地すべりの回復強度と安定解析

Recovered strength and stability analysis of landslide

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1. INTRODUCTION

Reactivated landslides have been subjected to repeated sliding and recession. The shear strength of shear zone is reduced to the residual state during sliding, but could be recovered to some extent during a stable period. Chandler (1977) investigated the Barnsdale landslide and indicated that the shear strength of slip-surface zone was recovered during such a stable period prior to re-sliding. However the recovered strength was not used in back analysis of the landslide because it was small and placing reliance on such recovered strength was judged unrealistic for design purposes. Nakamura and Gibo (2000) recognized the significant recovery of the residual strength under normal stresses of 30 to 150kN/m^2 in laboratory tests, in which the remolded landslide soils were subjected to large-displacement shear, re-consolidation, and re-shear. Stark et al. (2005) too carried out healing tests subsequent to shear on shale samples and had found evidence for strength gain. Residual strength has been used for stability analysis in Japan to represent the average strength of the slip surface of reactivated landslides, where the slide had occurred along a pre-existing slip surface (Agriculture Structure Improvement Bureau, Ministry of Agriculture, Forestry, and Fisheries, Japan, 2004). The present article describes the application of recovered strength in the stability analysis of the reactivated landslide that occurred at Xuechengzhen, China.

2. RECOVERED STRENGTH OF LANDSLIDE SOIL

The shear strength of the soil samples has been determined with a ring-shear testing apparatus designed by Gibo (1994). The soil samples are consolidated at different normal stresses ranging from 30 to 300kN/m^2. The soil has been subjected to shear in the immersed condition until the residual state is attained. After attaining the residual state, the soil is re-consolidated for two days without further displacement by shear and then re-sheared to estimate the magnitude of the strength recovery from the residual strength. The shear test is carried out with a shear rate of 0.01 mm/min to ensure that pore water pressure build up does not occur (Bishop et al., 1971).

The data shown in Table 1 are the shear strength parameters of the soil estimated by the Coulomb's law of friction. The parameters of the fully softened strength are estimated to be c_{sf} = 6.7kN/m^2 and

Table.1 Shear strength parameters of soil sample

Sample	Effective normal stress σ_n' (kN/m²)	Fully softened strength c_{sf} (kN/m²)	Fully softened strength ϕ_{sf} (°)	Residual strength c_r (kN/m²)	Residual strength ϕ_r (°)	Recovered strength c_{rc} (kN/m²)	Recovered strength ϕ_{rc} (°)
Xuechengzhen	30-300	6.1	30.1				
	30-150			4.1	25.8	5.5	26.4
	200-300			0	24.8		

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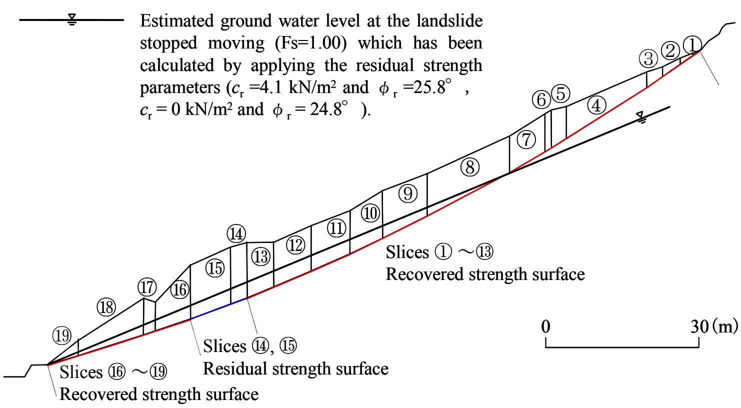

Fig.1 Cross-sectional diagram for the stability analysis

ϕ_{sf} = 30.1°. Residual strength parameters of c_{r1} =4.1 kN/m^2 and ϕ_{r1} =25.8° are estimated at normal stresses below 150 kN/m^2, while those of c_{r2} = 0 kN/m^2 and ϕ_{r2} = 24.8° are above 200 kN/m^2. Recovered strength parameters have been estimated to be c_{rc} = 5.5 kN/m^2 and ϕ_{rc} = 26.4° at normal stresses below 150 kN/m^2.

3. STABILITY ANALYSIS OF XUECHENGZHEN LANDSLIDE

The results of the ring-shear test are applied in the stability analysis of the most active sliding area of the Xuechengzhen landslide. Because sliding has occurred annually during rainy season, resulting in large displacements along the entire slip surface, the shear strength of the whole slip surface can be expected to be in the residual state. A large circular arc with a radius of 400 m has been assumed as the slip surface, based on the reconnaissance survey of the landform, geology and sliding condition of the area. It is reasonable to apply different strengths to the stability analysis according to the depth of the slip surface: the recovered strength τ_{rc} to the shallow slip-surface zone and the residual strength τ_r to the deeper slip-surface zone. When the landslide is reactivated, τ_r and τ_{rc} are mobilized simultaneously along the slip surface. Shown in Figure 1 is the cross-sectional diagram for the stability analysis. The recovered strength parameters (c_{rc} = 5.5 kN/m^2, ϕ_{rc} = 26.4°) have been applied to the slices of the head and the toe of the slide, under the effective overburden pressures equivalent to $\sigma_n' < 150$ kN/m^2, and the residual strength parameters (c_{r2} = 0 kN/m^2, ϕ_{r2} = 24.8°) have been applied to the slices of the central zone under the effective overburden pressures equivalent to $\sigma_n' > 150$ kPa. The safety factor *Fs* can be calculated by the Fellenius method.

First, the residual strength parameters (c_{r1} =4.1 kN/m^2 and ϕ_{r1} =25.8°, c_{r2} = 0 kN/m^2 and ϕ_{r2} = 24.8°) are applied in the equation. The residual strengths parameters of c_{r1} =4.1 kN/m^2 and ϕ_{r1} =25.8° are applied in place of recovered strength parameters. Setting *Fs*=1.00, the ground-water level at the time when the landslide stopped moving is determined by repeated calculation. By applying the recovered strength parameters (c_{rc} = 5.5 kN/m^2 and ϕ_{rc} = 26.4°) into the slices 1 to 13 and 16 to 19, the safety factor is increased from *Fs*=1.00 to *Fs*=1.05. This stabilization is the main reason why the landslide is able to lie in a stable condition until the next annual rainy season.

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