Compaction quality on the embankment slope and its evaluation method

Noriyuki Yasufuku i), Ryohei Ishikura ii) and Mitsuru Taniyama iii)

i) Professor, Department of Civil Engineering, Kyushu University, 744, Motooka, Nishi-ku, Fukuoka 819-0395, Japan.
ii) Assistant professor, Department of Civil Engineering, Kyushu University, 744, Motooka, Nishi-ku, Fukuoka 819-0395, Japan.
iii) Engineer, Asakawa Co., Ltd., 3-69 Komatsubaradori Wakayama 640-8551, Japan

ABSTRACT

Embankment is one of the most important soil structures that correspond with the diversity of performance. The typical regulation for embankment is the degree of compaction at the top of embankment. In order to properly prevent embankment failures due to natural disasters, improvements of quality and function of embankments are considered. In this paper, firstly, improvements of compaction effect are investigated by applying a general compaction method to the test embankment. Secondly, in order to develop a new system for evaluating the degree of compaction on the embankment slope, a non-destructive testing was performed in the laboratory and site. Furthermore, the relationship between the degree of compaction and ground stiffness obtained from non-destructive testing were investigated in detail. An effective procedure for evaluating the quality of the embankment slope was proposed.

Keywords: embankment slope, degree of compaction, falling weight deflectometer

1 INTRODUCTION

Recently, economic and environmental viewpoints have become very important factors in the construction of soil structures. Embankment is one of the most important soil structures that correspond with the diversity of performance. This soil structure is often utilized in roads, highways, railways, river dikes, and so on. The construction procedure is mainly regulated by the degree of compaction ($D_c=90\%$) on the top of embankment. Recently, embankment failures have occurred frequently due to the natural disasters (earthquake, heavy rain fall, and so on). In order to prevent embankment failures due to natural disasters, it is necessary to improve the quality and function of embankments. In this paper, structural integrity of embankment slope is considered for improving the disaster protection function based on the degree of compaction. Improvements of compaction effect were firstly investigated by using a general compaction method to the test embankment. Secondly, in order to develop a new system for evaluating the degree of compaction on the embankment slope, a non-destructive testing was performed in the laboratory and site. Furthermore, the relationships between the degree of compaction and ground stiffness obtained from non-destructive testing were investigated in detail. An effective procedure for evaluating the quality of the embankment slope was proposed.

2 SITE INVESTIGATION AND LABORATORY TESTING FOR TEST EMBANKMENT

2.1 Site investigation procedure

In this study, medium size embankment composed of compacted sediments excavated from Kainan city, Wakayama prefecture was used for investigating compaction effect on embankment slope. Fig. 1 shows the schematic illustration of the test embankment. The top of the embankment is $4m \times 12m$. Height and slope gradient are 2m and 1:1.8, respectively. Layer depth is 30 cm and number of rollings by vibratory roller is 8 rollings per layer. After reaching the specific height of embankment top, the shape of embankment slope was adjusted the shape by the bucket of excavator. The soil particles that exist in the range of 30 to 40 cm from the surface of embankment top and slope was replaced with different kind of soil particles (Soil A, B and C). The particle distribution curves and physical properties of
Soil A
Soil B
Soil C
Percent finer by weight (%)
Grain size diameter $d$ (mm)

Fig.2. Soil particle distribution curves.

Table1. Physical properties of soils.

| Soil          | Soil A | Soil B | Soil C |
|---------------|--------|--------|--------|
| $\rho_{d_{\text{max}}}$ (g/cm³) | 2.03   | 2.08   | 1.97   |
| $w_{\text{opt}}$ (%)           | 9.1    | 7.0    | 10.0   |
| $w_{\text{nature}}$ (%)        | 10.7   | 10.6   | 10.2   |
| JGS classification of soil     | GFS    | GS-F   | SG-F   |

these materials are shown in Fig.2 and Table1.

### 2.2 Compaction method for embankment slope

In this site investigation, two types of compaction method were applied for improving the slope quality. The embankment slope was compacted dynamically using a bucket of excavator. This is called tamping method (Yasufuku et al. 2012). The number of tampings was 0, 5, 15 and 30 blows, respectively. The embankment slope was also compacted using a vibration method (Kobayashi et al. 2012). Compaction plate was contacted to the slope surface and vibrated using the impact load of the hydraulics breaker. The compaction time was 0, 3, 6, 9 and 12 seconds, respectively.

### 2.3 RI measuring apparatus and Non-destructive testing method

After compacting, degree of compaction was measured by RI measuring apparatus. Degree of compaction $D_c$ is obtained as follows:

$$D_c = \left( \frac{\rho_d}{\rho_{d_{\text{max}}}} \right) \times 100(\%)$$

(1)

Here, $\rho_d$ denotes the dry density obtained from RI measuring. $\rho_{d_{\text{max}}}$ denotes the maximum dry density obtained from compaction test in laboratory.

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). In this study, in order to evaluate ground stiffness of embankment slope, this method was improved by geotechnical laboratory at Kyushu University (Ninomiya et al., 2009).

The schematic diagram of this device is shown in Photo1. Loading plate (Contact surface) fixed with accelerometers is grounded 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 force by adjusting the falling weight. Spring and falling height is constant. It is also possible to change the measuring range by adjusting the diameter of loading plate. In this research, the measuring depth is around 10 to 15cm, theoretically. Maximum stress $\sigma_{\text{max}}$ is obtained by dividing the maximum compressive force by the loading plate area. Maximum ground deformation $u_{\text{max}}$ is obtained by double integrating the measured acceleration. The modulus of FWD are defined by $\sigma_{\text{max}}$ and $u_{\text{max}}$ as follows,

$$k_f = \left( \frac{\sigma_{\text{max}}}{u_{\text{max}}} \right) (MN/m^3)$$

(2)

For large modulus of FWD values the ground is evaluated as high stiffness geomaterial.

### 3 COMPACTION QUALITY OF TEST EMBANKMENT

#### 3.1 Degree of compaction on embankment top

Fig.3 shows the relationships between degree of compaction and number of rollings on embankment top using soil A material. This figure indicates that the average values and distribution at every number of rollings, respectively. Measuring points were ranged from 4 to 16 points. Fluctuation ranges of degree of compaction were so large at several number of rollings. Averaged degree of compaction increased with an increase of number of rollings. However, from the fluctuation of compaction quality point of view, it was
considered that standard number of rollings (8 times) is enough to satisfy the specific degree of compaction under this embankment conditions.

Fig.4 shows the relationships between number of rollings and degree of compaction on embankment top for different kinds of soil at the same measuring point.

As shown in this figure, degree of compaction reached more than 90% at 8 rollings regardless of soil type, and converged to the constant value with an increase of number of rollings.

3.2 Degree of compaction on embankment slope

Fig.5 shows the relationships between degree of compaction and number of tampings on embankment slope composed of soil A material. This figure is arranged by the average values and distribution at every number of tampings. The number of tampings was 12, 24 and 50 blows, respectively. The averaged degrees of compaction were 87%, 85% and 88%, respectively. It was found that increasing the number of tampings does not affect the improvement of degree of compaction.

Fig.6 (a) shows the relationships between degree of compaction and number of tampings at the same measuring points. Regardless of soil type, degree of compaction was initially increase by 5 blows.

However, these converged to the constant value with an increase of number of tampings. Fig.6(b) shows the relationships between normalized degree of compaction and number of tamping by tamping method.

Normalized degree of compaction is defined as the degree of compaction divided by initial degree of compaction before compacting. Initial degrees of compaction $D_{c,initial}$ were 72.4%, 71.6% and 83.0% for soil A, B and C, respectively. As shown in the relationships between normalized degree of compaction and the number of tamping, normalized degrees of compaction has different tendency against kinds of soil particles. Tamping method has to strictly control the optimum compaction time and number of tamping according to different soil particles.
Fig. 7 shows the relationship between number of tampings and modulus of FWD on embankment slope. As a result of site investigations, it was clarified that compaction quality of embankment top and slope are different spatially. In comparison with the degree of compaction and the modulus of FWD of embankment top and slope, it was recognized that the compaction quality of embankment slope was inferior compared to the top of embankment.

4 APPLICATION OF NON-DESTRUCTIVE TEST FOR EXECUTION MANAGEMENT OF EMBANKMENT SLOPE

4.1 Test results in laboratory

In order to investigate the influence of degree of compaction and water content on modulus of FWD, standard proctor compaction test (JIS A 1210-E) and non-destructive testing using large size compacted specimens in laboratory were performed with Soil A. Large size compacted specimen is molded using the same compaction energy per unit volume of standard proctor compaction test. The specimen was around 30cm in diameter and 30cm in height. Soil particle size in Soil A is less than 4.75mm. The maximum dry density \( \rho_{d_{\text{max}}} \) was 1.88 g/cm\(^3\) and optimum water content \( w_{\text{opt}} \) was 13.3\%. In the case of actual soil particles including more than 4.75mm particles in Soil A, maximum dry density \( \rho_{d_{\text{max}}} \) was 2.03 g/cm\(^3\) and optimum water content \( w_{\text{opt}} \) was 8.7\%.

Fig. 8 shows the relationship between modulus of FWD and degree of compaction, water content. As shown in this figure, moduli of FWD with optimum water content increase with an increase of degree of compaction. Moduli of FWD in the same degree of compaction line \( (D_{C}=90\%) \) are almost equal around the area that water content \( w \) is smaller than \( w_{\text{opt}} \). On the other hand, moduli of FWD around the area that water content \( w \) is larger than \( w_{\text{opt}} \) becomes smaller than that of optimum water content \( w_{\text{opt}} \) in the same degree of compaction line \( (D_{C}=90\%) \).

If the threshold of \( D_{C} \) can be determined by using contour of modulus of FWD \( k_{F} \), there is possibility to manage the embankment slope effectively.

4.2 Test results in field measurement

Non-destructive testing was also performed in the test embankment with Soil A. Fig. 9 shows the investigating 52 grids of embankment slope. Degrees of compaction were measured 5 times and modulus of FWD were measured 10 times at the same grid. Fig. 10 shows the relationships between averaged dry density and averaged modulus of FWD at several grids. The total averaged value of \( k_{F} \) was around 251(MN/m\(^3\)). A standard deviation \( \sigma \) was 112. In order to apply non-destructive test for execution management of embankment slope, the relationship between dry density and modulus of FWD is drawn as a linear approximation in Fig. 9. In this study, detection rate is introduced for deciding adequate value of \( k_{F} \) whether embankment slope was compacted more than
Table 2. Regulation of embankment based on moduli of FWD.

| Definition of moduli of FWD | Number of detection | Detection rate |
|----------------------------|---------------------|----------------|
| $k_f=150$ (MN/m$^3$)       | 40/52               | 76.9%          |
| Linear approximation       | 30/52               | 57.7%          |
| Standard deviation +σ      | 18/52               | 34.6%          |
| Standard deviation -σ      | 39/52               | 75.0%          |

90% of degree of compaction or not. Here, in order to define the degree of compaction in site, maximum dry density measured is used as $\rho_{d_{\text{max}}}$ in this site.

Table 2 shows the regulation of embankment based on moduli of FWD. As shown in this table, when the $k_f$ is decided as 150 MN/m$^3$, the detection rate indicated highest value (77%) with Soil A.

5 CONCLUSIONS

In this paper, improvements of compaction effect are investigated by using a general compaction method to the test embankment with three different kinds of soil particles. Further, as a new method for execution management of embankment slope, non-destructive testing was applied in the laboratory and site.

The following conclusion could be mainly drawn:

1) It is found from experimental results that the average degree of compaction on the surface of embankment slope is always around 10% less than that on the top of the embankment, irrespective of type of soils.

2) FWD modulus obtained by Falling Weight Deflectometer is an important factor for judging the quality of the embankment.

ACKNOWLEDGEMENTS

The authors express their thanks to Mr. M. Nakashima, who is a technical staff and Mr. S. Suenaga, who is a former master student for variable experimental supports. In addition the authors acknowledge to Prof. H. Hazari for his continuous academic advice.

REFERENCES

1) Kobayashi, T., Taniyama, M. and Yasufuku, N. (2012): Soil compaction device using hydraulic hammer of excavator, *Proceedings of 2012 Symposium on Construction Method and Machinery*, 117-120 (in Japanese).

2) Ninomiya, H., Yasufuku, N. et al. (2009): Characteristic and purpose of portably nondestructive evaluation device of slope soundness, *Proceedings of 44th Japan Geotechnical Society of Annual meeting*, 69-70 (in Japanese).

3) Sakka, H., Ochiai, H., Yasufuku, N. and Omine, K. (2002): Evaluation of deformation-strength properties of cement-stabilized soils by falling weight deformation measurement apparatus, *Journal of Japan Society of Civil Engineers*, No.702/III/Vol. 58, 283-292 (in Japanese).

4) Yasufuku, N., Taniyama, M. and Kobayashi, T. (2012): Quality evaluation on slope of embankment based on the compaction control, *Proceedings of 2012 Symposium on Construction Method and Machinery*, 111-116 (in Japanese).