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Effective Factors on the Results of Geotechnical Penetration Tests by Using Manual Dynamic Penetrometer (MDP) in Sandy Soil

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ABSTRACT: Penetration tests in geotechnical engineering are field tests in order to estimate some soil parameters such as soil density, CBR (California Bearing Ratio) and internal friction angle. The advantages of these tests to other field tests are the easiness and rapidity in the application. Although the accuracy of these tests might be in question, the tests can be calibrated by other tests with accepted accuracy. In this paper, a penetration test, called Manual Dynamic Penetrometer (MDP), is introduced, which is designed and constructed at Ferdowsi University of Mashhad (FUM). The principles of the applicability of MDP are similar to other existing penetration tests (such as DCP introduced in ASTM D6591); however, the energy applied to the soil is much higher which facilitates to have more penetrated depth compared to other existing probes. In this apparatus, the probe is a solid 60-degree cone with a diameter of 18mm and the string rod diameter is 16 mm. The cone and string rod are impacted by a hammer with a mass of 10 kilograms which is manually raised and then it falls from a height of 600 mm. In this paper, MDP was applied within Firuzkuh-161 sandy soil with different soil relative densities (Dr = 55, 80, 100%). In this research, different factors influencing the penetration are investigated by using MDP. These factors are the geometry of the cone (cone apex=30o, 60o, and 90o), the cone diameter (18, 30, 40 mm), and the hammer mass (5, 8, 10 kg). The penetration results are presented in terms of penetration index (DPI) which is described as penetrated depth per each impact. By comparing the results, it is found out that cone apex has no influence on the penetration, but the cone diameter changes the rate of penetration. Furthermore, it is seen that there is a linear relationship between applied energy and the average DPI such as what is already used in SPT correlations. By considering the similitude of MDP test and pile driving, it is shown that the results of penetration tests can be used to estimate the internal friction angle of sandy soils.

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1. Introduction

Penetration tests are one set of field tests that are widely used in geotechnical site investigation. In these tests, a driving point (probe) is penetrated the ground by hitting a hammer over an anvil and the number of hits for a constant penetrated distance is measured. Based on the penetration rate of the probe, soil characteristics such as soil density, CBR, or internal friction angle can be estimated. Conventional tests in this group are DP (according to DIN4094[1]) and DCP (according to ASTM D6591[2]). Although a rough estimation of required parameters can be obtained by these tests, the advantages are the easiness and rapidity in the application. In this research, a newly developed apparatus is introduced and effective factors on the results of this penetrometer are investigated.

2. Methodology

In this paper, an apparatus called a Manual Dynamic Penetrometer (MDP) is used. This penetrometer is designed and constructed at Ferdowsi University of Mashhad (FUM) which is registered as a national patent with No. of 94510[3]. The penetrometer consists of a rigid cone with a 60-degree apex with a diameter of the diameter of 18 mm. The string rod, which is extensible to the desired length, has a diameter of 16 mm. A hammer with a mass of 10 kg is raised manually and it falls over the anvil which causes it to penetrate the cone into the ground. The global scheme of the apparatus is depicted in Fig. 1.

The main goal of the design of MDP is to be stronger and to have bigger penetration to existing probes. Table 1 compares the specific energy per each blow of different probes. As can be seen, the energy of MDP is much higher compared to DPL and DCP.

In this research, different factors that may influence the result of MDP, as a typical penetrometer, are studied. These factors in MDP include the cone apex (30, 60, 90 degrees), cone diameter (18, 30, 40 mm), and hammer mass (5, 8, 10 kg). All the tests were performed on Firuzkuh-161 sandy soil

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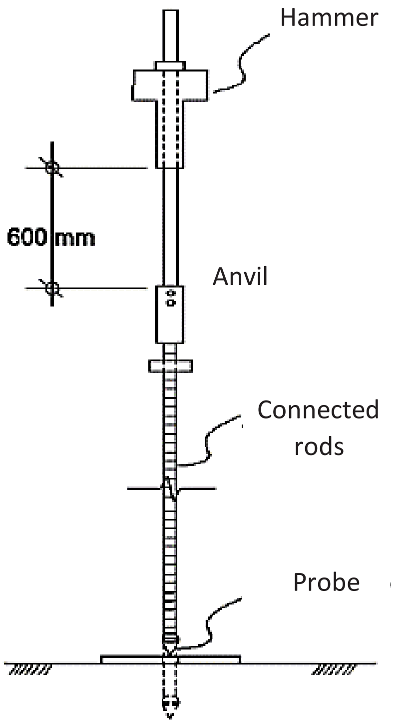

Fig. 1. Schematic view of MDP

Table 1. Comparison of specific energy for different penetrometers

1. No.	2. Apparatus	3. Specific Energy (kJ/m^2)
4. 1	5. DPL	6. 49
7. 2	8. DCP	9. 144
10. 3	11. MDP	12. 236

with three different relative densities of 55, 80, and 100%. Cu and Cc of the soil are 2.06 and 0.84, respectively.

Totally, 54 tests were performed by using MDP on the compacted soil according to the procedure described in ASTM D698[4]. A parameter called DPI (Dynamic Penetration Index) is defined as follows:

where Pi and Bi are the penetration depth (in terms of

$$DPI = \frac{P_{i+1} - P_i}{B_{i+1} - B_i} \quad (1)$$

mm) and blow count of the i-th hit. The unit of DPI is mm/blow. Since the DPI is varied along with the depth, the average weighted DPI (DPIwt-avg) is defined as follows[5]:

$$DPI_{wt\ avg} = \frac{1}{H}\sum_{1}^{N} Z_i^2 \quad (2)$$

where Zi is the depth and H is the total depth where DPI is measured. In the following parts, the results of the tests are discussed in terms of DPIwt-avg.

3. Results and Discussion

The results are presented here briefly and for detailed results, the paper is referred to.

3.1. Effect of cone diameter

As the cone diameter augments, the DPIwt-avg reduces. This is because the applied stress over the cone reduces and thus, the applied energy diminishes.

3.2. Effect of the cone apex angle

A comparison of the results shows that the cone apex has very little effect on the penetration rate and the results of different cone apex angles almost coincide with each other.

3.3. Effect of applied energy

For the apparatus with the cone apex of 60o, the ratio of applied energy (=mgh, where m is the hammer mass, h=0.6 m, g= gravity acceleration) to the weighted average of DPI is calculated for each test. It is found that this ratio is almost constant for different soil relative densities.

According to Fig. 5, it can be concluded that the DPIwt-avg is linearly proportional to the applied energy. This conclusion has been already reported by Schmertmann and Palacios[6], which is now widely used for the energy correction of SPT (Standard Penetration Test) in common practice.

3.4. Relative density

If the results of MDP tests are drawn in terms of Dr along with the DPIwt-avg, according to Fig. 2a, it is seen that there exists a nonlinear relationship for different hammer masses. However, if the Dr is sketched in terms of the normalized DPIwt-avg/E, it can be seen that a straight line can be drawn through the result, according to Fig. 2b, which is not dependent on the hammer mass anymore.

3.5. Internal friction angle

In all the tests performed in this research, the critical depth (Zcr) is obtained and the internal friction angle is estimated by using the graphs introduced by Mayerhof [7] for the estimation of the bearing capacity of driven piles. This idea comes from the fact that the behavior of the MDP is similar to pile driving and the resistance against pile penetration. Based on Mayrhof[7]'s results, the following equation can be re-expressed:

$$\phi_{res} = 11.765 \ln\left(\frac{Z_{cr}}{D}\right) + 6.9057 \quad (3)$$

By using Equation (1), 0res is derived in the range of 32.5~33.5 with the average value of 33, which is equal to the result obtained from the experiment (direct shear tests) as indicated in Table 1. In other words, it is possible to estimate satisfactorily the internal friction of the soil by using MDP results.

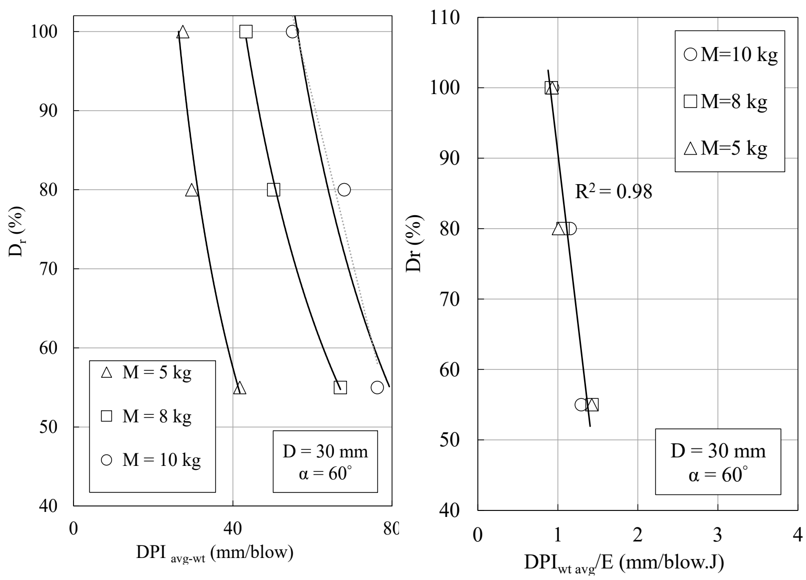

Fig. 2. Variation of relative density (Dr) with DPIwt-avg and the normalized value

4. Conclusions

Based on the experimental tests, the following results can be drawn:

- The cone apex angle does not influence the MDP result, while the cone diameter does.

- The DPI (representative of the blow counts per constant penetration) is linearly proportional to the applied energy from the hammer.

- It is possible to suitably estimate the internal friction angle from the MDP (or any other penetration tests) if the critical depth is obtained.

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