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Stability analysis of slope reinforced by roots network

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ABSTRACT: Many studies concerning about stability analysis of slope have been carried out. Most works of stability analysis were based on effects of strength parameters and the shape of slope. The trees at slope also affect to slope stability. Therefore, it is necessary to clarify the mechanism of slope failure which reinforced by roots network. But the effect of roots network depends on various conditions. Now, all relationships between the tensile strength of roots and the shearing strength of soil involving roots network are not clarified. The authors have tried three types of shear tests, direct shear test, triaxial compression test and field direct shear test under various conditions. The apparent cohesion c increase with the amount of roots. The stability analysis method on a slope formed from soil having roots network is proposed. The mechanism on the effects of roots network were investigated using Fellenius method and generalized limit equilibrium method. The experimental results obtained from model tests agree with the analytical ones. The stability analyses were carried out for the one site in which slope failure had occurred. It was confirmed that the presence of roots significantly influence to the slope stability.

1 INTRODUCTION

In Japan, much importance has been attached to the environmental problem of counter measure of slope. There is a case that the trees at a slope have not been cut at the execution of counter measure. This is due to the reason that the preservation of natural environment is strongly advocated. The trees at a slope are also useful to the strengthening of soil.

Many researches have been done on the mechanical characteristics of soils involving roots network. But the effects of roots network on slope stability are not enough elucidated.

In this paper the results of the tensile strength of roots and the shearing strength of the soils involving roots network are described. Three types of shear tests , direct shear test, triaxial shear test and field direct shear test, were carried out. The apparent cohesion c increase with the amount of roots. The angle of shear resistance does not change with the amount of roots.

The mechanism on the effects of roots network were investigated using Fellenius method and generalized limit equilibrium method. The experimental results obtained from model tests agree with the analytical ones.

The stability analysis method on a slope formed from soil having roots network is proposed. The stability analyses were carried out for the one site in which slope failure had occurred. It was confirmed that the presence of roots significantly influence on the slope stability.

2 STRENGTH CHARACTERISTICS OF SANDY SOIL WITH ROOTS

2.1 In-situ direct shear test

The influence of roots for the strength characteristics of a sandy soil was investigated by in-situ shear tests using the large direct shear apparatus.

In Fig. 1, the schematic diagram of direct shear apparatus was shown. The size of shear box is 30 cm × 30 cm with the height of 12 cm. The experimental procedure is follows. The surface soil was shaped about 30 cm × 30 cm × 12 cm. The shear box and the another apparatus were set up. The normal stress was applied by the air cylinder and the shear stress was applied with the hydraulic jack.

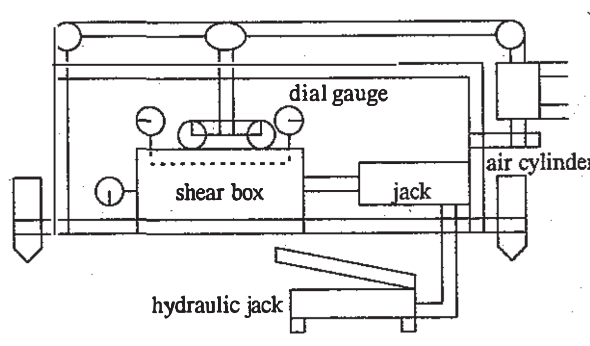

Fig. 1. Schematic diagram of large direct shear test apparatus.

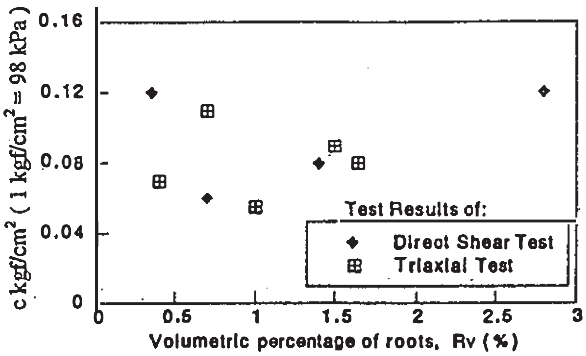

Fig. 2. Relationship between the cohesion c and the volumetric percentage of roots Rv.

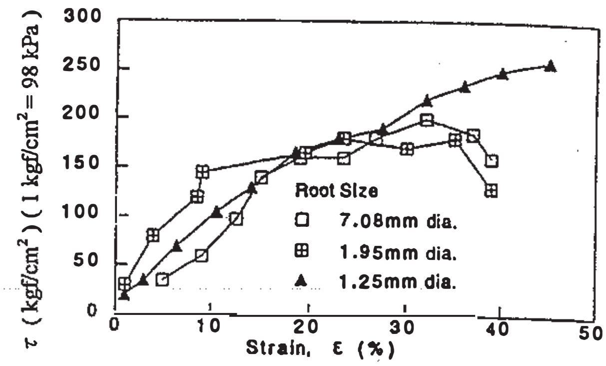

Fig. 4. Relationship between the tensile strength and the axial strain of roots.

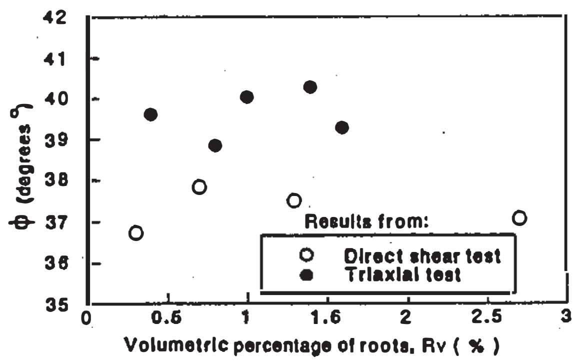

Fig. 3. Relationship between the angle of shearing resistance ϕ_d and the volumetric percentage of roots Rv.

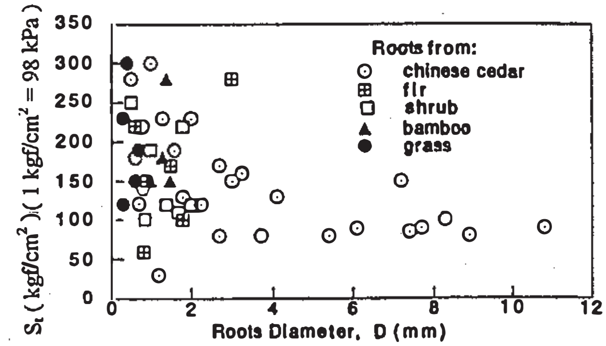

Fig. 5. Relationship between the tensile strength and the diameter of roots.

In-situ direct shear tests were carried out at the several sites. The soil is weathered granite soil. If the weathered granite soil do not involve the roots, the cohesion c at the saturated condition is nearly zero. In Fig. 2, the relationship between the cohesion c and the volumetric percentage of roots Rv was shown. The void ratio of these specimens are almost equal to about 0.7~0.8. It is clarified that the soils containing roots have cohesion c of 0.05 ~ 0.15 kgf/cm^2 (1 kgf/cm^2 = 98 kPa).

The relationship between the angle of shear resistance ϕ_d and the volumetric percentage of roots Rv was shown in Fig. 3. The angle of shear resistance ϕ_d vary between 37° ~41°. This scattering is common in the granite soil. Furthermore, there is no distinctive pattern that indicate whether ϕ_d increase or decrease with respect to the amount of roots.

In Fig. 2 the results also do not give any distinctive pattern comparing with Fig. 3, however there is a tendency for c to be constant. The reason for this is not clear. It is important to note that c becomes zero in the absence of roots.

2.2 The tensile strength and pullout strength of roots

It is depend on the tensile strength of roots that the soils involving roots have a cohesion. The tensile strength of roots were investigated. In the tensile test, the roots were cast in plaster and tensioned until they break, at a rate of 1.5 mm/min.

For the pullout test the size of roots used were 1 mm and 2 mm diameters. Typically the tensile stress and strain of roots is shown in Fig. 4. All the roots tested broke at 30 % strain more. Smaller diameter roots have larger tensile strength than bigger ones. Fig. 5 shows this point. This may be explained by the fact that smaller root are more fibrous and furthermore in bigger roots skin tends to tear off during tensile test. In the pull out test, the results are not uniform even though 2 mm diameter roots distinctively exhibit higher pullout strength. This may be due to the wavy shape of roots.

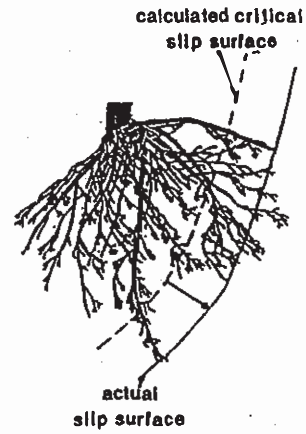

Fig. 6. Schematic diagram of soil reinforced by roots network.

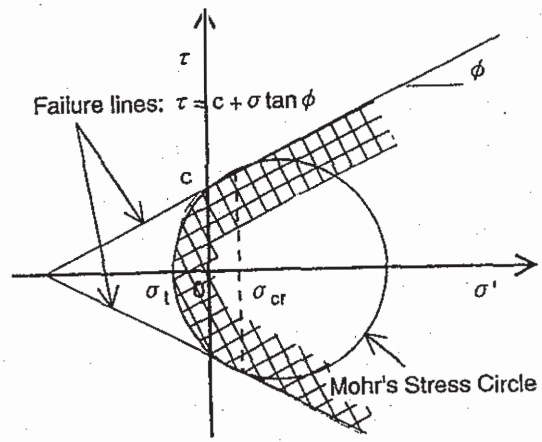

Fig. 7. Schematic diagram of stress condition and Mohr-Coulomb's failure criterion of soil element considering tension crack.

3 STABILITY ANALYSES OF SLOPE REINFORCED BY ROOTS NETWORK

3.1 Reinforcement mechanism

The schematic failure envelope of soil reinforced by roots network is shown in Fig. 6. The reinforcement of soil by roots network is complex and the modeling is difficult, which may require the use of sophisticated finite element analyses employing appropriate constitutive relationships. It is difficult to consider the stress and strain of roots network in soil. It depend on nature of roots, i.e. its wavy shape. Many authors have proposed a more simplified reinforcing mechanisms of fibers, geotextiles (Yagi N., Enoki M. and Yatabe R. 1992). In this study, it is assumed that there is no pullout phenomenon.

When we evaluate the stability of slope which have the apparent cohesion c, it is dangerous to neglect the effect of tension crack which occurs on the top of slope. There are a few problems for the old stability analysis methods which consider the effects of tension crack. The problems are follows; the depth of tension crack is not affected by the height or angle of slope, the tension crack does not occur vertically on the slope, the block which have tension crack does not guarantee the balance of forces. In this section, the method of stability analysis which consider the effects of tension crack is presented.

3.2 The stability analyses method considering tension crack

The soil failure is presented by shear failure and tensile failure. Fig. 7 shows the stress condition and Mohr-Coulomb's failure criterion of soil element considering tension crack. The soil element which is reinforced by roots networks is able to exist in the shadowed portion. Where; σ_t: tensile strength (<0), σ_{cr}: normal stress acting on the slip surface. σ_{cr} can be expressed as follows;

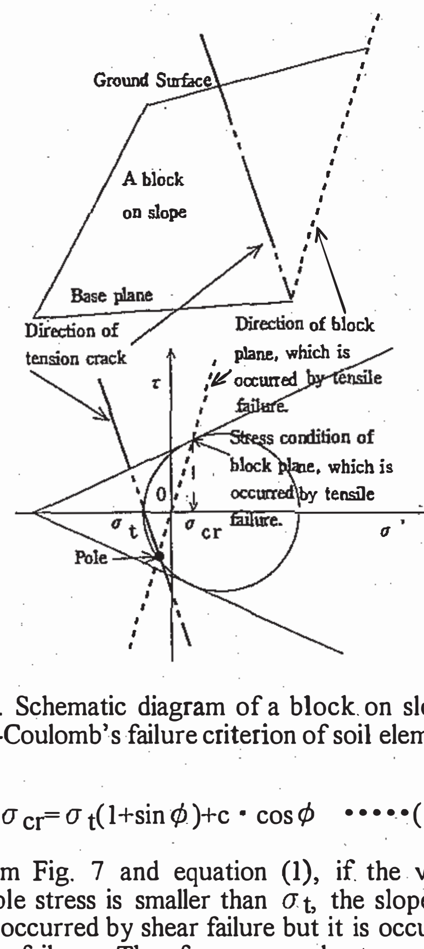

Fig. 8. Schematic diagram of a block on slope and Mohr-Coulomb's failure criterion of soil element.

$$\sigma_{cr}=\sigma_t(1+\sin\phi)+c\cdot\cos\phi \quad \cdots\cdots(1)$$

From Fig. 7 and equation (1), if the value of principle stress is smaller than σ_t, the slope failure is not occurred by shear failure but it is occurred by tensile failure. Therefore, normal stress of slip surface is always grater than σ_{cr}. The Fellenius method and Generalized Limit Equilibrium Method (GLEM) which are proposed in the present paper are extended to analyze stability problems with roots network. If stress level of slip surface where safety

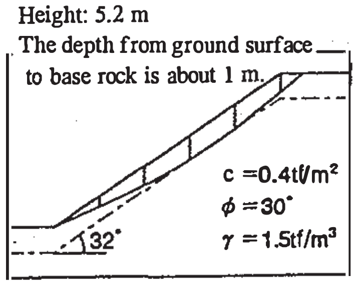

Fig. 9. Schematic diagram of model slope.

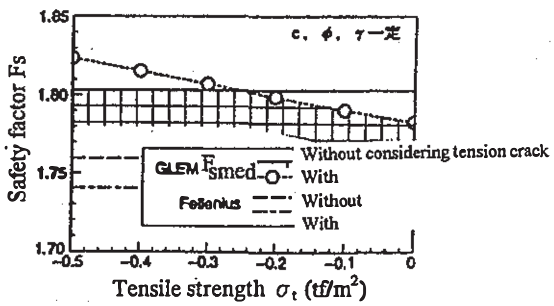

Fig. 10. Influence of tensile strength to safety factor Fs.

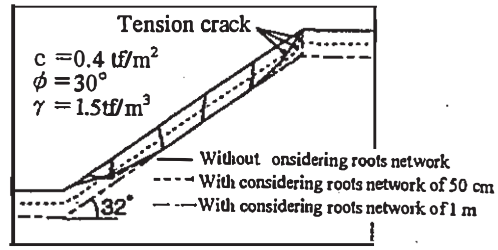

Fig. 11. Influence of tensile strength the roots network to the slope by GLEM.

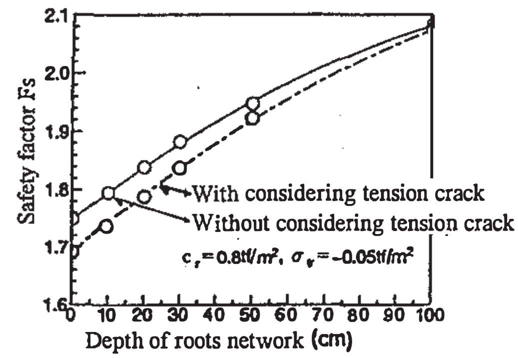

Fig. 12. Relationship between the existence of roots network and safety factor Fs by GLEM.

factor is equal to unity is on the failure criterion and stress condition of soil element is explained by Mohr's stress circle, tensile failure can be evaluated from normal stress and equation (1) on the block plane.

3.3 Fellenius method

If the slice width b is very small, the block weight divided by b becomes equal to γz. When σ_{cr} is grater than normal stress of soil element σ, tensile failure occur on the block plane. Therefore the depth of tension crack z_c is explained as follows;

$$z_c = \sigma_{cr} / (\gamma \cdot \cos^2 \beta) \quad \cdots\cdots (2)$$

Where β is the angle of base plane.

It is clarified from equation (2) that z_c varies with change of β. When we analyze the value of z_c estimated by equation (2), the block plane failured by tension crack should be divided.

3.4 GLEM

GLEM can estimate all of forces acting on block planes, both base planes and interslice planes. Therefore it is easy to judge the occurrence of tensile failure on the slope. It is easy to introduce tensile strength on the interslice plane failured by tensile force. The method of analysis with considering tension crack is follows; ① it analyze safety factor and slip surface without considering the tension crack, ② if the tensile failure is occurred, the block plane failured by tensile force is divided by the pole and direction shown in Fig. 8, where the shear strength becomes zero, ③ if the given tensile force is same value as the re-calculated one, GLEM give the optimized safety factor.

3.5 Effects of tension crack on model slope

In Fig. 9, the schematic diagram of model slope was shown. The influence of tensile strength to safety factor Fs is shown in Fig. 10. In both of Fellenius method and GLEM, Fs was affected by the occurrence of tension crack. But in Fellenius method, Fs was not affected by the change of tensile strength because it was impossible to consider the tensile strength of interslice planes. In GLEM, as the value of tensile strength gets larger, Fs gradually increases. It is not correctly that Fs considering the occurrence of tension crack is larger than one without considering it. If Fs considering tension crack differs from one without considering it, we must choice the smaller value from them.

3.6 Effects of roots network on model slope

There are two important points on the influence of roots network to the slope stability. One is that the existence of roots network increase shear strength

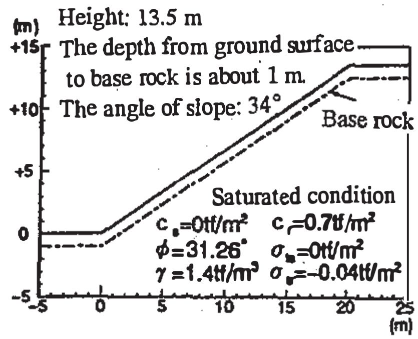

Fig. 13. Vertical section of natural slope.

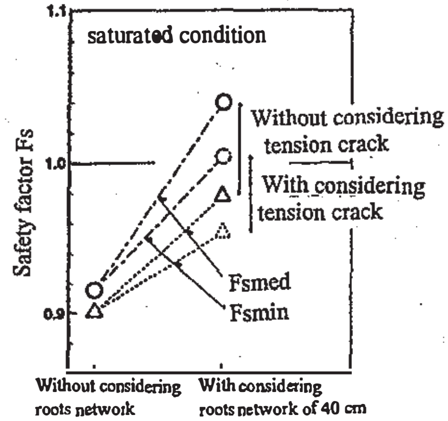

Fig. 14. Relationship between the existence of roots network and safety factor Fs.

with the increase of apparent cohesion c. The other is that the existence of roots network decrease the occurrence of tension crack because of the increase of tensile strength. Therefore it is important for natural slope stability to consider the effects of shortening the tension crack and increasing of c due to roots network.

Fig. 11 shows the infuluence of the roots network to the slope by GLEM. The occurrence of tension crack are considered in all analyzes. Fig. 12 shows the relationship between the existence of roots network and safety factor Fs by GLEM. In this figure, Fs without considering tension crack is drawn in solid line and Fs with tension crack is drawn in broken line. In Fig. 11, it also can be seen that the roots network in slope becomes deeper, the angle of tension crack approaches vertical.

3.7 Stability analysis for natural slope failure

Fig. 13 shows vertical section of natural slope stability analysis by GLEM. In this analysis, the values of strength parameters and the shape of slope are investigated by shear test and field survey. In this figure, the saturated condition means the soaked specimen in water. The depth from surface to base rock is about 1 m.

The relationship between the existence of roots network and safety factor Fs is shown in Fig. 14. The Fs increase about 0.1 point by the existence of roots network with or without tension crack. Fs with roots network is nearly 1.0. Therefore the effect of reinforcement by roots network contribute to slope stability under both natural and saturated conditions.

4 CONCLUSIONS

Stability of slope reinforced by roots network was investigated from shear tests and stability analyses. The following conclusion can be drawn.

1. The soils containing roots have the apparent cohesion c of 0.05 ~ 0.15 kgf/cm^2 (1 kgf/cm^2 = 98 kPa).

2. There is no distinctive pattern that indicate whether ϕ_d increase or decrease with respect to the amount of roots.

3. In pullout tests, it clarified that smaller roots are more fibrous and furthermore in bigger roots skin tend to tear off during tensile tests.

4. Generalized limit equilibrium method can consider the effect of tension crack and tensile strength of roots correctly.

5. The effects of shortening the tension crack and increasing of c due to roots network are evaluated quantitatively.

6. Actual slope failure was analyzed. Fs calculated using the shortening the tension crack and the increasing of c due to roots network is nearly 1.0. Therefore the effect of reinforcement by roots network must be considered in slope stability.

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