Design and Numerical Modeling of Light Compactor for Very Low Energy Dynamic Compaction by Finite Element Method

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ABSTRACT

The purpose of this study is to find a method for obtaining all soil dynamic parameters numerically. Moreover, it is intended to predict the dynamic parameters after each impact, and to obtain the predicted compaction as well as the desired dynamic parameters after a certain number of impacts. In the study, four hammers with different dimensions are modeled on sandy soil using ABAQUS. Additionally, the activated wave stiffness test is used to extract the dynamic parameters of each hammer for loose sand, and it is shown that which hammer under what conditions yields the highest efficiency. The peak particle velocity is obtained using the finite element technique for each hammer, and the results are used to determine the safe distance after each blow. The results indicate that the unsafe distance of compactor from the location of impact increases with the weight of the compactor. In the study, a hammer with a mass of 875 kg, falling through a distance of 1 m. horizontal safe distance of 3.80 m, and a vertical safe distance of 2.30 m is designed to deliver five blows to achieve the maximum stiffness with an improved depth under the foundation from 0.9 to 1.2 m in a loose soil and a relative error of 5% is obtained. The improvement depth obtained numerically is in good agreement with the experimental results of centrifuge tests at accelerations of 1, 10, 20, and 30 g as well as the field results of Parvizi and Merrifield, Allen, Maxwell and Briaud.

KEYWORDS

soil compaction, compactor, activated wave stiffness test, unsafe distance, improved depth.

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1. Introduction

Access to suitable land is an important factor in construction activities, especially for various coastal and marine structures. The growth in population has largely hindered the access to lands with good geotechnical characteristics [1]. Deep foundation construction, earthwork, and replacing high quality materials are very costly processes. Consequently, various methods, such as dynamic compaction, which is a very popular ground improvement technique, have been proposed to improve the stiffness and quality of soil [2]. From ancient times to the 1930s, the Russians drove piles into ground using hammers falling from certain heights. For example, they released 1- or 2-ton hammers from a height of 5 or 6 meters to drive piles into ground. In the late 1960s, a French engineer, Louis Ménard, developed a new idea for compacting soil to greater depths using high-energy waves. After Ménard, many researchers have conducted experimental studies on soil dynamic compaction, including Kuhlemeyer and Lysmer [4], West et al. [5], Leonards et al. [6], Charles and Et al. [7], Scolombe [8], and Lukas [9]. In 1994, a research on low-energy dynamic compaction was led by Cardiff Metropolitan University and University of Manchester. In this research, field study was conducted by Cardiff University, while the University of Manchester designed the experimental model of the research. Some experimental studies on dynamic compaction have been conducted by Orrje [10], Merrifield et al. [11], GU et al. [12]. In the present study, ABAQUS FEA software is used for numerical modeling. The main purpose of this study is to present a method for easily obtaining all dynamic parameters based on numerical approaches. Moreover, this study aims at predicting the soil dynamic parameters after each blow, and obtaining the predicted compaction as well as the desired soil dynamic parameters after a specific number of blows.

2. Methods

2-1- Prediction of soil dynamic parameters

In the present study, four types of compactors with different dimensions are modeled for improving sandy soils. Moreover, the wave activated stiffness K (WAK) test is used to extract the dynamic parameters of each compactor for loose sand. Finally, the compactor with the highest efficiency under different conditions is chosen. For the sake of brevity, the results from the less efficient compactors have been omitted in the present study and the results of the most efficient compactor are only presented in the article. In some sites with underground utilities, such as water pipes, electricity cables or tunnels, the effective depth of the compactor should not exceed the depth of the underground utilities, while maximum dynamic stiffness should be achieved. To avoid the destructive effects on nearby structures, an appropriate type of compactor should be used considering the distance from the nearby structures. The WAK test can be carried out only by a computer and one user. The proposed method is verified by comparing the numerical results with the laboratory results obtained from the centrifuge test. The laboratory results were obtained based on the following process. In the laboratory, the force and acceleration signals were recorded for each blow and the data were transferred to MATLAB software. Then, the soil dynamic parameters were determined using a custom written MATLAB program. In the range where the blow was predicted to be effective, stress sensors (designed by Parvizi) were placed in both vertical and horizontal directions to record the signals generated by each blow. These signals needed to be calibrated before plotting the desired curves by the custom written program. After applying the calibration coefficients, the peak of each signal was determined in vertical and horizontal directions at different depths. During each low-energy dynamic compaction test, a large amount of data (1024 data points) was recorded from different devices. However, these data in the 2N form could be used for different purposes, such as transformation from the time domain to the frequency domain in fast Fourier transform (FFT).

2-2- Safe distance

In the first step, the finite element method was used to obtain the maximum velocity at the points located between the tamping site and the desired structure, and then, the curve of maximum velocity of the particles versus the distance was plotted. In the second step, the maximum allowable velocity was specified on the curve, and then, the intersection point between the line and curve was determined. The velocity near the structure should be less than the allowable velocity, so in the third step, the safe distance was determined based on the impact point and allowable velocity.

Table 1. Specifications of the compactor.

Diameter of circular foundation (m)	Falling height (m)	Weight of Compactor (kg)	Number of impact	Compactor
0.8	0.8	448	10	1
1	1	875	10	2
1.2	1.2	1512	10	3
1.5	1.5	2950	10	4

3. Conclusion

1- In this research, a compaction system with constant energy (constant tamper mass and height of fall) was developed. This research focused on a low-energy compactor (low tamper mass and low height of fall). Therefore, the results of this research can be generalized to high-energy compactors (higher tamper mass and low height of fall).

2- Software-based dynamic compaction analysis provided the user with the dynamic parameters after each blow. As an example, for the compactor No. 2 (875 kg), the fifth blow on loose soil yields the maximum stiffness and further blows reduce the stiffness. Therefore, the user had to set the number of blows to "5" for loose soil.

3- The maximum particle velocity in compacted soil was less than that in loose soil. However, during the fifth blow, the maximum particle velocities in both compacted and loose soil samples were equal. Consequently, the horizontal safe distance was the same for both soil samples, or in other words, the soil had reached the maximum stiffness after the fifth blow.

4- The minimum horizontal distances between the nearby structures and the impact point should be more than 3.30 m in compacted soil and 3.80 m in loose soil.

5- The minimum depths of underground utilities from the surface (impact surface) had to be more than 1.60 and 2.3 m in compacted and loose soils, respectively.

6- The improvement depth was obtained using the WAK test and stress-depth curve. The improvement depth from ABAQUS based on Boussinesq stress distribution was compared with the results from the laboratory tests and there was a good agreement between these results. Accurate calculation of the improvement depth from the stress-depth curve is relatively difficult, so the concept of improvement depth range was used. For example, the second blow on compacted soil led to an improvement depth of about 1 m using the WAK method, while the improvement depth from the stress-depth curve was about 1.05, with a relative error of 5%.

7- To compact loose soil, the compactor used in this study has the following specifications:

- Tamper mass: 875 kg
- Height of fall: 1 m
- Horizontal safe distance: 3.80 m
- Vertical safe distance: 2.30 m
- Number of blows required to achieve maximum stiffness: 5
- Improvement depth underlying the foundation: 0.9 to 1.2 m

4. References

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