Relation between Rock Bolt Setting and Shear Strength of Reinforced Ground by Rope Net and Rock Bolt Method

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Many unstable slopes exist about 1000 slope failures each year have occurred in Japan. An about 90% of the failed slope is natural slope having the tree vegetation and the failure occurred in the surface ground within 3 meters in depth. The slope failure is mainly caused from the heavy rain and small earthquake. While the failures have to be prevented, the natural environment such as trees and vegetations on the slope has to be also maintained. Therefore, the retaining structure and the shotcrete, which have to cut the trees on the slope, are not suitable from the point of view of the conservation of natural state. From this point, the rock bolt and rope net method is developed to protect the slope failure with the nature conservation. The purpose of this research is to understand the mechanism of the reinforcement effect of rock bolt setting of the method. The shear test by the model 1/10 scale is conducted. As a result, it is clarified that the rock bolt setting has a large effect on the slope behavior.

1. INTRODUCTION

Fig.1 shows a picture of example of construction in Rope net and Rock bolt method. We recommend the method as a slope stability method. This method is consisted of three members are rock bolt, pressure plate and rope net as shown in Fig.2. It has the function of prevention of surface failure and preservation of the natural environment by reason of its possible construction without cutting of existing trees on a natural slope. Therefore, it shortens the work period and hold down wasted expense. But the mechanism of this method is not remained to be clarified in detail and this study such various issues.

Figure.1 Example of construction

2. REINFORCEMENT MECHANISM

Fig.3 shows the concept of the reinforcement method. It is assumed in this method that the reinforcement mechanism changes according to the stage of ground deformation.

The overall process of preventing slope failure is described below. First of all, during concentrated heavy rain, and due to weathering, sliding force which is the cause of failures occurs.

The shear resistance brought by the soil's own

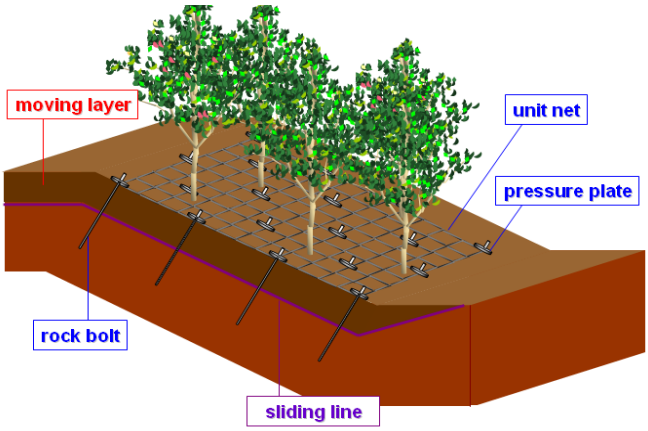


Figure.2 Concept of the rope net and rock bolt method

weight restrains the collapse when the ground deformations are still negligible.

As the ground deformations worsen, the rock-bolts provide flexing and pull out resistance.

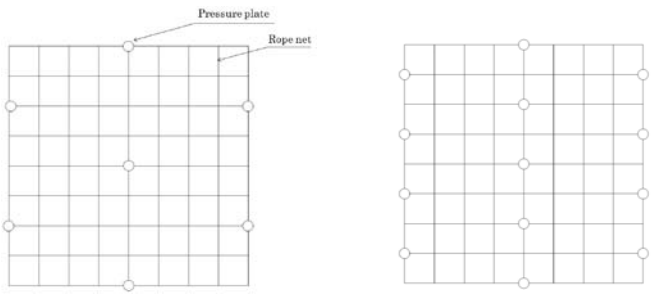
At the next stage, the connection of rock-bolts and rope-nets with pressure plates provides stress dispersion.

As the deformation further worsens, the rope-nets and pressure plates help keep the ground in place reducing soil deformations.

The reinforcement concept of this method is to provide compound slope stabilization as described above.

3. EXPERIMENTAL METHODOLOGY

The 1/10 scale model in the shear test machine is a 600mm in length, 500 mm in width, 350mm in height re-create the method on a slope as shown in Fig.4. The ground materials and reinforcement members set in the box. An automatic load is used to apply a shearing transformation at a constant of 2.00mm/min. The surface position of the shear is 150mm from ground level. In experiment case, rock bolt spacing and water content are changed as shown in table.1. Fig.5 show a plan view of both of rock bolt spacing. The geomaterial is used decomposed granite sandy soil and mechanical property as shown in table.2. Both of the rock bolt and rope net are SS400 steel materials, the pressure plate is stainless-steel. The rock bolt is attached strain gauges to understand behavior at regular intervals as shown in Fig.6. The rope net is attached it at half of all position as shown in Fig.6. The double layers stainless steel pressure plates are used at the heads of rock bolts, and fixed to the rope net.



Narrow rock bolt spacing Normal rock bolt spacing

Figure.5 Rock bolt spacing plan view

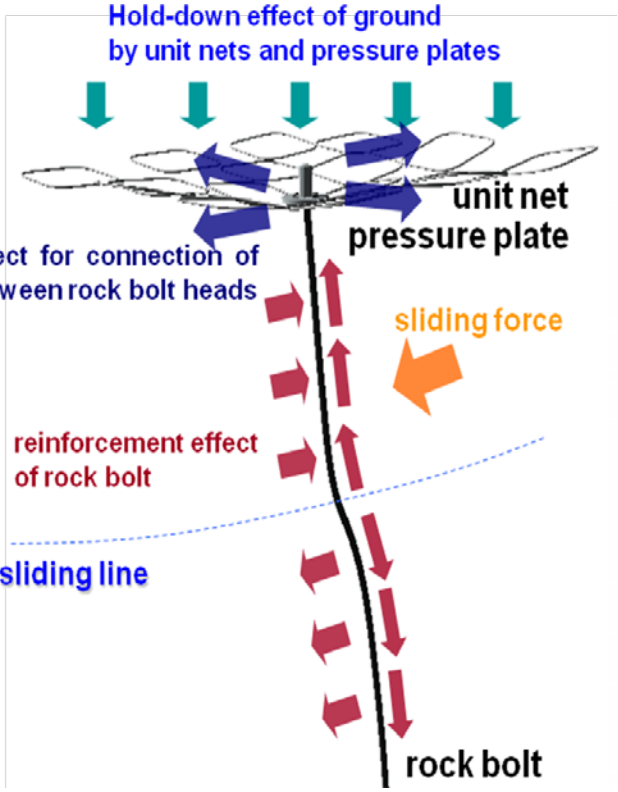


Figure.3 Reinforcement mechanism of this method

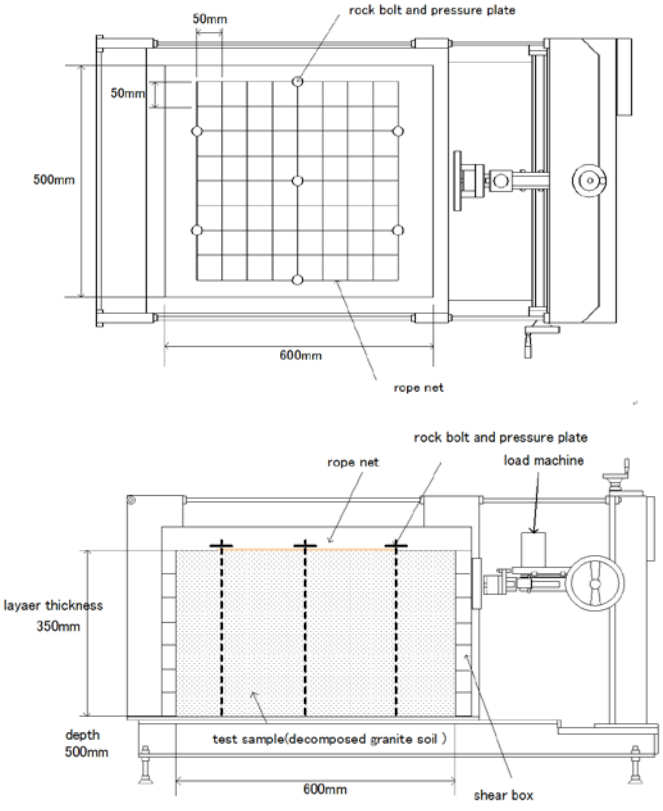


Figure.4 Outline of shear test machine

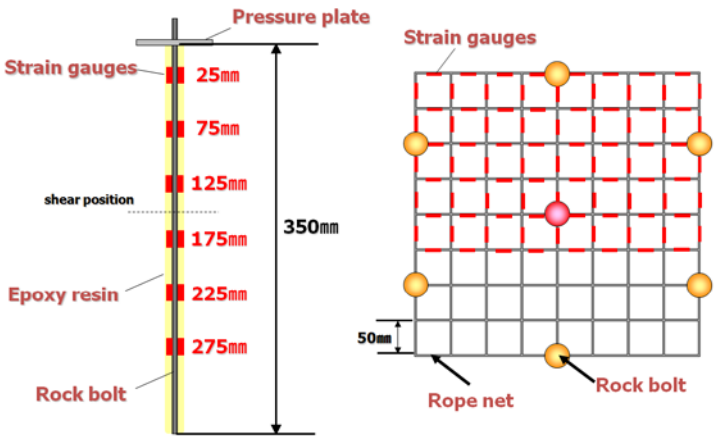


Figure.6 Strain Gauges position

4. SUMMARY OF RESEARCH RESULTS

(1) Shear strength

Fig.7 show shear test results between shear stress and shear displacement in experiment case1~9. Then experimental case show as in table.2

It found shear resistance in narrow rock bolt spacing to shear is the most highest as indicated by this figure. The effect of water content gives decreasing of shear strength both of rock bolt spacing, but decrease ratio of shear stress in the narrow rock bolt spacing is smaller. The shear resistance is high value in the order of water content 5% to 15%. The shear stress in water content 5% of narrow rock bolt spacing indicate 0.07N/mm^2 , 0.06N/ mm^2 in normal rock bolt spacing, 0.04N/mm^2 in unreinforced ground. Then, it found reinforced ground by the narrow rock bolt spacing have 1.2 times shear resistance force of normal of it. It considers experiment cases in water content 5% because the result of reinforcement effect is most obvious in it.

(2) Tensile force on rock bolt

It is estimated the reinforcement of rock bolt using the axial force as an index of tensile acting on rock bolt. Fig.8 show axial force and the distance from the surface of the ground in shear displacement 15mm. The axial force acting on rock bolt in normal spacing is higher than the narrow spacing of it. Then, it found that the nearer the surface ground, the axial force is lower in both of rock bolt spacing. Therefore, it was confirmed that rock bolt spacing setting exerts influence on tensile force.

Table.1 Geomaterial of mechanical property

Geomaterial		Properties
dry density(g/cm3)		1.45
soil particle density(g/cm3)		2.65
optimum moisture content(%)		9.0
grain size	gravel fraction(%)	0
	sand fraction(%)	96
	silt fraction(%)	0.4
	clay fraction(%)	3.6

Table.2 Experiment cases

Case	Rock bolt setting	Water content
1	No reinforcement	5%
2	Normal spacing	5%
3	Narrow spacing	5%
4	No reinforcement	10%
5	Normal spacing	10%
6	Narrow spacing	10%
7	No reinforcement	15%
8	Normal spacing	15%
9	Narrow spacing	15%

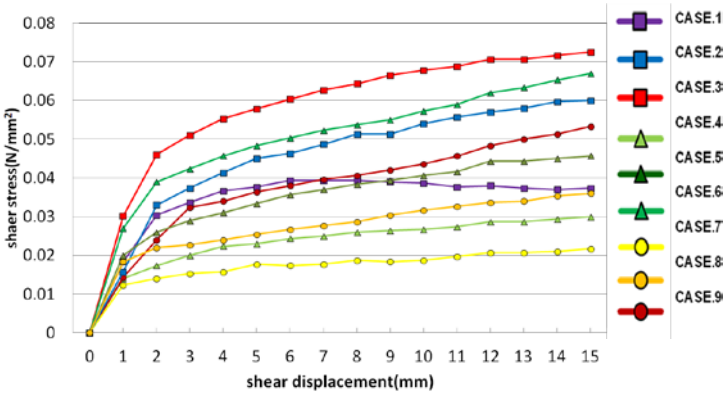


Figure.7 Shear strength

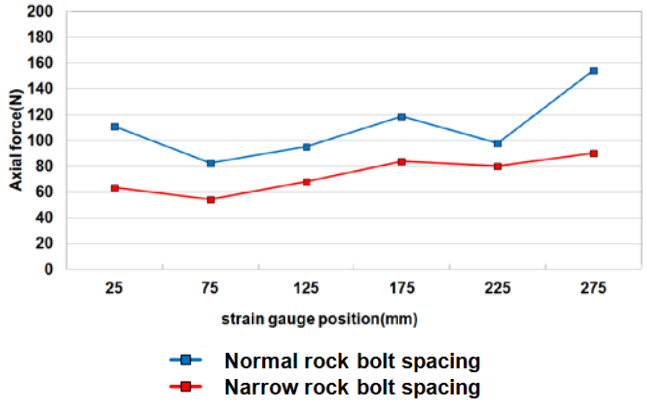
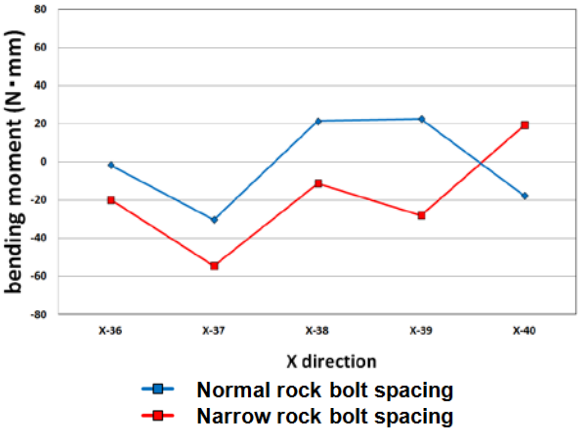


Figure.9 Bending moment on rock bolt

(3)The reinforcement effect of rope net

The strain gauges are attached to the rope net and examine deformation characteristic of rope net in this research. The ground of high relatively is made. It assumed to occur of positive dilatancy with shear displacement increasing. The reinforcement effect is evaluated by bending moment of rope net, the Fig.9 show the bending moment acting rope net and distance from the surface of the ground in shear displacement 15mm. Then, the X direction and the Y direction indicate position on rope net as is shown Fig.10. In the narrow rock bolt spacing, negative bending moment occurred around the rock bolt setting occurred in the X direction. In the narrow rock bolt spacing, negative bending moment occurred at X-38 for rock bolt setting. In the Y direction, bending moment in narrow rock bolt spacing is higher than normal rock bolt spacing of it. It was found that increasing of the number of rock bolt and narrowing rock bolt spacing tend to raise the bending moment of rope net because the connection of rope net and rock bolt with pressure plate become increasingly and earth pressure under the rope net is high and help keep the ground in place occurring positive dilatancy.



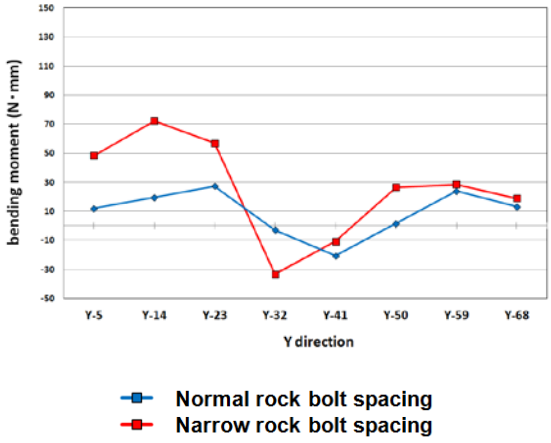
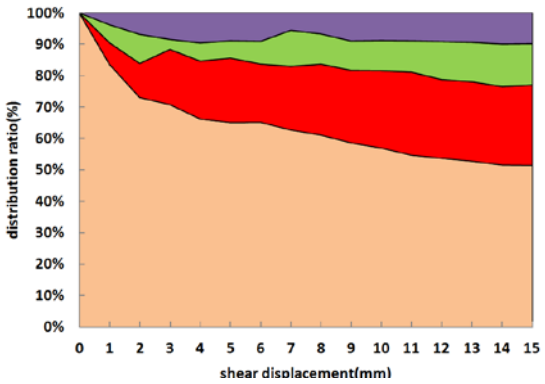


Figure.10 Bending moment on rope net

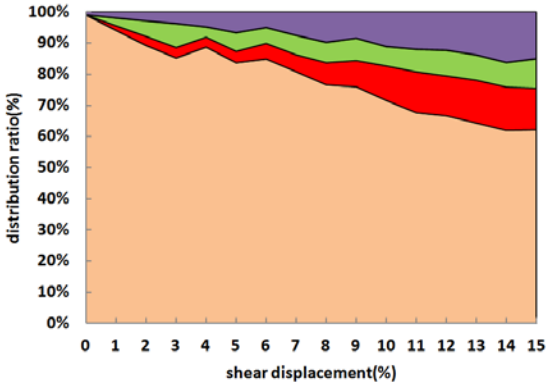
(4) The distribution ratio of reinforcement effect

It evaluates the distribution of the reinforcement effect which is reinforcement members (rock bolt and rope net, pressure plate) make a significant contribution to the shear strength. The formula for computation of the distribution ratio of reinforcement effect are given by Equation(1.1). The results were calculated are shown in Fig.11.

It was found that the reinforcement effect of rock bolt in a narrow rock bolt spacing was obtained high value from shear displacement, but the reinforcement effect of the pressure plate and rope net are not much more than the normal rock bolt spacing of it. Then, it confirmed the reinforcement effect of rock bolt was associated with a twofold increase by narrowing rock bolt spacing.



Narrow rock bolt spacing



Distribution ratio of rock bolt
Distribution ratio of pressure plate
Distribution ratio of rock bolt
Distribution ratio of soil

Figure.11 The distribution ratio of reinforcement effect

$$R_{sand} = \frac{\tau_{sand}}{\tau_{B+P+N}} \times 100$$
$$R_{RB} = \frac{\tau_B - \tau_{sand}}{\tau_{B+P+N}} \times 100$$
$$R_{PP} = \frac{\tau_{B+P} - \tau_B}{\tau_{B+P+N}} \times 100 \qquad (1.1)$$
$$R_{RN} = \frac{\tau_{B+P+N} - \tau_{B+P}}{\tau_{B+P+N}} \times 100$$
$$R_{sand} + R_{RB} + R_{PP} + R_{RN} = 100(\%)$$

τ_{B+P+N} : shear stress at countermeasure B+P+N
τ_{B+P} : shear stress at countermeasure B+P
τ_B : shear stress at countermeasure B
τ_{sand} : shear stress at no reinforcement
(B:rock bolt P:pressure plate N:rope net)

(5)The reduction coefficient on the slope construction

It is necessary to evaluate rope net and pressure plate as a slope stability worker. The most general evaluation index on the slope stability worker is a reduction coefficient of supported slope as shown in Fig.12. The reduction coefficient on the slope is calculated as following equation (1.2).

$$\mu = \frac{T_0}{T_{\max}} \qquad (1.2)$$

T_0 : A pull force of reinforcement members that affects connections of the reinforcement members and the slope construction (kN per bolt).

$T_{\max}$: The largest value of the pull force of reinforcement members (kN per bolt)

Then, due to the position of strain gauge on the rock bolt, T_0 is a value of axial force measured at attached strain gauge 25mm position from the surface ground because of the axial force at the connection between the rope net and rock bolt can't measure. Next, a new proposal reduction coefficient is evaluated different from previously indicated it. In the design of the slope stability method, the tensile force by occurring deformation of the ground is divided into three types according to guide for construction [(1)].

It is known for the number of collapse by slipping out of clod is the most occur among these types as shown Fig.14. The resistance force of the collapse is given by the follow equation.

$$T_{pa} = 1/(1-\mu) \cdot L \cdot t_a \qquad (1.3)$$

L: the length of rock bolt in the moving layer
ta: the allowable adhesion

Then, (1- μ) arise from the fixing force in the moving layer of the rock bolt and residual μ arise from the supported slope face .

Therefore, develop the expression for the following equation (1.4) as a new reduction coefficient μ '.

$$\mu' = \frac{R_{pp} + R_{RN}}{R_{RB} + R_{PP} + R_{RN}} \qquad (1.4)$$

The Fig.14 show the reduction coefficient between conventional μ and μ ' in each shear displacement.

The μ have variation within a certain definite of range value comparatively. The μ ' indicate few variations. The average value of μ is 0.46 in the narrow rock bolt spacing and 0.68 in the normal spacing. The value of μ ' is 0.46 in the narrow rock bolt spacing and 0.56 in the normal spacing.

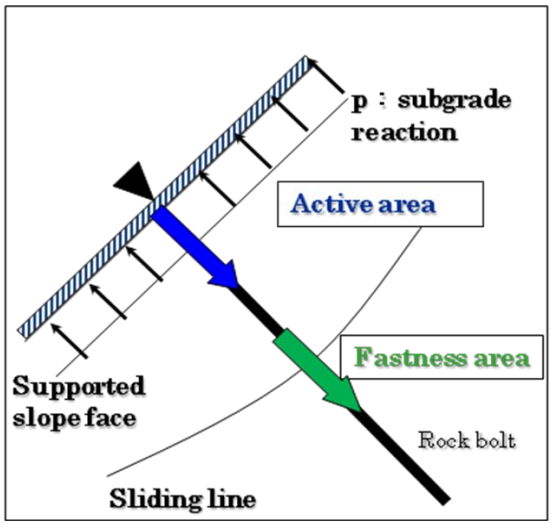


Figure.12 Concept of supported slope face

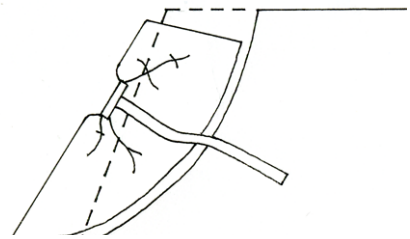


Figure.13 Collapse by slipping out of clod

5. CONCLUSION

1) The reinforcement effect of rock bolt spacing in the rope net and rock bolt method was estimated by the shear test performed.
2) The shear strength using narrow rock bolt spacing is higher than normal of it.
3) It was found the tensile strength and the bending strength of the rock bolt indicated lower values in narrow rock bolt spacing.
4) The design for bending reinforcement on rock bolt is not established, but it can be expected to reinforce it because of the bending resistance force tend to indicate higher than tensile resistance force and this slope stability method tolerates deformation of the ground.
5) The function of rope net is evaluated by bending resistance force acting on it. The bending moment tends to show higher minus value around rock bolt setting in the narrow rock bolt spacing. Therefore, the hold-down effect of ground by acting the rope net in the narrow rock bolt setting has the high expectation effect.
6) In the reduction coefficient on the slope construction, the coefficient values become larger with increasing of the number of reinforcements. Then, it has equal to a shotcrete method.

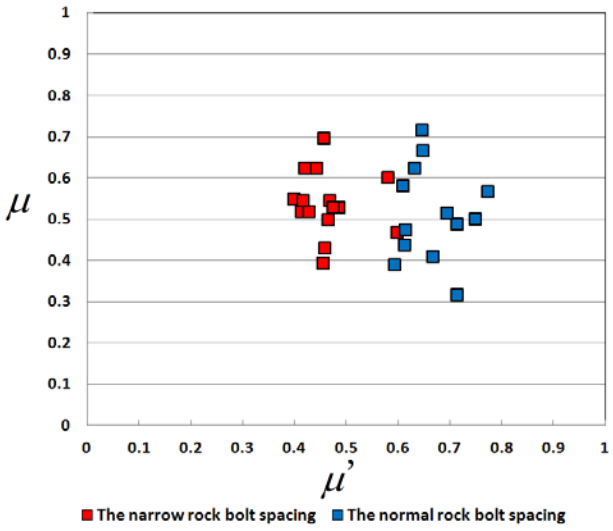


Figure.14 The reduction coefficient

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