Estimation of Average Shear Strengths along the Slip Surface of Rainfall induced Mudstone Landslides

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Abstract

Landslides have several contributory causes. Among them, soil shear strength is important for the activation and reactivation, and the shear strength of the soil at the slip surface is directly related to sliding. Soil shear strength is not a uniform characteristic of a particular soil, but it changes from post-peak to fully softened and residual strength according to the soil condition. In order to plan effective control works for the prevention of landslides, what is important in the safety evaluation of landslides is to understand shear strengths of the soil or rock along the slip surface, based on both the slide patterns and actual slip surface conditions and to determine the appropriate average shear strength that acts along it. In Japan, the average shear angle of shear resistance is generally estimated by back calculation assuming the average cohesion in kilopascals to be equal to the average depth in meters of the slip surface. This method is practical and relatively based on empirical factors, but the basis of soil mechanics is scant. Although, in several studies, it has been attempted to use the shear strength obtained from laboratory shear tests in the stability analysis of landslides, it takes a long time to determine shear strength using ring shear and triaxial tests.

As far as landslides in Okinawa, Japan, are considered, many have occurred in the Shimajiri-mudstone area in the past. The Neogene Shimajiri-mudstone is widely distributed in the central and southern areas of the Okinawa Island and along the marine terrace in the North Eastern part of Miyako Island. The average shear strength of the Shimajiri-mudstone landslides having different slide patterns have been obtained by two methods involving an estimation method using the shear strength diagram, the relationship between the shear strength and mineralogical properties of landslide soils and an ordinary method using the results of laboratory shear tests of soil samples. The deference of the two average shear strengths was small in the case of the landslides where the residual and fractured-mudstone peak strengths had been mobilized, while the two methods produced close agreement in case of the landslides where the residual and fully softened strengths had been mobilized. Although the determination of appropriate average shear strength is done using the measured shear strength of slip surface soil as a fundamental rule, when it is difficult to do so due to certain restrictions, the average shear strengths can be effectively estimated using the shear strength diagrams.

1. Introduction

Landslides have several contributory causes. Among them, the shear strength of the soil at the slip surface is directly related to sliding. What is important in the safety evaluation of landslides is to understand shear strengths of the soil or rock along the slip surface, based on both the slide patterns and slip surface conditions. However, it takes a long time to determine shear strength in the laboratory with high accuracy (Skempton, 1985; Nakamura et al., 2010). This study discusses the estimation of shear strengths of slip surface soil through the soil properties, such as plasticity index and clay minerals (Gibo et al., 2000; Nakamura, 2001; Gibo et al., 2003b; Nakamura et al., 2010) and the estimation of average shear strength along the slip surface of Shimajiri-mudstone landslides, Okinawa, Japan.

2. Shimajiri-mudstone, Okinawa, Japan

Okinawa prefecture

- Most southern part of Japan
- About 160 islands
- Temperature
  22.7 ℃ (average annual)
- Precipitation
  2036.9 mm
  (average of 1971-2000)
- Area
  2265 m²
- Population
  1,380,000

Geological background

Shimajiri-mudstone area is very much prone to landslides (Gibo et al., 2008).

The Neogene Shimajiri-mudstone is widely distributed in the central and southern areas of the Okinawa Island and along the marine terrace in the North Eastern part of Miyako Island (Kizaki and Takayasu, 1976).

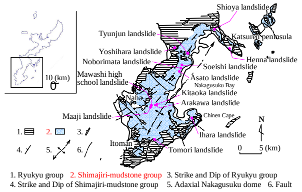


Fig.1 Location map in the area of Shimajiri-mudstone (addition to Sasaki et al., 1990)

3. Shear strength diagrams of landslide soils

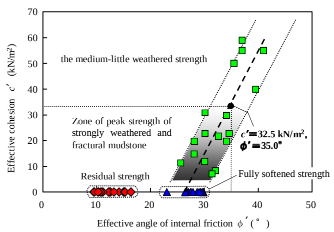


Fig.1 The shear strength diagram of mudstone of the Shimajiri group,Okinawa (Gibo et al., 2003a)

Fig.1 described by Gibo et al. (2003a) shows the variability of shear strength that exists in the Shimajiri-mudstone of Okinawa, where the strength characteristics of each weakened mudstone are identified in the matrix of the relationship between c' and ϕ' obtained from shear tests. The strength zone for strongly weathered and fractured mudstones was given first by drawing the small area that reaches from the strength of **c' = 32.5 kN/m² and ϕ' = 35.0°** close to the fully softened strength in the c-ϕ figure. The parameters of fully softened strength and residual strength were within the range of ϕ_d = 23-30° and ϕ_r = 9-17°, respectively.

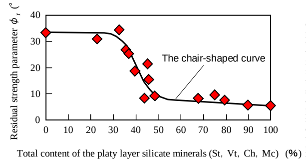


Fig.2 Variation of the residual strength parameter ϕ_r versus total contents of prefered-oriented clay minerals (Smectite, Vermiculite, Chlorite, Mica) in the sub-425-μm soil fraction (Gibo et al., 2003b)

Fig.2 shows the variation of the residual strength parameter ϕ_r as a function of the total content of smectite, vermiculite, chlorite and mica in the sub-425-μm soil fraction. In fig.2, ϕ_r and the total content of these minerals show a relationship that allows all soils examined in the fraction to **be plotted near the regression line of a chair-shaped curve**. We find that the total content of the platy layer silicate minerals in the bulk soil can be used for predicting ϕ_r, because it adequately reproduces the differences in ϕ_r for a wide range of landslide soils that differ in geology, soil type, physical and mineralogical properties and shear strength.

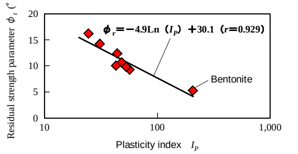


Fig.3 The diagram of relationship between the plasticity index I_p and residual strength parameter ϕ_r of mudstone of the Shimajiri group,Okinawa (Kimura et al., 2010)

Fig.3 shows the relationship between the plasticity index I_p and residual strength parameter ϕ_r of mudstone of the Shimajiri group and bentonite. Good agreement was found between ϕ_r and I_p, and the equation for the entire set of data points in Fig.3. The statistical fit r equals 0.929.

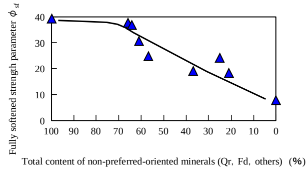


Fig.4 Variation of the fully softened strength parameter ϕ_d versus total contents of non-preferred-oriented minerals (Qr, Fd, others) in sub-425-μm soil fraction (Gibo et al., 2003b)

Fig.4 shows the variation of the fully softened strength parameter ϕ_d as a function of the total content of quartz, feldspar and others (kaolinite, calcite, dolomite) in the sub-425-μm soil fraction. The total content of these minerals is over 70 %, and ϕ_d gradually decreases from 40° to 35° with decreasing total content of minerals, and decreases from 35° to 10° in an approximated line as shown in the figure.

4. Estimation of shear strengths and stability analysis

Tyunjun landslide

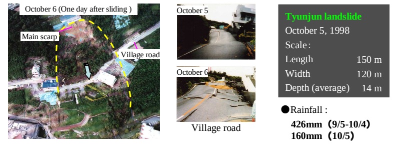


Photo 1 Aerial view of the Tyunjun landslide

Tyunjun landslide	
October 5, 1998	
Scale:	
Length	150 m
Width	120 m
Depth (average)	14 m

●Rainfall :
426mm (9/5-10/4)
160mm (10/5)

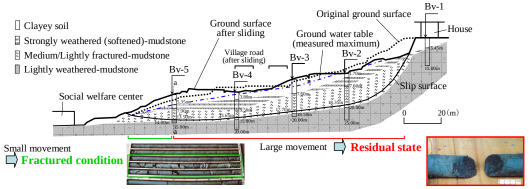


Fig.5 The cross section of Tyunjun landslide

GRAPHICAL ESTIMATION of the SHEAR STRENGTHS

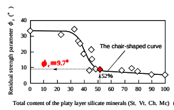


Fig.6 Estimation of the residual strength parameter using the chair-shaped curve

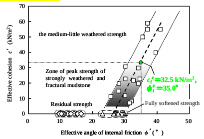
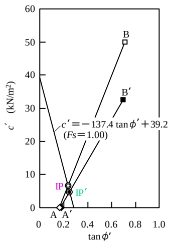


Fig.7 Estimation of the fractured peak strength

COMPARISON of BACK CALCULATED AVERAGE SHEAR STRENGTH



Shear strength parameters using the shear strength diagrams	Shear strength parameters using laboratory shear tests
A′ : Residual strength (tan9.7°, 0.0 kN/m²) B′ : Fractured peak strength (tan35.0°, 32.5 kN/m²)	A : Residual strength (tan9.3°, 0.0 kN/m²) B : Fractured peak strength (tan35.5°, 50.0 kN/m²)
IP′ : Average shear strength along the slip surface (tan14.0°, 4.9 kN/m²)	IP : Average shear strength along the slip surface (tan13.3°, 6.7 kN/m²)

The difference of the two average shear strength parameters along the slip surface was small

The c' − tan ϕ' diagram from the stability analysis of Tyunjun landslide

Noborimata landslide

Photo 2 Noborimata landslide

Noborimata landslide	
June 17, 2005	
Scale:	
Length	150 m
Width	100 m
Depth (average)	7 m

●Rainfall :
549 mm (6/11-6/17)

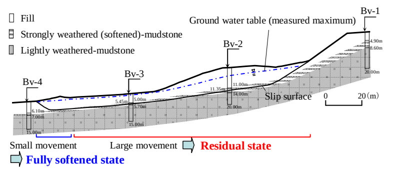


Fig.8 The cross section of Noborimata landslide

GRAPHICAL ESTIMATION of the SHEAR STRENGTHS

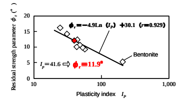


Fig.9 Estimation of the residual strength parameter using the equation

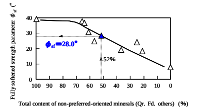
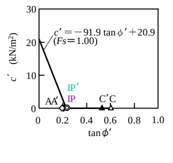


Fig.10 Estimation of the fully softened strength parameter using the approximated line

COMPARISON of BACK CALCULATED AVERAGE SHEAR STRENGTH



Shear strength parameters using the shear strength diagrams	Shear strength parameters using laboratory shear tests
A′ : Residual strength (tan11.9°, 0.0 kN/m²) B′ : Fully softened strength (tan28.0°, 0.0 kN/m²)	A : Residual strength (tan11.5°, 0.0 kN/m²) B : Fully softened strength (tan31.3°, 0.0 kN/m²)
IP′ : Average shear strength along the slip surface (tan12.8°, 0.0 kN/m²)	IP : Average shear strength along the slip surface (tan12.8°, 0.0 kN/m²)

The two methods produced close agreement

The c' − tan ϕ' diagram from the stability analysis of Noborimata landslide

5. Summary

Average shear strength parameter along the slip surface of the four Shimajiri-mudstone landslides having different slide patterns have been obtained by two methods involving an estimation method using the shear strength diagrams of landslide soils and an ordinary method using the results of laboratory shear tests of soil samples. The deference of the two average shear strengths was small in the case of the landslides where the residual and fractured-mudstone peak strengths had been mobilized, while the two methods produced close agreement in case of the landslides where the residual and fully softened strengths had been mobilized. Although, the determination of appropriate average shear strength parameter is done using the measured shear strength of slip surface soil as a fundamental rule, when it is difficult to do so due to certain restrictions, the average shear strength parameter can be effectively estimated using the shear strength diagrams.

References

Gibo S., Nakamura S. and Egashira K. (2000): *Trans. of JSIDRE*, 210, 69-74 (in Japanese with English abstract). Gibo S., Nakamura S., Higa Y., Yoshizawa M. (2003a): *Trans. of JSIDRE*, 227, 113-118 (in Japanese with English abstract). Gibo S., Nakamura S. and Sasaki K. (2003b): *the Japan. Landslide Soc. J.* 40(4), 1-7 (in Japanese with English abstract). Kimura, S., Gibo S. and Nakamura S. (2010): *Trans. of JSIDRE*, 270, 9-17 (in Japanese with English abstract). Nakamura, S. (2001): *PhD thesis*, Univ. of Kagoshima. Nakamura, S., Gibo, S., Egashira, K. and Kimura, S. (2010): *Geology*, 38(8), 743-746. Skempton, A.W. (1985): *Géotechnique*, 35(1), 3-18.