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Model loading tests of reinforced slope with steel bars

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ABSTRACT: In order to study the effect of the steel bar reinforcement in a sandy slope, vertical loading tests for reinforced slope models were carried out. In these tests, only the placement angle of reinforcement bars was varied, and the surface deformation of the model slope and the stresses of the reinforcement bars were measured.

The results show that 1) the effect of the reinforcement increases in the order horizontal, downward and upward placement of the reinforcement members, 2) the location where the largest increase in axial stress is observed at each loading step for reinforced and un-reinforced slopes, 3) bending and shearing resistance of reinforcing members contribute little to the reinforcing effect.

1. INTRODUCTION

In Japan, the land is being used for a wider range of applications. Therefore, various geotechnical methods have been developed in recent years, most of which are intended to be economical and simple. As one of these methods, reinforcing earth with steel bars is recognized as being effective in excavation and is becoming widely used. Basically in this method, the strength - deformation characteristic of the natural ground is improved by the insertion of steel bars.

However, though the mechanism of the reinforced earth with steel bars has been studied in some degree by the triaxial compression test and direct shear test (Jewell 1980, Tatsuoka et al. 1983), the loading tests on small or large in-situ model slopes have only been carried out a few times (Stocker et al. 1979, Hayashi et al. 1986, Kitamura and Nagao 1988).

Accordingly, in order to study the reinforcement effect, the authors carried out the vertical loading tests on reinforced model slopes with silty sand.

This paper describes the deformation of slope, mode of failure, axial and frictional stress of reinforcing members derived from the test results.

2. MODEL SLOPE AND LOADING TEST

The loading tests were performed on the model slopes, which had a width B of 900mm, a height H of 750mm and a length L of 2100mm shown in Figure-1. A general view of the loading test is shown in Figure-2. The model was made by compacting 15cm thick layers of sand in a steel frame, the reinforcing members were placed in locations before compaction. The frame was removed after compaction, and then it was cut to the profile shown in Figure-1.

The properties of the soil used for the test are as follows:

- maximum particle size : 29mm
- gravel content : 24%
- fine particle content : 13%
- specific gravity of particles: Gs=2.65
- natural moisture content : W_n=11%

The properties of the model slopes are as follows:

- wet density : ρt=2.00g/cm^3
- void ratio : e=0.47
- cohesion : c=0.15kgf/cm^2
- internal friction angle: ϕ=33°

Reinforcing members made of aluminum plate, 450mm long, 25mm wide and 2mm thick, were used instead of steel bars normally used in practice. Its Young's modulous (E) was 7.03*10^{5}kgf/cm^2 and the horizontal and vertical spacings were 225mm. Three placement angles were used in the test; sloping upwards at 20°, horizontal and sloping downwards at 20°. Sand was affixed to the surface of the reinforcing members with epoxy adhesive. Bond between the head of the reinforcing members and the slope surface was ensured by setting a 40mm *

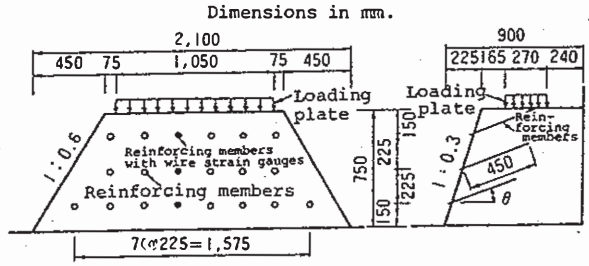

Figure-1 Reinforced slope model

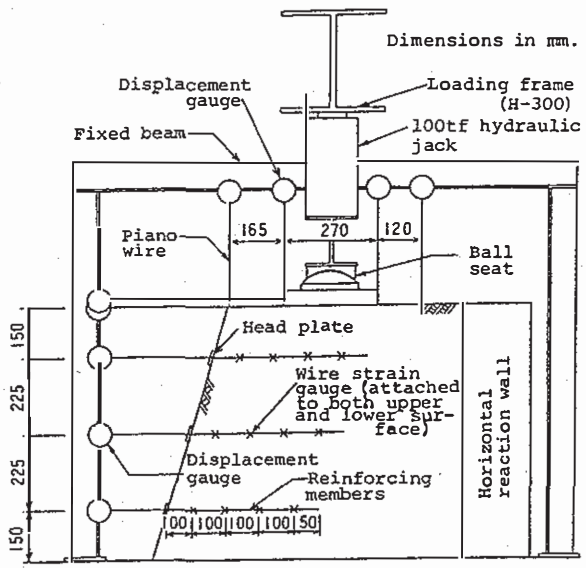

Figure-2 Instrumentation of the loading test

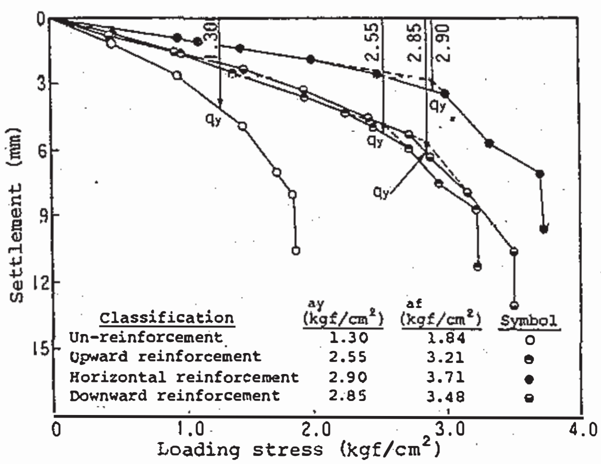

Figure-3 Loading stress vs. settlement of loading plate

40mm aluminum plate on the head. Wire strain gauges were set on the three reinforcing members on the centerline of the slope and the strain in these members was measured.

The model dimensions of slope height and front and side gradients of 750mm, 1:0.3 and 1:0.6 respectively, were decided upon to prevent failure of the side of the specimen under loading.

The loading plate was 270mm wide (B) and 1050mm long (L). This is considered as a two dimensional strip footing because L/B is very nearly 4 (Muhs 1965).

The load was applied through a hydraulic jack system in steps of 0.5kgf/cm^2, and was maintained until the settlement rate was less than 0.5%/min. at each loading step. At each load increment the load was held for fifteen minutes. When the loading approached the yield condition, loading steps were reduced 0.25kgf/cm^2.

The deformation of loading plate and slope surface, and stress of the reinforcing members were measured.

3. DEFORMATION OF SLOPE SURFACE AND SLIP SURFACE

Figure-3 shows the relation between the settlement of the loading plate and loading stress. Yield stress q_y in the figure is equivalent to the first inflection point of settlement, and it is shown as the intersection of the broken lines. Failure stress q_f is equivalent to the stress at the time of a sudden increase of settlement. The yield stress is 2.9kgf/cm^2 in both horizontal and downward reinforcement, the value, 2.9kgf/cm^2, is twice as large as that of a un-reinforced slope. The difference in the reinforcement effect between horizontal and downward placing appears in the difference between settlements at yield stress: the settlement of downward reinforcement is nearly twice as large as that of horizontal reinforcement.

The difference of reinforcement effect as shown in Figure-3 also has an influence upon the horizontal displacement of the slope surface. Figure-4, 5 and 6 show the relation between the loading stress and surface displacement of an un-reinforced slope, downward reinforcement and horizontal reinforcement respectively: the displacement increases in the order of horizontal, downward and un-reinforced.

The displacement for upward reinforcement shows a tendency similar to that of downward reinforcement, as shown on the curve of Figure-3. Further, it is observed that the horizontal displacements at points 2 and 3 are larger than at points 1 and 4 in all figures, and also that the horizontal displacements at points 2 and 3 are nearly equal. This means that the whole soil mass is pushed out uniformly above the measuring point 4. Thus, deformation of the slope surface is closely related to the slip surface.

Figure-7 shows observation results of the slip surface after the loading test. The slip surfaces for reinforced slopes are further back than the slip surface observed for un-reinforced slopes.

The degree in shift of slip surfaces is in the order of horizontal, downward and upward reinforcement. In particular, in the case of upward reinforcement the lower part of the slip surface lies along the lowest reinforcing members.

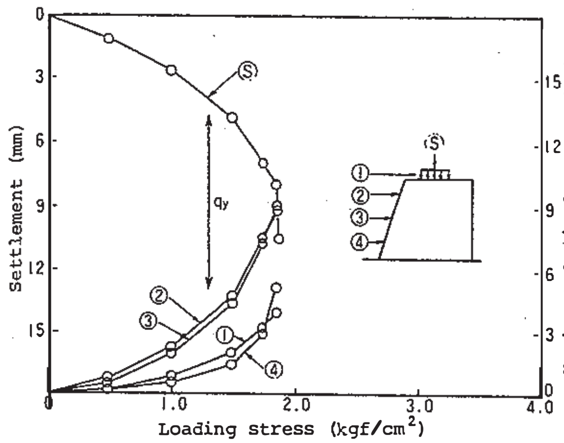

Figure-4 Loading stress vs. horizontal displacement of un-reinforced slope

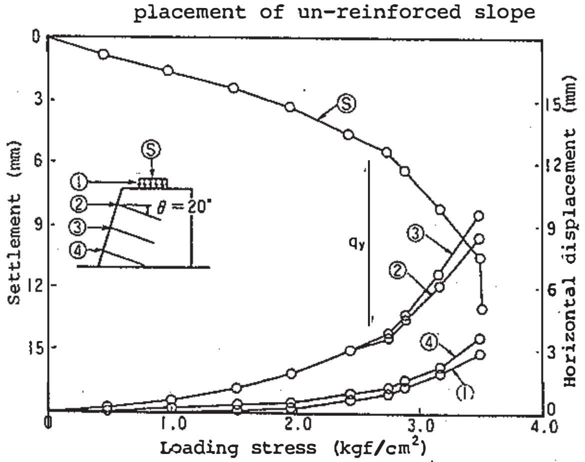

Figure-5 Loading stress vs. horizontal displacement of downward reinforced slope

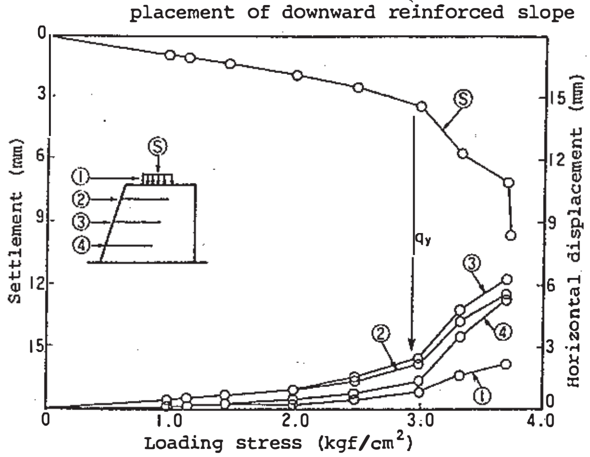

Figure-6 Loading stress vs. horizontal displacement of horizontal reinforced slope

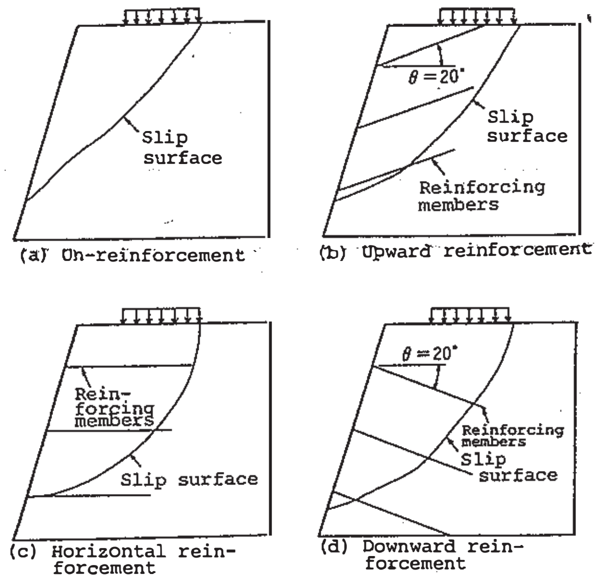

Figure-7 Observed slip surface

4. STRESS IN REINFORCING MEMBERS

It was observed from the deformation of the slope and the shape of slip surface that the upper part of the reinforced zone was pushed out with the slip surface passing between the middle and lower reinforcing members. Change of axial stress, which occurs in the reinforcing members with an increase of loading stress, is shown in Figures-8 to 12.

Axial stress of the middle reinforcing members increases in the order of upward, downward and horizontal reinforcing members. The stress is almost the same for horizontal and downward reinforcement, and that of upward reinforcement is particularly small. Also the axial stress increases beyond the value at the slope yield point q_y.

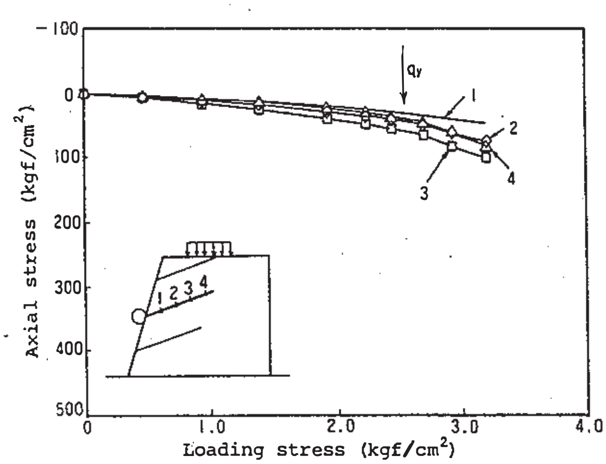

Figure-8 Loading stress vs. axial stress in upward reinforcement (middle member)

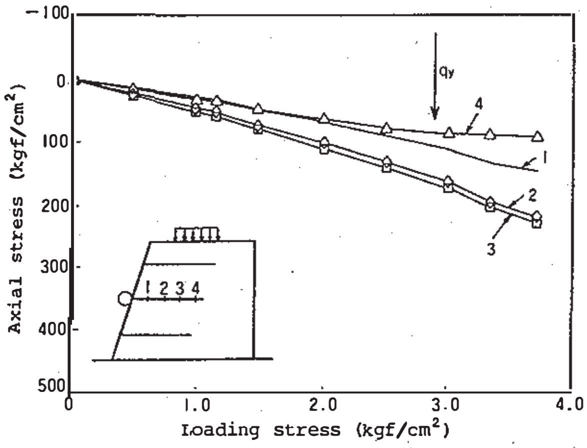

Figure-9 Loading stress vs. axial stress in horizontal reinforcement (middle member)

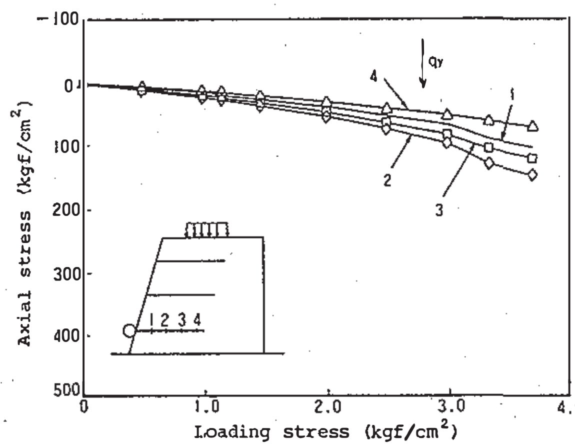

Figure-12 Loading stress vs. axial stress in horizontal reinforcement (lower member)

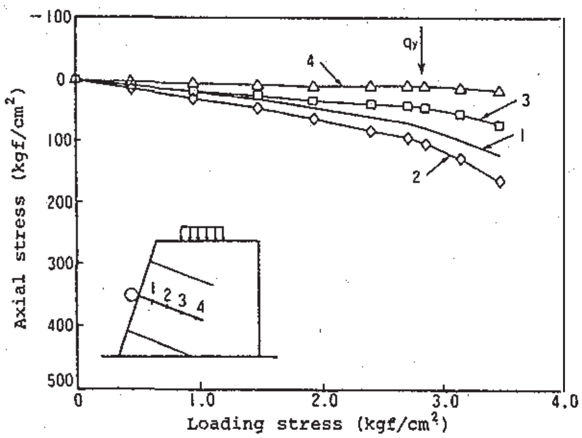

Figure-10 Loading stress vs. axial stress in downward reinforcement (middle member)

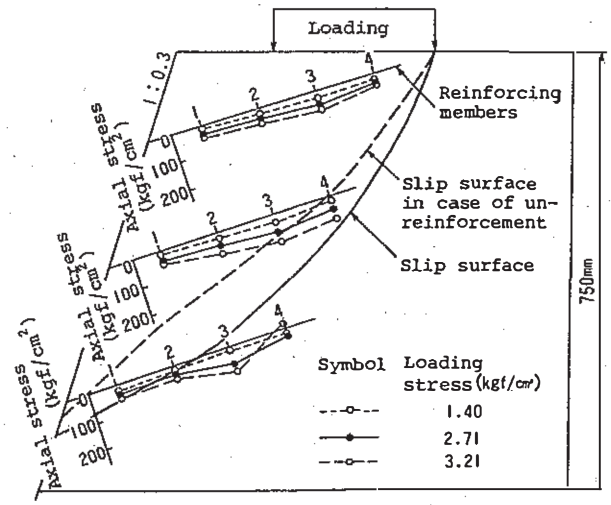

Figure-13 Axial stress distribution in upward reinforcement

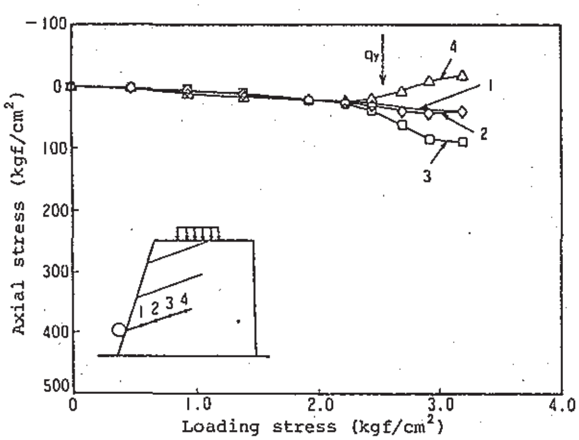

Figure-11 Loading stress vs. axial stress in upward reinforcement (lower member)

Figures-13 to 15 show the axial stress distribution for each stage of the loading stress: the white circle dotted lines show the distribution before the yield stress, the black circle solid lines show that near the yield stress, and the broken lines show that at failure stress. From the relative position of the slip surface in the figures the maximum axial stress occurs near the slip surface. The loading increments are small in all cases. The maximum axial stress in the middle members lies near the point where the member cuts the slip surface. In the case of horizontal reinforcement, the increase of axial stress at measuring point 3 of the middle reinforcing members is larger than that of measuring point 2. Similarly, for the downward reinforcement the axial stress at point 2 increases more rapidly than at the other points. The points where the largest increase in axial stress occur lie between the slip surfaces for reinforced and unreinforced slopes. The reason for this is assumed to be that the increased slope deformation moves the slip surface further back from the face, thus increasing the effectiveness of the reinforcing members.

Figures-16 to 18 show the frictional stress occurring on the surface of the reinforcing members; the frictional stress

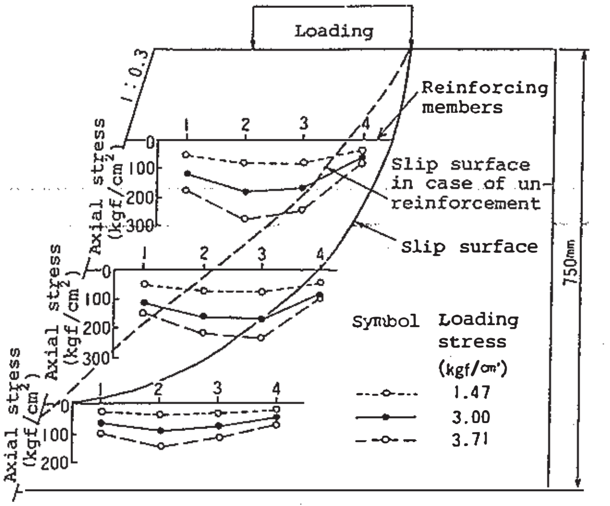

Figure-14 Axial stress distribution in horizontal reinforcement

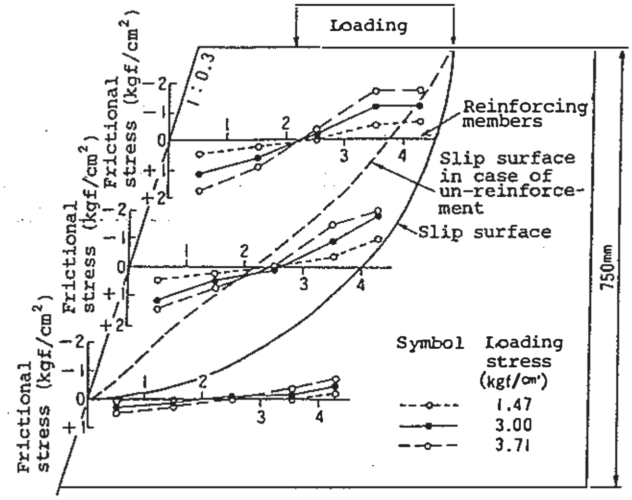

Figure-17 Frictional stress distribution in horizontal reinforcement

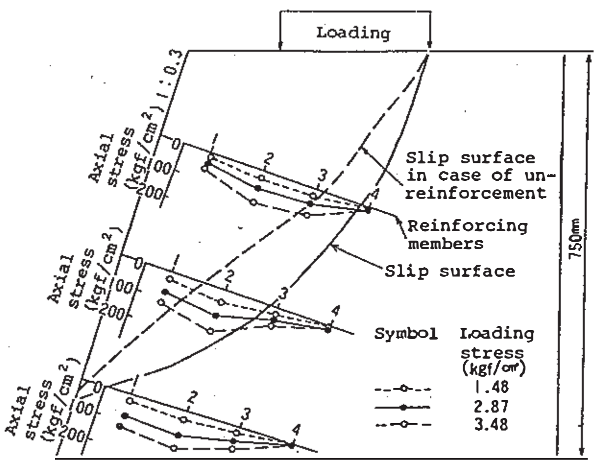

Figure-15 Axial stress distribution in downward reinforcement

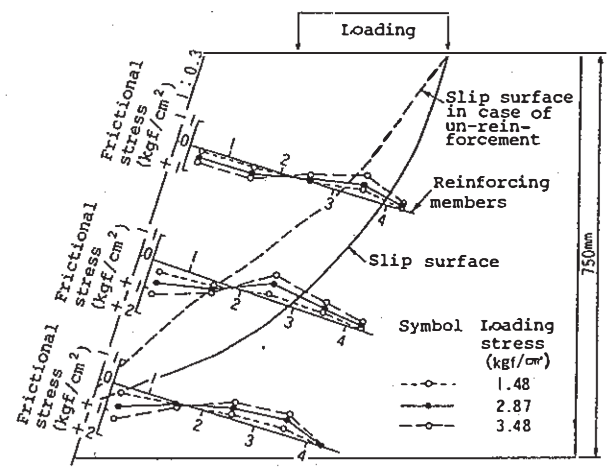

Figure-18 Frictional stress distribution in downward reinforcement

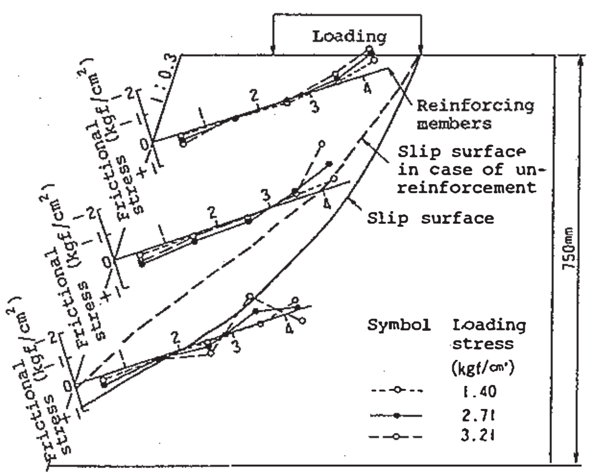

Figure-16 Frictional stress distribution in upward reinforcement

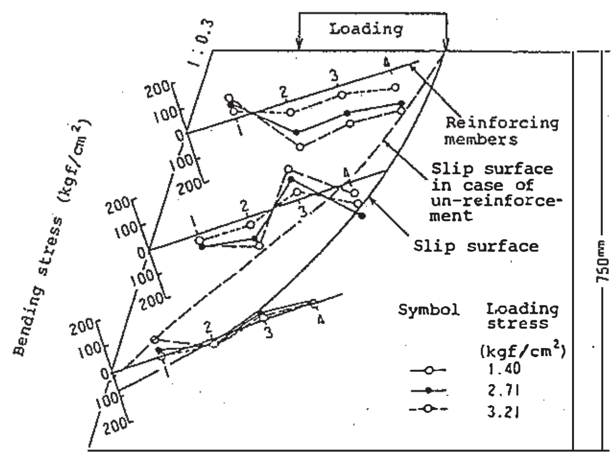

Figure-19 Bending stress distribution in upward reinforcement

was calculated by considering the frictional force on the face of the reinforcing members to be equal to the difference in adjacent axial forces. The frictional force is lower for the upward reinforcement than for the other cases. For the horizontal and downward cases the greatest increase in frictional stress is in the

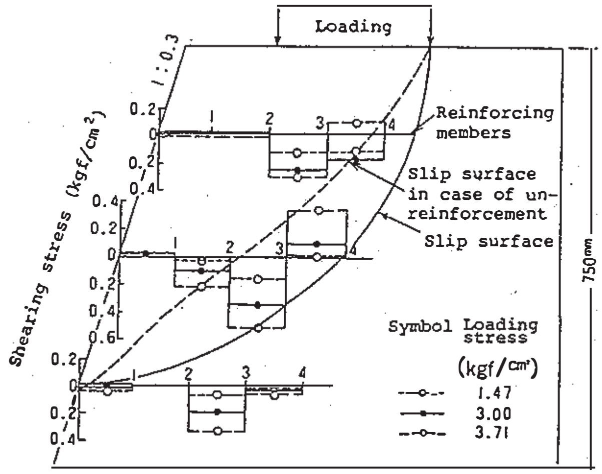

Figure-20 Shearing stress distribution in horizontal reinforcement

middle member, between the slip surfaces for reinforced and un-reinforced slopes, as for the axial stress.

Figure-19 shows the bending stress of reinforcing members shown typically for upward reinforcement. It shows that the distribution of bending stress bears little relationship to the location of the slip surfaces, the other cases show similar results. Further, when the curvature of reinforcing members is calculated, its radius is shown to be 2.3m even for the largest bending strains observed; the radius is extremely large compared to the model size.

Figure-20 shows the shearing stress occurring in the horizontal reinforcing members. The shearing stress was obtained by numerical differentiation of the measured bending strain. The value of the subgrade reaction calculated from the observed bending strain becomes extremely small.

Therefore, it is considered that reinforcing members do not contribute to the strength through bending and shearing resistance, because they behave identically with the surrounding ground.

5. CONCLUSIONS

In order to confirm the effect of reinforcement, the failure pattern of the slope and the stresses in the reinforcing members were measured by vertical loading tests for model slopes. The main conclusions obtained are as follows.

(1) The results of the vertical loading tests showed that the reinforcement effect increases in the order of horizontal, downward and upward reinforcement. The reason is that the failure slip surfaces are shifted back from the slope in that order.

(2) The location where the largest increase of axial stress is observed at each loading step is between the slip surfaces of reinforced and un-reinforced slopes. The reason is that the increase of slope deformation shifts the location of the slip surface which increases the effectiveness of the reinforcing members.

(3) It was observed that bending and shearing resistance of reinforcing members contribute little to the reinforcement effect. Therefore, this suggests that only the axial force in reinforcing members should be considered for design in reinforced earth.

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