INFLUENCE OF FIXED PLATE ON REINFORCEMENT OF A NEW NAILING METHOD

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Abstract

In Japan, disasters related to slope instability annually cause serious loss to human life and economy. The study of stabilization method of slope becomes very important subject, as such. With the forest area and mountainous area respectively covering 66.4% and 75% area of nation(1), this subject is no longer the study of stabilization method for forested slopes. For protecting the vegetation on natural slopes, minimizing the effects of human into the natural environment, a new nailing method(2) was proposed. This method can stabilize natural slopes while preserving the natural environment of cultural properties and landscapes, etc. New nailing method includes steel bars having fixed plate at their heads. When the topsoil layer becomes unstable and slides down, the steel bars inserting from topsoil layer into bedrock are deflected laterally and thus they fix unstable soil into bedrock. The shear force, bending moment, axial force of steel bars and axial settlement of fixed plate will respectively increase with the displacement of unstable soil. In this paper, we focused into the reinforcement of steel bar under the influence of fixed plate. The relationship between shear force, fixed plate settlement and axial force are analyzed as the functions of lateral displacements and depth of steel bar. Also, the calculated results of mathematical model of fixed head steel bar in combination with data of laboratory experiments were used to improve the analysis.

Mathematical model of steel bar:

As we know, an artificial slope has the designed properties of soil such as coefficients of friction; cohesion while natural slope usually has much weaker soil properties. Reinforcement of steel bar in an artificial slope is traditionally calculated by the resistance capacity of friction forces between steel bar and the soil layers. In case of a natural slope, friction force of topsoil is very small, and sometimes it approaches zero. Shear reinforcement at the slip surface and axial resistance force due to vertical settlement determines the steel bar reinforcement unless the topsoil is very weak in friction.

Considering the equilibrium condition of a steel bar in Fig. 1, we have equations 1 and 2(3):

$$EI\frac{d^4y}{dx^4} + Es(y-p) = P_x\frac{d^2y}{dx^2} \quad \cdots\cdots\cdots\cdots \ (1)$$

$$P_x = Kv \cdot S_p \cdot Dx \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \ (2)$$

where: *E, I* Young modulus and bending stiffness of steel bar, *p*: soil displacement, *Px*: axial force, *Sp*: area of fixed plate, (*y*, *x*): horizontal and vertical axes, *Dx*: vertical settlement of fixed plate, *Kv*: coefficient of vertical subgrade reaction, *Es*: Young's modulus of soil.

Equations 1 and 2 are solved to determine deflection, deflection angle, bending moment, shear force and axial force of steel bar(3).

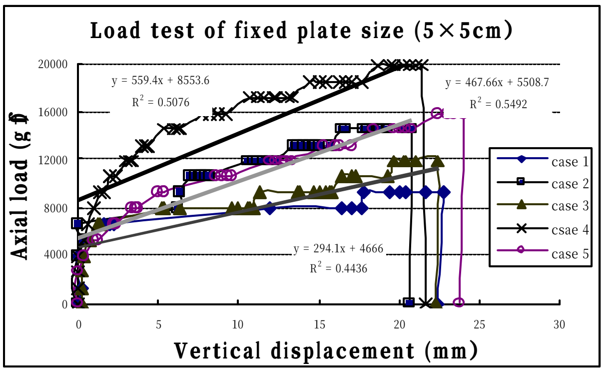

Fig. 2 Axial loading test - fixed plate size 5x5 cm2

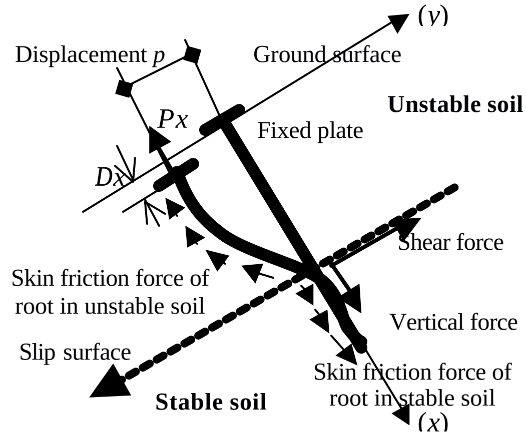

Fig. 1 Steel bar with fixed

The Young's modulus of soil was taken from axial loading test. Results of experiment are shown in the Fig. 2. By using these results in combination with the empirical equation for Young modulus, Es, of a cylindrical plate(4) and the other equations for Es of a square(5), we have Es=6.57 kN/m^2 for steel bar of 3mm diameter.

Experiment:

Two steel boxes were used in the experiment (Fig. 3). The upper box containing soil is the model of topsoil layer, while the lower one containing soil-cement represents bedrock. During the experiment, when the driving force became greater than the resisting force, the upper box started to slide down. The strain gauges glued upon steel bar recorded the stress distribution along the steel bar.

Table 1 Properties of soil in upper box

Properties of soil	Value	Unit
Grain diameter	< 4.75	mm
Unit weight of soil	2.647	g/cm3
Unit weight of dried soil	1.769	g/cm3
Saturation	13.9	%
Cohesion	0.9	kN/m2
Shear resistance angle	36.7	degree

Keywords: *Fixed head steel bar, natural slope, new nailing method, slope stabilization.*
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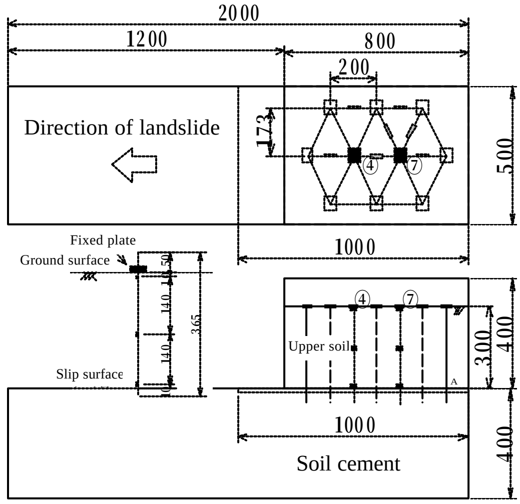

Fig.3 Experiment of steel bar with fixed plate

Comparison of calculation and experiment results:

Fig. 4 shows quite good agreement between calculated results and experiment data of fixed plate settlement (Es ranged from 60kN/m^2 to 1kN/m^2). The calculated result for soil elastic modulus Es=6.57 kN/m^2 is very similar to that of experiment data, especially with the displacements of topsoil layer less than 35mm (with displacements greater than 35mm, the behavior of topsoil probably may become different to that of an elastic material).

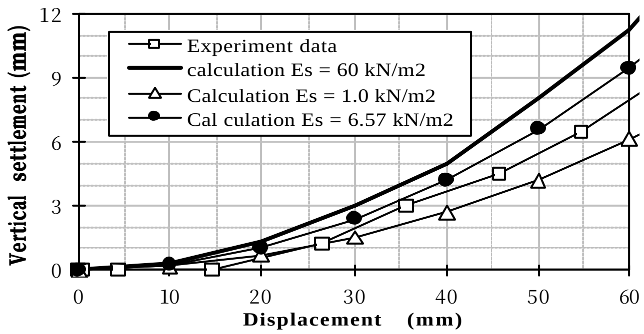

Fig. 4 Vertical Settlement of fixed plate

Fig. 5 shows the distribution of bending moment with respect to depth of steel bar at horizontal displacement 10.4 mm. The calculated results of bending moment are also close to experiment data.

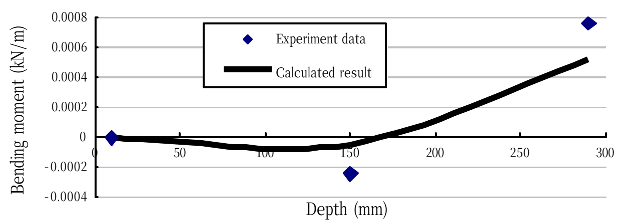

Fig. 5 Distribution of bending moment at displacement =10.4mm)

The maximum bending moment takes place very near to the slip surface. This value is main factor to determine the ultimate stress, and hence the breakage of steel bar. Fig. 6 shows relationship between the maximum bending moment and horizontal displacement. Experiment data and calculated results of bending moment are similar and linearly increase with displacement (Fig. 6).

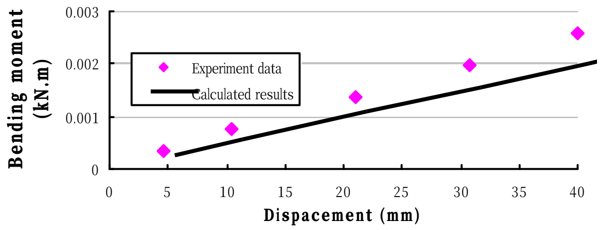

Fig.6 Bending moment of steel bar at slip surface

The calculated results of mathematical model for a fixed head bar, in practice are also compared with field experiment data of JH (Japan highway public corporation)(6). The steel bars in practice have fixed plate of size 0.5×0.5 m^2 or diameter 2.85cm. Interval between each bar is 2m×1.73m (Fig. 3). The influence coefficient of fixed plate α is computed by Eq. 3 (6):

$$a = \frac{A_p}{A_f} = \frac{1}{1-m} \quad \cdots\cdots(3)$$

where: A_p is reinforcement of steel bar with fixed plate, A_f is reinforcement of steel bar without fixed plate and m is negative coefficient(6). Calculated results are remarkably close to experiment database of JH (Fig. 7). That means the calculation model is also suitable for computing reinforcement of steel bar in artificial slopes.

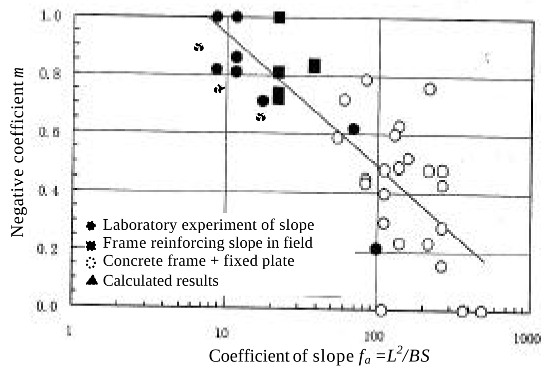

Fig.7 Slope coefficient f_a and negative coefficient m (6)

Conclusions:

Experiment shows that the reinforcement increases with the installation of fixed plate to steel bar reinforcing the soil slope. The calculation model, considering influence of fixed plate, is successfully applied to calculate reinforcement capacity of fixed head steel bars. Good comparison between calculated results and experiment data of bending moment and vertical settlement proves the possibility of mathematical model for designing new nailing method. Presented calculation method (for natural slopes) is different from the traditional method of JH (for artificial slopes), but it is still able to calculate reinforcement of steel bar in artificial slope. Fig. 7 shows the calculated results of two methods are very close to each other.

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