貯水池盛土土壌の諸指数による残留摩擦角の予測
Predicting residual frictional angle by different indexes for reservoir embankment soil

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1. Introduction

Slope stability is one of the greatest issues of concern in geotechnical engineering. In slope stability analyses, the residual frictional angle of slip zones is the most important parameter for evaluating slope stability and for understanding the reactivation mechanisms. However, the performance of laboratory tests to obtain the residual frictional angle through shear testing is complex and costly. Therefore, many researchers have focused their attention on predicting the residual frictional angle from the available indexes. It is noted that most of the existing correlations reported in literature have been derived for fine-grained particles (FGP; 0-0.075 mm) with few or none for coarse-grained particles (CGP; more than 0.075 mm). According to the Japanese Institute of Country-ology and Engineering, the desirable soil material for reservoir embankments, in terms of the amount of FGP, should be between 15% and 50%. That is to say, the formulas of prior researchers who focused on the correlations between the residual frictional angle and the different indexes cannot be applied to reservoir embankment soil which has a higher amount of CGP. The aim of this research is to propose formulas for predicting the residual frictional angle from the available indexes for reservoir embankment soil with a high amount of CGP.

2. Materials and methodology

It is said that the residual shear strength can be measured by testing remolded samples and that the residual shear strength is not influenced by the stress history. Therefore, remolded soil samples were used in this research. Samples were taken from Hojo, Matsuyama, Japan, as suitable material for reservoir embankments. Based on the basic theory of desirable soil for reservoir embankments, eight soil samples were made with a 0.075-mm sieve.

In this research, a grain size analysis, a liquid limit test, a plastic limit test, a compaction test, a soil particle density test and a Bromhead ring shear test were conducted. All tests were performed according to the standards of the Japanese Geotechnical Society.

3. Results and discussion

Details of the samples and their residual frictional angles, φ_r, are given in Table 1, along with the corresponding soil properties. From this table, it is seen that the residual frictional angle of the soil samples varied considerably, from 18° to 29°, in the scope of desirable soil material for reservoir embankments; the value of the liquid limit varied from 25.1% to 36.6%; and similarly, the value of the plastic limit varied from 14.6% to 19.4%. Notably, the liquid limit, plastic limit and plasticity index increased with the increasing FGP. It is also evident that the residual frictional angle was inversely related to the liquid limit, plastic limit, plasticity index and ratio of FGP.

The determination coefficients of the linear correlations among the different indexes are given in Table 2. From this table, it is seen that all the indexes here have correlations with the residual frictional angle. These correlations between the residual frictional angle and the liquid limit (ω_L), plastic limit (ω_P), and ratio of FGP (R_t) are shown in Figs, 1-3, respectively. Compared to the other indexes, the liquid limit has a better correlation with the residual frictional angle, with R^2 = 0.97. That is to say, the liquid limit could be used for predicting the residual frictional angle with high accuracy. It is also found that the ratio of FGP correlates well with the liquid limit, plastic limit and residual frictional angle, using the high determination coefficients given in Table 2.

The correlations between the residual frictional angle and the different indexes are shown here, especially for the desirable soil material of reservoir embankment dams. However, the actual ratio of FGP in reservoir embankments nowadays is 0 to 100%. Therefore, conducting research which considers a wider scope of FGP amounts, and finding a more precise formula for predicting the residual frictional angle should be done.

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Table 1 Details for creating original samples of embankment soil as well as soil properties and residual frictional angle of each sample (Fang *et al.*, 2019, revised)

Sample	Ratio of FGP (%)	Every 1 kg of original soil	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)	φ_r
1	15.1	− 243g FGP	25.1	14.6	10.4	28.7
2	20.0	− 196g FGP	28.4	15.0	13.3	26.6
3	25.0	− 143g FGP	30.8	15.5	15.2	24.4
4	30.0	− 81g FGP	31.5	16.0	15.5	22.4
5	35.7	Original soil	32.7	16.9	15.7	22.2
6	40.0	+ 72g FGP	33.8	18.3	15.4	21.1
7	45.0	+ 169g FGP	34.4	18.9	15.4	20.6
8	49.5	+273g FGP	36.6	19.4	17.1	18.6

Table 2 Determination coefficients of linear correlations among the parameters

Index	φ_r	ω_L	ω_P	I_P	R_t
φ_r		0.97	0.85	0.84	0.94
ω_L	0.97		0.85	0.88	0.94
ω_P	0.85	0.85		0.54	0.96
I_P	0.84	0.88	0.54		0.69
R_t	0.94	0.94	0.96	0.69	

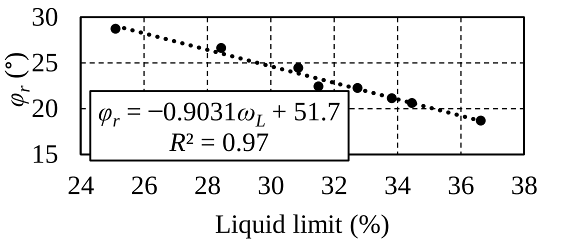

Fig. 1 Residual frictional angle vs. liquid limit (Fang *et al.*, 2019)

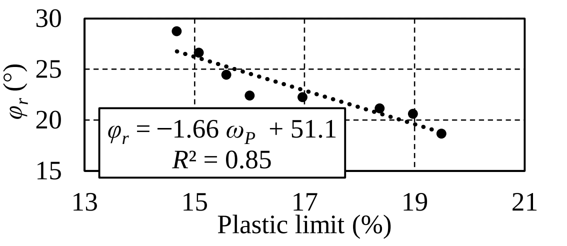

Fig. 2 Residual frictional angle vs. plastic limit (Fang *et al.*, 2019)

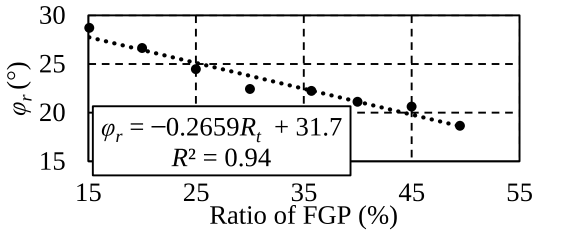

Fig. 3 Residual frictional angle vs. ratio of FGP

4. Conclusions

The aim of this research was to find the correlations for predicting the residual frictional angle for reservoir embankment soil by different indexes which could be obtained in a short time. This paper described a series of drained ring shear tests on eight soil samples, created from suitable material for reservoir embankments by changing the ratio of FGP, with the Bromhead ring shear apparatus. The results presented in this paper have led to the following general conclusions:

The residual frictional angle is in inverse correlation to the liquid limit, plastic limit and plasticity index. By increasing the ratio of FGP, the liquid limit, plastic limit and plasticity index also increase, whereas the residual frictional angle decreases. These results follow the basic theory of geotechnical engineering. Compared with the other indexes, the liquid limit has a better correlation for predicting the residual frictional angle by the linear relationship in such a soil, which provides a convenient perspective with high accuracy for application in geotechnical engineering.

From the research viewpoint, this study has proposed formulas for reservoir embankments in one type of soil. In the next research, focus should be placed on general soil for reservoir embankments. It is anticipated that one more precise formula will be introduced in the next step.

Reference

Fang, C., Shimizu, H., Nishiyama, T., Nishimura, S.: Predicting Residual Frictional Angle by Atterberg Limits for Reservoir Embankment Soils, *Int. J. GEOMATE*, 2019, in press.