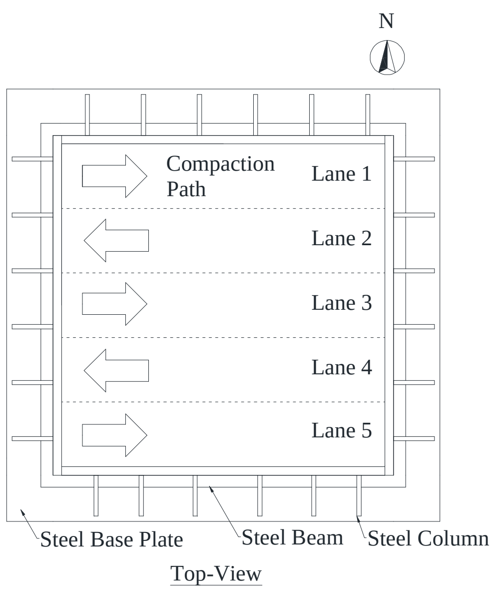


Figure 7 Compaction path on fill surface (after Lin, 2015)

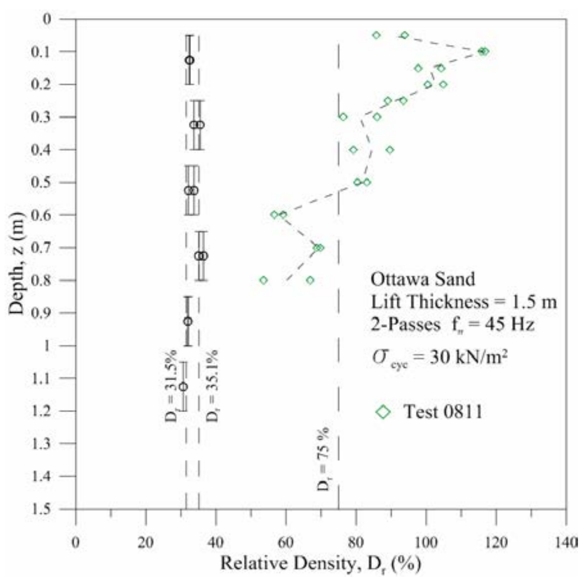


Figure 8 Distribution of relative density with depth at f_{rr} = 45 Hz

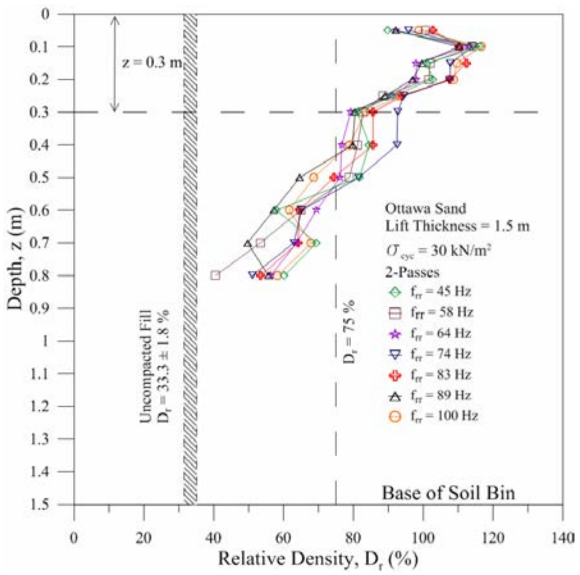


Figure 9 Distribution of relative density with depth at different compaction frequencies

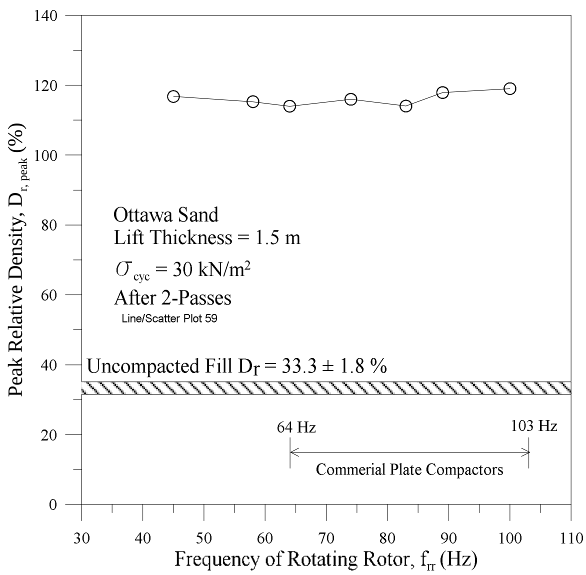


Figure 10 Peak relative densities at different compaction frequencies

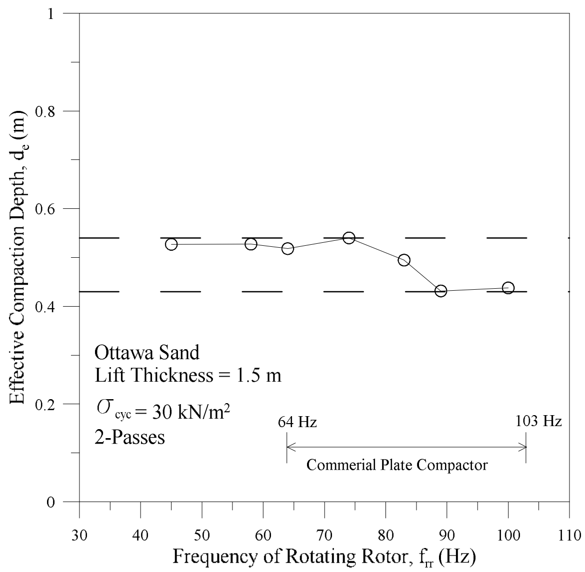


Figure 11 Variation of effective compaction depth with compaction frequency

5. CONCLUSIONS

For the cohesionless fill improved with the compaction frequencies of 45, 58, 64, 74, 83, 89 and 100 Hz, the density increase was most significant within the depth of 0.3 m. The density increase effect was reduced with increasing depth.

The measured peak relative densities varied from 114 to 119 %. The peak relative density of the fill was not significantly affected by the compaction frequency.

The effective compaction depths varied from 0.43 to 0.54 m, which was deeper than the maximum permissible lift thickness 0.15 ~ 0.30 m suggested by NAVFAC DM-7.2 (1982).

Under the same amplitude of cyclic normal stress, both the peak relative density of the fill, and the effective compaction depth were not significantly influenced by the applied compaction frequency.

6. REFERENCES

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