Procds. of the 16th Asian Regional Conference on Soil Mechanics and Geotechnical Engineering,
October 14-18, 2019, Taipei, Taiwan

An estimation method of degree of compaction on embankment slope using the non-destructive testing method

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ABSTRACT

Embankment slope failures have recently occurred frequently due to the natural disasters. The typical regulation for embankment constructions is the degree of compaction on the top of embankment. However, there is no regulation for degree of compaction on the embankment slope. In this study, in order to develop a new system for evaluating the degree of compaction on the embankment slope, non-destructive testing method which measures ground stiffness was developed and performed in laboratory and in-situ. In this paper, in order to investigate the correlation between the dry density (degree of compaction) and ground stiffness obtained by the non-destructive testing method, the non-destructive tests were performed on specimens compacted with various moisture content and soil type conditions in laboratory. The validity of the estimated dry density (degree of compaction) on the embankment slope was confirmed by comparing to the results of RI method.

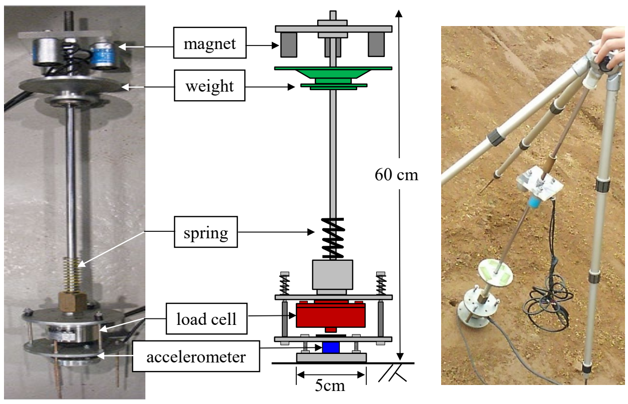
Keywords: embankment slope; degree of compaction; non-destructive testing method

1 INTRODUCTION

Recently, the increase in scales of natural disasters such as localized torrential rain, severe earthquakes and so on has been noticed. As a result, the failure of newly constructed and existing embankment slopes which have never been damaged have occurred. The failure of embankment slope leads to collapsing the whole embankment. Lack of compaction is considered as one of reasons of embankment slope failure.

The degree of compaction of embankment slope tends to be smaller than that of embankment top. The construction procedure is mainly regulated by degree of compaction (D_C = 90%) on the top of embankment. However, there is no regulation for degree of compaction on the embankment slope. This study aims at developing an embankment slope degree of compaction management method. In order to establish a new system for evaluating degree of compaction on the embankment slope, a non-destructive testing method was developed.

In this paper, firstly, in order to investigate the correlation between degree of compaction and ground stiffness obtained by the non-destructive testing method, an indoor non-destructive test was performed on specimens compacted with various moisture contents and soil type conditions. Linear regression equations between dry density and the value measured by this testing method were obtained as a function of normalized moisture content. Secondly, this in-situ test was performed on an embankment slope and the degree of compaction of the embankment slope was estimated. Finally, the estimated dry density (degree of compaction) of the embankment slope by this method was verified by comparing to the results of RI method.



(a) Contrivance of FWD (b) Set up in site

Fig. 1. Schematic diagram of portable Falling Weight Deflectometer (FWD).

2 NON-DESTRUCTIVE TESTING METHOD

As a non-destructive testing method, portable Falling Weight Deflectometer (FWD) was developed for measuring deformation modulus of cement stabilized soil (Sakka et al., 2002). Furthermore, in order to evaluate ground stiffness of embankment slope, this method was improved (Suenaga et al., 2013, Yasufuku et al., 2015).

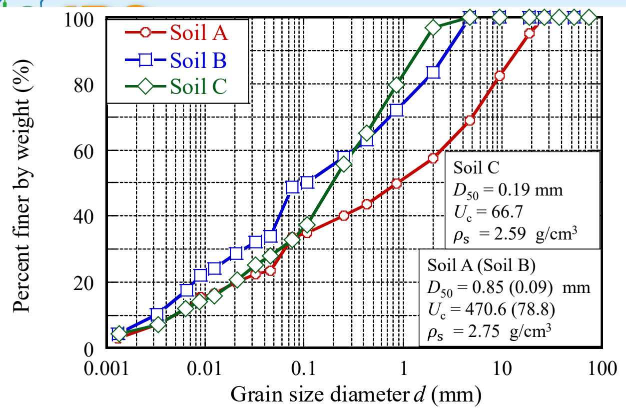


Fig. 2. Particle size distributions of soils used in tests.

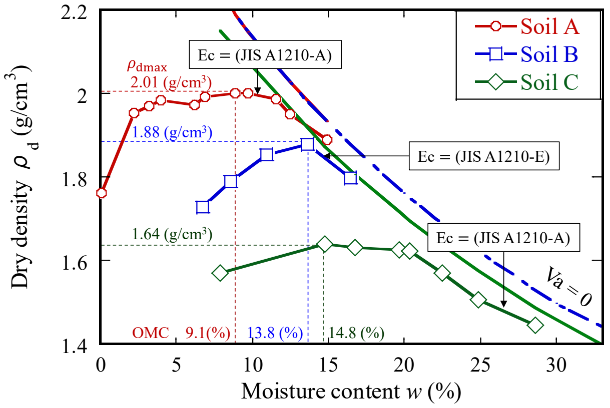


Fig. 3. Compaction curves of soils used in tests.

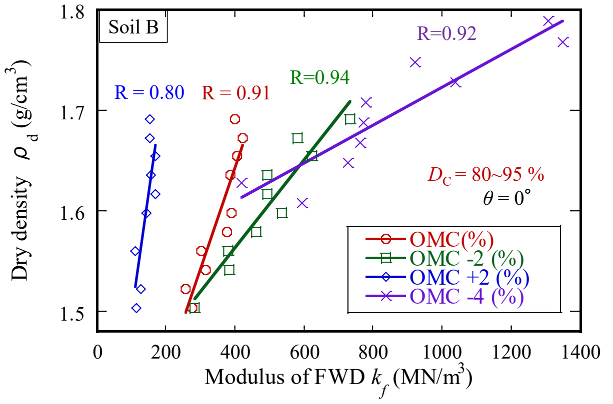


Fig. 4. Relationship between dry density of soil B and modulus of FWD around OMC.

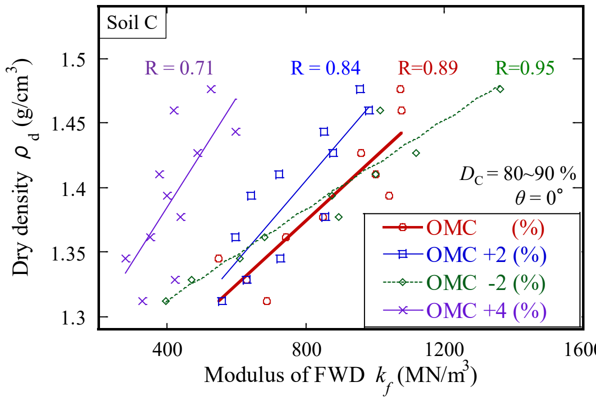


Fig. 5. Relationships between dry density of soil C and modulus of FWD around OMC.

The schematic diagram of this device is shown in Fig. 1. Loading plate fixed with accelerometers is placed horizontally on the embankment slope. The dynamic load caused by falling weight is applied to the ground through the elastic spring. It is possible to change the compressive forces by adjusting the falling weight and the measuring range by adjusting the diameter of loading plate. In this research, the measuring depth is around 10 to 15cm. Maximum stress $\sigma_{\max}$ is obtained by dividing the maximum compressive force by the loading plate area. Maximum ground deformation $u_{\max}$ is obtained by double integrating the measured acceleration. Modulus of FWD are defined by $\sigma_{\max}$ and $u_{\max}$ as follows,

$$k_f = {}^{\sigma_{\max}}/_{u_{\max}} \ (\mathrm{MN/m^3}) \quad (1)$$

It must be noted that the ground stiffness becomes larger by increasing the modulus of FWD.

3 RELATIONSHIP BETWEEN DRY DENSITY AND MODULUS OF FWD IN LABORATORY TEST

3.1 Test procedures in laboratory and characteristics of soils used in tests

When an embankment is constructed, the density and moisture content of the soil are based on the maximum dry density and the optimum moisture content (OMC) obtained by the proctor compaction test. Therefore, in order to investigate the relationship between dry density and the modulus of FWD at OMC, model ground specimens were compacted with various moisture contents and the FWD tests were performed in laboratory. The particle size distribution curves and compaction curves of soil materials used for specimens are shown in Fig. 2 and Fig. 3 respectively. Soil B was obtained by sieving soil A and remove the particles larger than 4.75 mm. The specimens were compacted in five layers by a tamper. The specimens were 150 mm in height and 195 mm in diameter. The specimens were compacted at the degree of compaction ranging between 80 to 90%. The modulus of FWD is defined as the average value in 10 times measurement. By using this test, relationships between dry density and modulus of FWD at optimum moisture contents are already obtained(Fujiwara et al., 2018).

3.2 The effect of moisture content variation on modulus of FWD

OMC was adopted as a base line for embankment construction. However, real scale embankment constructions adopt moisture contents fluctuating around the OMC due to various factors. In order to investigate the effect of variation of moisture content on modulus of FWD, model ground specimens were compacted with various densities and moisture contents less, equal to, larger than the OMC, then FWD tests were carried out. Soil B and Soil C were used for specimen preparation. The specimens prepared with Soil B were compacted at OMC±2% and OMC-4%. Specimens prepared with Soil C were compacted at

OMC ± 2% and OMC+4%. The specimens were compacted at degree of compaction ranging between 80 to 95%. The mold was horizontal to the ground. Fig. 4 and Fig. 5 show the relationships between dry density and modulus of FWD under various moisture contents for each soil. As shown in these figures, the correlation between dry density and modulus of FWD changes under different moisture content conditions. Modulus of FWD tends to decrease by increasing the moisture content for same dry density. It can be observed that the degree of influence of water content on modulus of FWD changes with soil type. However, it was observed that moduli of FWD at same moisture content increase by increasing the dry density. Therefore, there is some possibility to estimate the degree of compaction of ground with known moisture content by using the FWD.

4 APPLYING OF NON-DESTRUCTIVE TEST ON EMBANKMENT SLOPE

4.1 Correlation between dry density of embankment material and modulus of FWD

In order to obtain the linear regression equation between dry density and modulus FWD before field testing on an embankment slope, the correlation between dry density of embankment material and modulus of FWD was investigated in laboratory. The embankment material was Soil A. Specimens were compacted at degree of compaction ranging between 72 to 94%. The size of specimens and compaction procedure were identical as mentioned in section 3.1. Since the embankment for the in-situ experiment would be compacted at natural moisture content, indoor specimens were compacted with moisture content slightly larger than the OMC (11% and 12%). The mold was horizontal to the ground. The maximum stress $\sigma_{\max}$ in FWD test was adjusted by changing the height of falling weight in a way to account for the in-situ embankment (30 degree). The Correlation between dry density of embankment material and modulus of FWD and their linear regression equations are shown in Fig. 6. These linear regression equations in graph were obtained by least squares method. These liner regression equations can be used for estimating the degree of compaction of an embankment with known modulus of FWD.

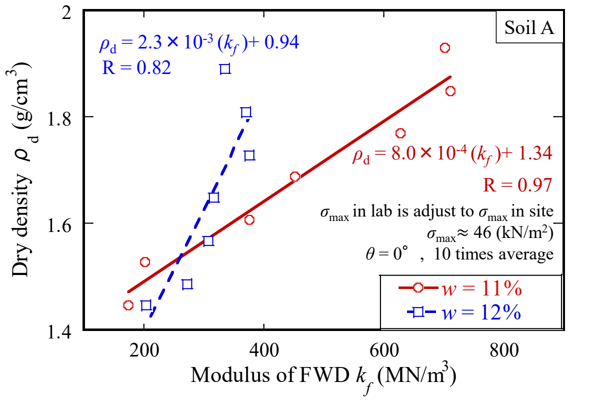


Fig. 6. Correlation between dry density of embankment material soil and modulus of FWD and regression equations.

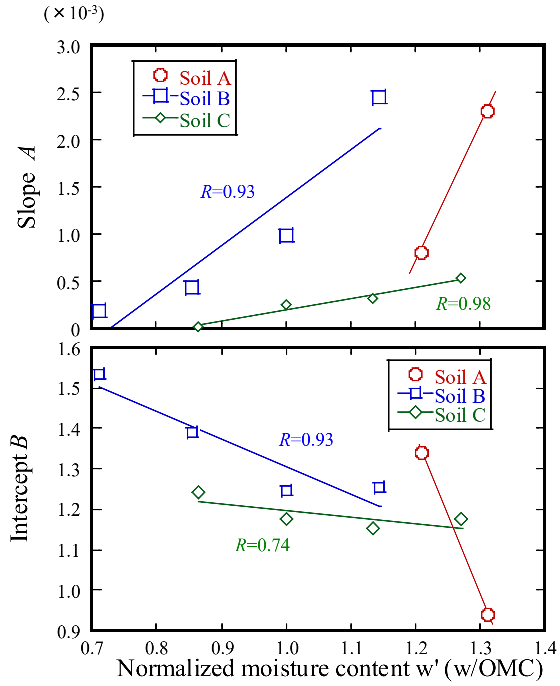


Fig. 7. Relationships between linear regression parameters and normalized moisture contents.

In laboratory, it was clarified that strong linear correlations between dry density and modulus of FWD can be observed under various moisture content conditions for each soil such as Fig. 4, 5 and 6.
These linear relationships can be expressed as follows:

$$\rho_d = A \times k_f + B \tag{2}$$

The relationships between linear regression parameters slope A, interpret B and normalized moisture contents which are divided by optimum moisture content(OMC) are shown in Fig. 7 for estimating dry density of embankment slope at various moisture contents.
In spite of soil type, parameters of A and B have linear correlations with normalized moisture contents.

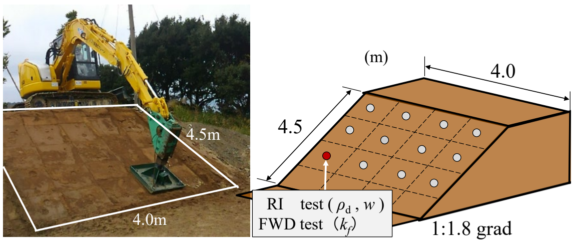


Fig. 8. Schematic diagram of site experiment.

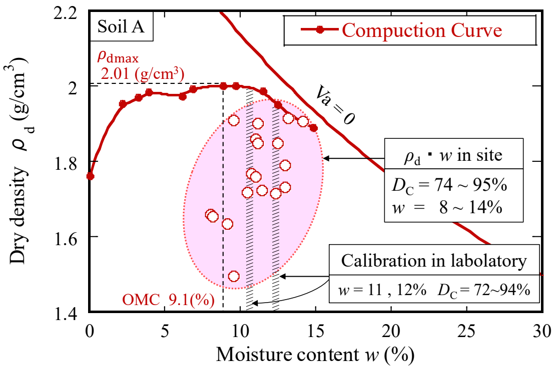


Fig. 9. Compaction curve of the embankment material and dry density and moisture content at the embankment slope in site.

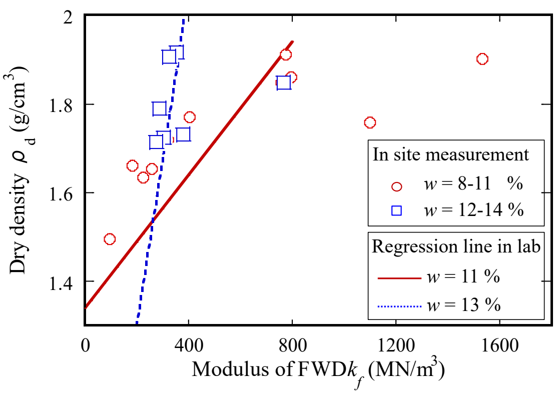


Fig. 10. Relationships between dry density and Modulus of FWD in site and regression equations in laboratory test.

4.2 Test results on embankment slope and discussions

The schematic diagram of in-situ experiment embankment is shown in Fig. 8. Medium size embankment composed of compacted sediments excavated from Kainan city (Soil A), Wakayama prefecture was used in this site. In-situ experiment, the degree of compaction on the embankment slope was controlled by using backhoe. FWD and RI tests were conducted under the different degrees of compaction. FWD tests for measuring moduli of FWD and RI test for measuring dry densities and moisture contents of ground were conducted at the same points. The modulus of FWD is defined as the average value in 10 times measurement. The compaction curve of soil A and dry densities and moisture contents at measuring points of the embankment slope obtained by RI test are shown in Fig. 9. In-situ experiment, the range of moisture content of the embankment slope was 8 to 14% and the range of degree of compaction of embankment slope was 74 to 95%. The relationships between the averaged values of the modulus of FWD and dry densities obtained by RI tests at same points are plotted in Fig. 10. For all plots, a poor correlation between dry density and modulus of FWD in site with large deviation was observed. The plots were separated into two ranges of water content and compared with regression lines obtained by Eq.(2) and Fig. 7 in laboratory. As shown in Fig. 10, most of embankment slope results are in good agreement with the regression lines. The large scattering plots can be attributed to the gravel presence. In future, FWD apparatus needs to be improved to account for various soil types by controlling the fall weight and size of loading plate.

5 CONCLUSIONS

In this paper, as a new method for management of embankment slope, a non-destructive testing method (FWD) was developed. In laboratory, the relationships between dry density and the value measured by FWD test with various moisture contents were investigated. In site, FWD tests were conducted on the embankment slope and the dry density (degree of compaction) of the slope was estimated and compared to the results of RI method.

The following conclusions can be drawn:

1. A strong correlation between dry density and the value measured by FWD test in laboratory for the adopted three soils with different moisture content was observed.
2. Dry densities measured by RI method on the embankment slope are in good agreement with the estimated values by the in-situ FWD test and the regression lines obtained in laboratory.

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