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Nailing effects on cut slope with alternating sandstone and mudstone

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ABSTRACT: In a nailing reinforcement of cut slope alternating sandstone and mudstone, bending moment of steel bars embedded into the slope may play an important role in increase of resistance for the slide of the slope. This paper shows the experimental results about characteristics of the bending stress distribution obtained from model tests in a laboratory. We measured the strains of steel bars using such an element model of the nailed slope as two concrete blocks, one of which was put on top of another and between of which we had placed granulated mudstone. And this paper includes an insitu measured data of axial forces of steel bars.

1 INTRODUCTION

The reinforced earth of nailing a cut slope has been recently used to make stabilization of the slope. In this reinforced earth, the tensile and shear forces of steel bars play a role in increase the resistance for slide and steel bars have been designed mainly with respect to the axial tensile stresses. Laboratory and field tests (see Jewell (1980), Tatsuoka (1984-1985), Hayashi (1986) and Kitamura (1987-1988)) have been performed to clarify the influence of the length, the embedding angle and the spacing distance of the steel bar on slope stabilization. From these researches the contribution of the tensile and shear forces of steel bars to the slope stabilization have been made clear.

When the material of slope is isotropic or the slope does not have originally potential slide surfaces, the above mentioned tensile and shear stresses of the steel bars work well and bending moment of the steel bars does not seem to have any role in the slide resistance. Because the material composing a slope, like soil and small rocks, will slip through space among steel bars during the slide of slope and the slope is, as a whole, held up by the steel bars through surfacing structures of the slope. The bending stresses of the steel bars may not be caused in such slope failure.

But the bending stresses may be caused in the cut slope alternating sandstone and mudstone which we often meet in the South of Kyushu. Because the thickness of the mudstone is much smaller than that of the sandstone and the mudstone becomes sliding surface. In such case we may see the movement of the sandstone along the surface of mudstone is like that of rigidity and the steel bars in the cut slope may be loaded like pile in the ground. And the report of this type of research does not seem to have been published to date. The present report aims at making it clear that to what degree the bending moment of steel bars in the above slope can contribute to the slope stability.

In order to investigate the characteristics of the bending stresses, we made two concrete blocks and placed granulated mudstone between the two concrete blocks, which we considered as a model for the tertiary alternation of strata of sandstone and mudstone. Embedding steel bars into the model and inclining the table on which the model was placed, we measured the stresses of steels. We would like to report on two or three findings we have made by this experiment.

2 EXPERIMENTAL METHOD

2.1 models for the slope alternating sandstone and mudstone

Fig.1 shows the axial force distributions of steel bars at a nailed slope, which we got by reinforcing bar stress transducers after 3 months of the nailing construction. The slope gradient is 1:1.5. Before the experiment a sliding surface was assumed as shown in the figure. Three steel bars (Diameter=19mm) were embedded into the upper and the lower slope from the berm, respectively, with 1.5m pitch in longitudinal direction of the slope.

The slope was made by cutting talus. The axial stresses may be produced by steel bar holding up the talus through the surfacing structure as was stated previously. Now, let's assume that the slope in Fig.1 is composed of the alternate deposit of sandstone and mudstone as shown in Fig.2(a). There are three layers of sandstone, and mudstone too. In that case, the embedded steel bars may be deformed like the broken lines in the figure when the second layer of the above sandstone, SS(2) moves along the sliding surface of mudstone, MS(2). The bending stresses of steel bars may be produced accompanied with the deformation in Fig.2(a).

We assumed a model shown in Fig.2(b) regarding the part of the slope in which oblique lines were drawn. Then, we made the slope model composed of two concrete blocks and granulated mudstone smaller than 2mm grain size, as shown in Fig.3. The size of concrete blocks are 1m× 1m× 0.15m(model A) and 1m× 2m× 0.15(model B). The depth of the granulated mudstone put between the two concrete blocks is 2cm in both models. Placing the test model on a table and inclining the table on which the lower concrete block was fixed, we examined the relations between the bending stress of steel bars and the inclining angle. The steel bars (Diameter=9mm) were embedded vertically to sliding surface in order to make the bending stress predominant over axial stress (Theoreti-

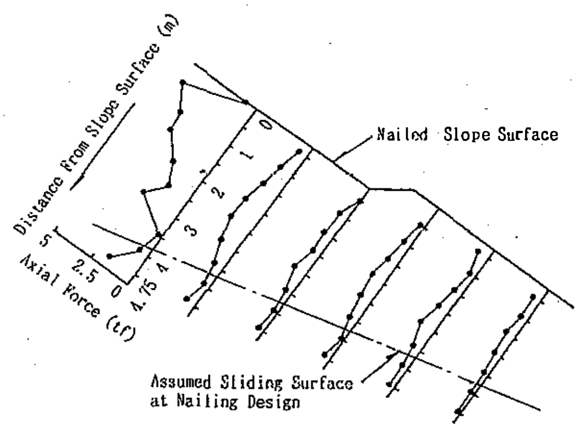

Fig. 1. AXIAL FORCE OF STEEL BAR AT IN-SITU OF NAILED SLOPE

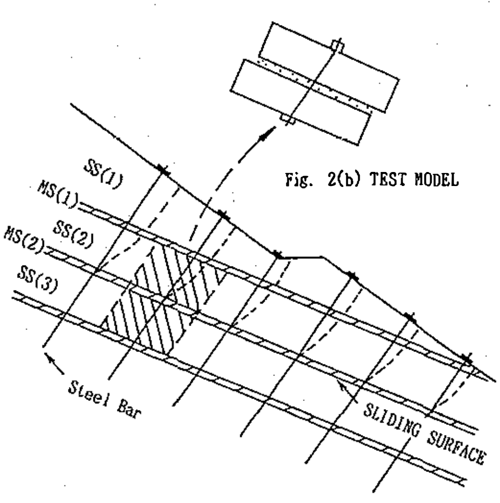

Fig. 2(a). STEEL BAR DEFORMATION OF ASSUMED SLOPE ALTERNATIMG SANDSTONE AND MUDSTONE

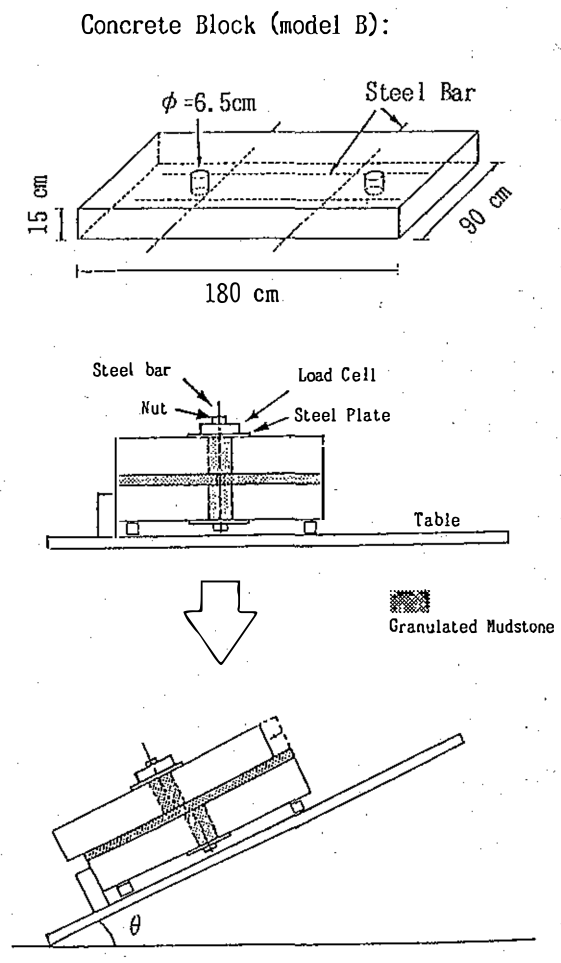

Fig. 3. OUTLINE OF TEST

cally the axial stresses should be estimated to be zero). The diameter of hole in which the steel bar was put was 65mm and we filled vacant space between wall of the hole and the steel bars with sand (model A) and the granulated mudstone (model B). The steel bars were fixed through steel plates (120mm× 120mm) at the top surface of the upper concrete block and the bottom surface of the lower concrete block. And we tightened the steel bars with nuts.

Before the nailing test we did sliding tests without embedding steels into the concrete blocks. Every time we did the test, we changed the water content of the granulated mudstone.

2.2 The granulated mudstone

We got small blocks of mudstone or weathered mudstone at cutting site of the slope alternating sandstone and mudstone, and crushed them into fine grain in the laboratory. We used granulated mudstone smaller than 2mm grain size. The value of the consistency limit of the soil sample is shown in Table.1.

Table 1. The value of consistency of granulated mudstone.

natural water content	w= 2.74%
plastic limit	w=16.96%
liquid limit	w=27.05%

3 EXPERIMENTAL RESULTS AND DISCUSSION

3.1 The influence of water content on sliding resistance

Fig.4 shows the relation between water content of the granulated mudstone and slide angle of the concrete blocks, which was obtained from tests of model A without steel bar. The sliding angle is critical value at which the sliding displacement of the upper block increases rapidly, namely the curvature of the displacement changes rapidly. We inclined maximumly the table up to 45 degrees. The mark ● on the 45 degrees line indicates that the sliding angle does not appear by the maximum angle 45 degrees.

As may be seen from Fig.4 the curve has a peak. There may be an optimum water content which gives the granulated mudstone a high sliding resistance in the neighbor-

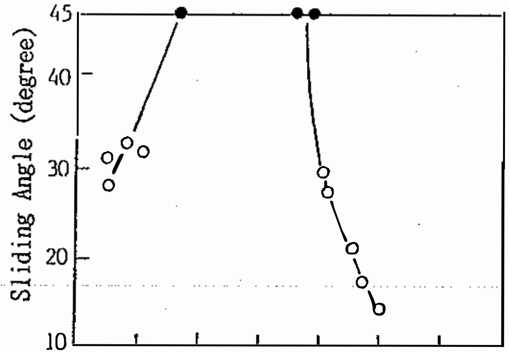

Fig. 4. RELATION BETWEEN SLIDING ANGLE AND WATER CONTENT

hood of the plastic limit of the granulated mudstone. We did the sliding test of nailing using the granulated mudstone with natural water content, w=2.7% .

3.2 The effects of nailing

In order to express the nailing effects by using the increase of internal friction angle ϕ and cohesion C of the granulated mudstone, we loaded three kinds of surcharges, 0kgf, 100kgf and 200kgf on the upper concrete block (model A) and inclined the sliding plate to examine the effects of nailing. A steel bar was embedded into the center of the upper concrete block.

Fig.5 shows the influence of nailing on sliding angle of the upper concrete block. According to the increase of the inclina-

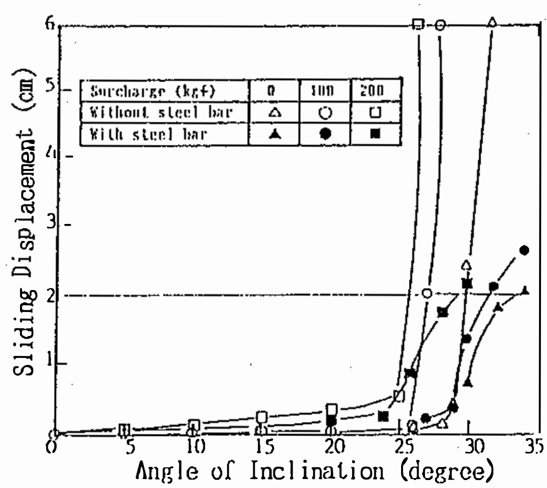

Fig. 5. EFFECTS OF NAILING ON SLIDING DISPLACEMENT

tion angle, the difference of the sliding displacement between the nailed model and unnailed model becomes evident.

Supposing that the allowable sliding displacement, δ, is 2cm, the increase of shearing strength may be expressed as follows:

Considering the shearing strength of the granulated mudstone is expressed as

$$\tau = C + \sigma \tan\phi$$

where,

- τ : Shearing strength of granulated mudstone
- C : Cohesion
- σ : Normal stress on failure surface
- ϕ : Internal friction angle,

we can get the following equation for the slide of concrete block.

$$W \sin\alpha = C A + W \cos\alpha \tan\phi \quad (1)$$

where,

- W : Load acting vertically to sliding surface
- A : Area of sliding surface
- α : Angle of slide

Substituting the value of α, the angle of inclination at δ =2cm, in Fig.5 into Eq.(1) together with the value of W for both cases of "without steel bar" and "with steel bar", we can express the nailing effects by the increase of ϕ and C as shown in Fig.6. The increasing rate of the ϕ and C by nailing are approximately 15% and 30%, respectively. The force of tightening steel bar with a nut, P, was 30kgf.

Fig.7 shows the influence of the material filled into the vacant space between the steel bar and the wall of hole on the

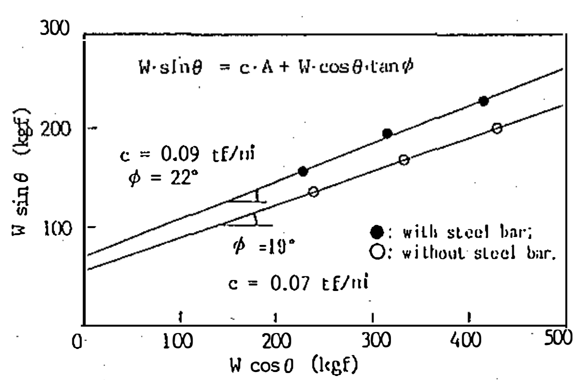

Fig. 6. EFFECTS OF NAILING ON INCREASE OF ANGLE OF INTERNAL FRICTION AND COHESION

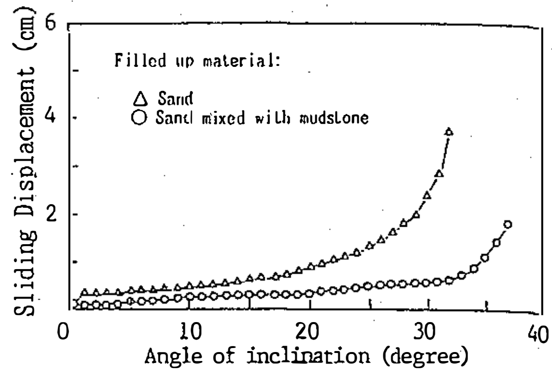

Fig. 7. EFFECTS OF MATERIAL FILLING UP VACANT SPACE ON SLIP DISPLACEMENT

sliding behavior. We used sand and granulated mudstone as the filling material in order to confirm the effect of cohesion on slide resistance. It can be seen from this figure that the sliding angle is apt to increase according to the increase of cohesion.

3.3 The distribution of bending stresses of steel bar

Fig.8 shows the relation between sliding displacements, δ and inclination angle of the concrete block, θ (model B). The mark ○ expresses test results about unnailed concrete block and the marks of ●, △, □ mean the test results in which the force of tightening steel bar with a nut, P, is 10kgf, 30kgf, 60kgf, respectively. We show only two representative curves with regard to each P-value and don't recognize

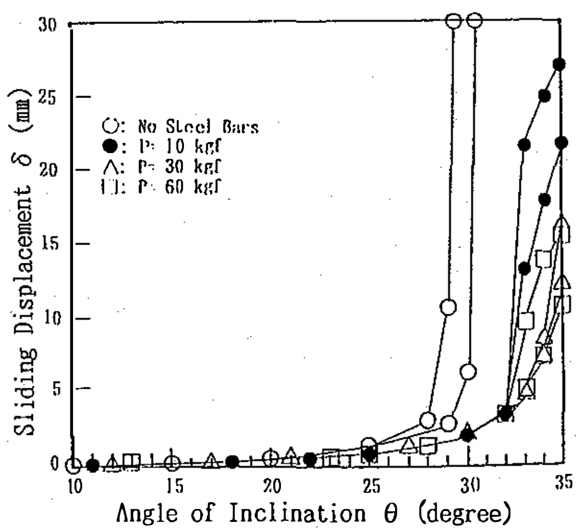

Fig. 8. RELATION BETWEEN SLIDING DISPLACEMENT AND ANGLE OF INCLINATION

the differences of test results between P=10 kgf and P=60kgf, though we can see the critical angle of "no steel bar" is, of course, smaller than that of "with steel bar".

Fig.9 shows the bending stress distributions of steel bar in a large sliding displacement, obtained from values of gauges at five points of the steel bars (The axial stresses of steel bars were approximately zero, as expected). The abscissa expresses the distance from surface of the upper concrete block. The distributions are mean values of the two steel bars in the model B. We show only two representative test results like in Fig.8. In Fig.9 the tightening force, P, is 30kgf with the sliding angle, θ , ranging from 33 to 35 degrees. Though the difference is noticed between the two test results (marks △ and ▲) with respect to the magnitude of the bending stresses, the tendency of bending stress distribution is quite same. The distributions seem to be a point symmetry about intersection of the steel bar and sliding surface, showing the large value at upper half of the upper concrete block and lower half of the lower block. We may estimate the shearing force of the steel bar has the maximum value at the sliding surface, namely the contact surface of the two concrete blocks because that we may see the maximum value of the gradient at the surface. The distribution is roughly similar to the bending stress distribution of a pile.

Fig.10 shows the mean values of bending stress in which the range of the sliding angle, θ , is from 33 degrees to 35, regarding the tightening force P=10, 30, 60kgf. The figure shows the representative stress distributions (two or four data) as well as Fig.8. The tightening force, P, ranging from P=10 to 60 kgf does not seem to affect the stress distribution.

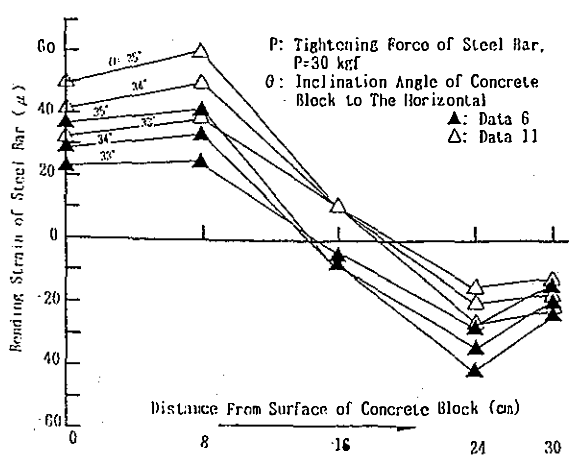

Fig. 9. DISTRIBUTION OF BENDING STRAIN OF STEEL BAR

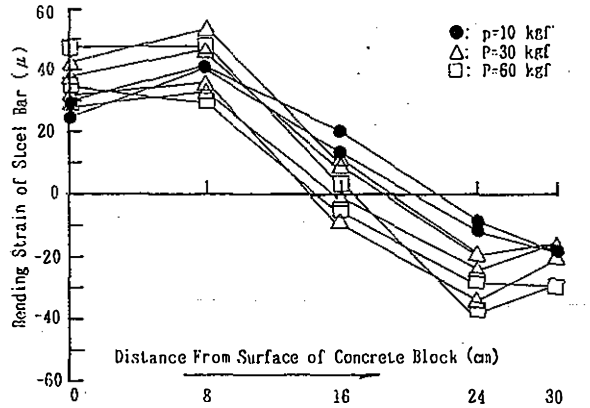

Fig. 10. DISTRIBUTION OF BENDING STRAIN OF STEEL BAR (Mean Vaule of θ= 33, 34, 35 Degrees)

4 CONCLUSION

We made experiments of the nailing effects in which the bending moment of steel bar play a predominant role in the slide resistance of a slope alternating sandstone and mudstone. The following became evident from the experiments.

1)There seems to be an optimum water content of the granulated mudstone giving the maximum resistance for the slide of the unnailed slope.

2)We could estimate the reinforcement effects of nailing as the increase of C and ϕ by assuming an allowable displacement of the slide.

3)When the embedding angles of the steel bars are vertical to the sliding surface, the axial stresses of steel bars may be estimated to be zero, and only bending stress plays a role in the resistance for the slide.

4)And the distribution of bending stress seems to be a point symmetry about the intersection of the steel bar and sliding surface. The bending stress has the large value at upper half of the upper concrete block (and lower half of the lower concrete block). We may estimate the shearing force has the maximum value at the sliding surface. And we may see the distribution is roughly similar to the bending stress distribution of a pile.

Though we got the above results as the characteristics of the steel bar embedded into the cut slope alternating sandstone and nudstone, there are such problems as the number of gauge, the embedding angle of steel bars, model itself and the method of applying force, etc. We are going to make an experiment, for example, changing the embedding angle and size of steel plate fixed the steel bars.

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