New Horizons in Earth Reinforcement – Otani, Miyata & Mukunoki (eds)

Steel nails for stabilizing forested slopes

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ABSTRACT: In Japan, slope failure often occurs under influences of earthquake and rainfall. Annually, it causes serious loss of dead, affects economy and threatens the safety of cultural or landscape heritage sites. However, traditional landslide countermeasures are often damaged the landscapes by clearing off the vegetation. To stabilize forested slopes while preserving the vegetation, a new nailing method, named Non-frame, was proposed. It is structured from three main parts: steel nail, fixed plate at nail head and the wire net connecting nail heads. Non-frame stabilizes a forested slope by fixing the unstable soil layer into the bedrock. The reinforcement of Non-frame mainly depends on the axial force that was born by settlement of fixed plate in combing with skin friction force between steel nail and slope and shear reinforcement was born by nail deforming. The wire net ties steel nail heads and topsoil moving together as a block to reduce partial failures that occurred very often in natural slopes. This paper introduces reinforcement mechanism of Non-frame and its applications in fields.

1 INTRODUCTION

The stabilization of forested mountains avoiding natural disaster such as landslide and slope failure is one of most important work of forest landscape conservation. On these papers, we discuss about Non-frame, a new method that stabilizes mountain slopes while preserving forest landscape in the strict conditions of typhoon and earthquake. The new method fulfills all the basic requirements of a landslide countermeasure such as producing enough reinforcement for design factor of safety. That is easy and simple of construction with light and standardized parts for setting up in fields. It also has to fulfill extra requirements for protecting landscape and cultural heritage sites such as: will not cut off vegetation, perfect soundproof under construction time, suitable for narrow scaffold and steep slope (up to 80°), suitable for various weather such as heavy rainfall and frost heave. In other side, we knew that tree roots could only penetrate into soft topsoil. If a traditional stabilization method such as soil nail, anchor or retaining wall was chosen, the weak topsoil must be cleared off and thus trees on slope with root reinforcement must be cleared also.

Non-frame protects vegetation and topsoil of the forested slopes those easily displace when factor of safety is smaller than 1.0. The displacement of topsoil, however, causes steel nail deformed and vertical soil pressure occurred under settled fixed-plate those respectively born shear reinforcement and vertical resistant. These reinforcement are not only depend on skin friction as a traditional soil nail, but also depends on axial resistant of settled fixed-plate and shear reinforcement of deformed steel nail.

2 MECHANISMS OF NAILING METHOD IN JAPAN AND NON-FRAME FEATURES

The mechanism of soil nailing methods is to fix unstable part of slope to the stable bedrock. It can be classified into two main types: Concrete-frame and Non-frame. Concrete-frame includes a number of nails in combining with a concrete frame covering slope

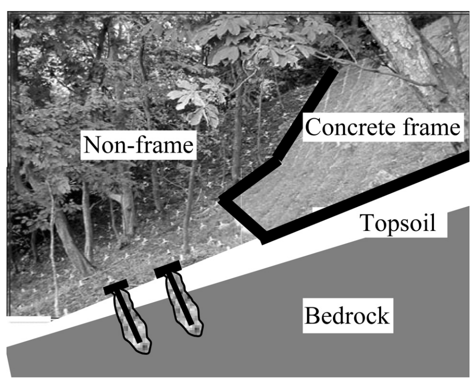

Figure 1. Non-frame stabilizing forested slope.

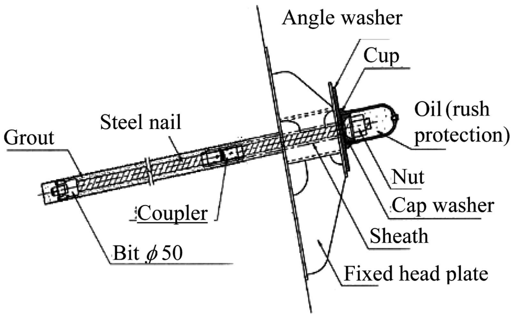

Figure 2. Structure of Non-frame.

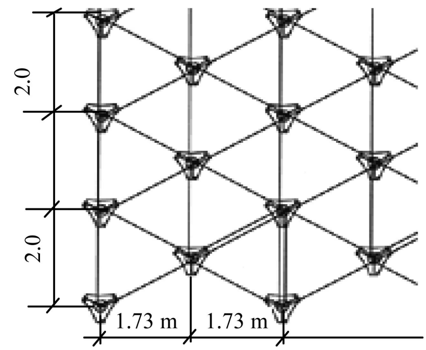

Figure 3. Distribution of Non-frame.

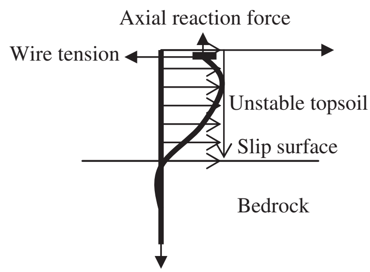

Figure 4a. Mechanism of Non-frame.

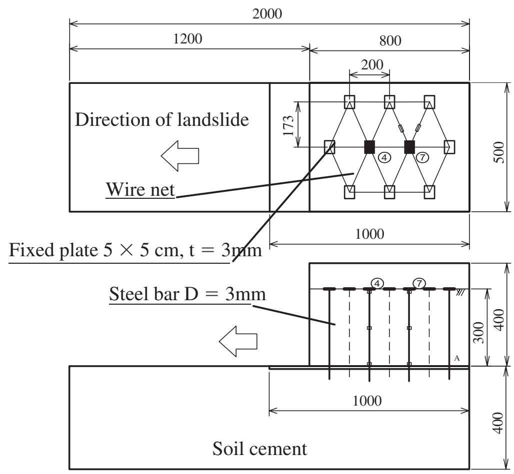

Figure 4b. Experiment of steel bar with fixed plate.

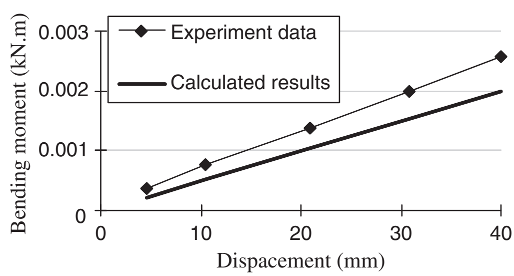

Figure 4c. Bending moment of steel bar at slip surface.

surface (see Figure 1). Soil nails fix topsoil tidily into the bedrock while concrete frame connects soil nails into each other as a frame. Hereby, concrete frame, soil nails and topsoil are locked as a rigid block. Concrete frame nailing method is suitable for stabilizing the slope of highway, port, infrastructures and other urban constructions where slope had good properties with large skin friction. In practice, concrete frame methods cannot be applied at cultural or landscape heritage sites where the natural landscape including vegetation must be conserved as well as possible. Furthermore, to build the construction by heavy machines, the environment around is disturbed. Non-frame, a new nailing method has the similar structure compare to the concrete frame method, but steel nails and unstable soil of slope are connected to each other by a flexible wire net system (not by a concrete frame) thus the trees on the slope surface can be totally remained as original situation.

The distribution of Non-frame on slope is showed in Figure 3 and the structure of Non-frame is showed in Figure 2. Steel nails stabilize a slope by flexibly reducing the movement of unstable slope. The vertical axial force is born by vertical settlement of fixed plate, which fixes unstable soil into bedrock. The triangular wire net connects steel nail heads to each other to avoid the partial failure of slope. Base on the equilibrium condition of a steel nail (see Figure 4), it reinforce slopes by transporting resisting force from bedrock to topsoil, equations (1) and (2) (Nghiem et al, 2004) are written:

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

$$P_x = Kv \cdot S_p \cdot \Delta x \quad (2)$$

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

where: E, I Young modulus and bending stiffness of steel nail, *p*: soil displacement, *Px*: axial force, *Sp*: area of fixed plate, (y, x): horizontal and vertical axes, Δx: vertical settlement of fixed plate, *Kv*: coefficient of vertical subgrade reaction, *Es*: Young's modulus of soil. Solutions of equations (1) are deflection, deflection angle; bending moment, shear force and axial force of steel nail. Solution of equation (2) leads to the axial force *P*. There are three main factors of reinforcement that influences the reinforcement of Non-frame: shear force of steel nail, axial reaction force of soil acting on fixed plate and wire tension at nail head. These three factors can be calculated by equations (1), (2) considering influences of wire tension. Reinforcement of steel nails on the slip surface is given by Equation (3):

$$R_c = S + S_w + P_x \cos(\phi) \tag{3}$$

where *Rc*: reinforcement of steel nail, *S*: shear force of steel nail on slip surface, *Sw*: wire tension, ϕ: inertial friction angle of soil. P_x is often calculated from skin friction between soil and grout around steel nails, it sometime is called pullout resistance. A reinforcement coefficient that shows the increase of resistance force by influences of shear force, fixed plate and wire tension compare to resistance force was born by only pullout resistance is previously calculated. Then the reinforcement is simplicity calculated by P_x and the reinforcement coefficient. A simple experiment was conducted to compare the results of the theoretical solution (Nakamura et al, 2005). Two steel boxes were used in the experiment. The upper box containing soil is the model of topsoil layer, the lower one containing soil-cement represents bedrock.

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. Figure 4c shows a good agreement of comparison between the calculated data and experiment data of bending moment.

The factor of safety (F_s) of slope can be presented by the Equation (4):

$$F_s = \frac{Resisting\ force + Rc}{Driving\ force} \tag{4}$$

Figure 5. Shrine was buried by land-slide (Nagaoka, Niigata Prefecture).

Incase of forested slope, the factor of safety is usually chosen as 1.2 for common design and is usually chosen as 1.0 for seismic design.

3 APPLICATION OF NON-FRAME

Japanese consider that forest is not only a place just has many plants; but they also considered forest as a complex system of plants, animals, society and culture. The trees sometimes become a sacred symbol that the people respect and protect with their high spirit. In that context, stabilization of slope must consider about the protection of the trees. As mentioned above, Non-frame was born to prevent shallow landslide while protect the vegetation on slopes. It was applied in many fields concerning the natural environment and landscape conservation issues. However, some of the cultural sites were damaged by landslide since the managers did not find out a suitable method such as Non-frame for stabilizing slope. Figure 5 shows a shrine was buried by shallow landslide after Chuetsu earthquake in Niigata Pref. of Japan. The structures at center and at right side of picture were ruined by deposit of landslide. Hereby, typhoon 23rd in combination with earthquake caused terrible earth disasters occurred not only on the natural slope, but also on the cement slope. The rainfall weakened topsoil, reduced skin friction between slope and soil nails, and then the slope and concrete frame were probably shaken to move separately until slope was failed. Incase of Non-frame, the flexible steel nail can move together with soil as a block that can avoid partial movement between steel nail and soil. In only three days 20~22nd March. 2005 more than 10 times earthquake M $\geq$ 4 and three times of rainfalls about 10 mm occurred in Fukuoka city. The field was surveyed on Mar. 24th, 2005. Figures 6a and 6b were taken at that time show Kumano shrine, which was protected by Non-frame. The slope

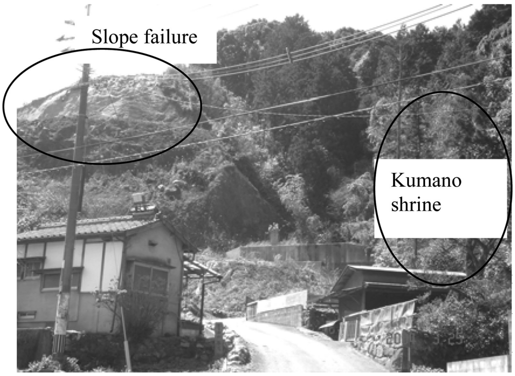

Figure 6a. Slope failure by earthquake and rainfall.

Figure 6b. Non-frame protected Kumano shrine.

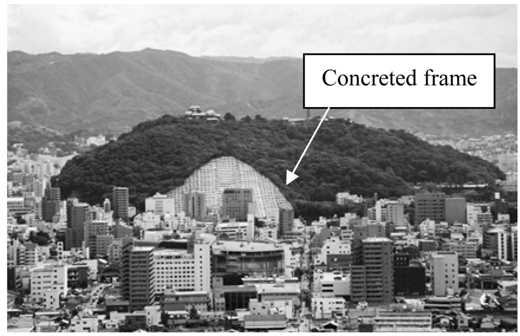

Figure 7a. Concrete frame method used in Ma-tsuyama castle (CG).

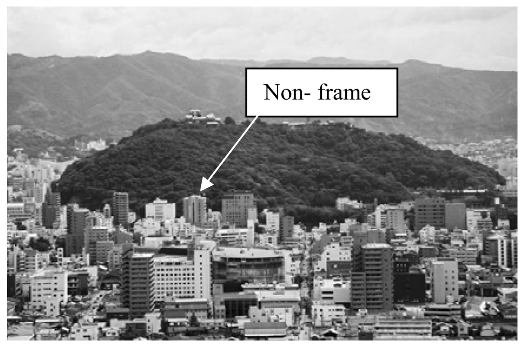

Figure 7b. Non-frame method for conserving Matsuyama castle (1 year).

near the shrine (on the left side of Figure 6b) was stabilized successfully while the slope on the left side of Figure 6a was fail by the effects of rainfall and the West off Fukuoka earthquake.

In addition, the Non-frame slope was greened while the slope without Non-frame (Figure 6a) was eroded seriously. Hereby, the wire net system played importance role in avoiding surface erosion and in protecting vegetation growing stable on the steep slope. Fixed plates also have similar role to reduce the surface erosion by stop topsoil movement.

Figures 7a, 7b show Non-frame protecting Matsuyama castle. It is the symbol of Matsuyama city, also is a very precious cultural heritage and landscape site in Japan. In 2001, the lower part of slope under the castle became unstable that threatened the safety of the castle at the top. The slope instability also affects to the safety of buildings at the foot of the slope. In this case, Non-frame was applied not only for preserving the castle, but also for the safety of the people living in the buildings. Figure 7a shows imagination of concreted slope, one of most common method in Japan. The sightseeing would become terrible with a part of slope covered in concrete without green.

To avoid such a problem, Non-frame was used at upper slope where people can see and concrete frame was only applied at lower places behind the building (where people cannot see the trees were cut off). Fig 7b was made one year after Non-frame was constructed that shows the sightseeing was successfully preserved while stabilizing the forested slope.

On Jun. 14th, 1998, about five events of 50 mm rainfalls caused area B (Figure 8) of Izuinatori slope failed (Fig 9b). There is a national rout at top of slope (Figure 8, area A) and Izu express railway in combining with other rout at foot of the slope. The slope must be stabilized carefully. In other side, the vegetation need to be preserved as well as possible because of Izuinatori is a famous landscape spot. Izu peninsula also was known as a center of Nankai earthquake. On Jul. 12nd, 2005 earthquake M4 and typhoon occurred at the same time that caused many shallow landslides close to the Izuinatori slopes occurred (Figure 10). Figures 10a, b show shallow landslide occurred at Imaihama area, about 1 km South of Izuinatori slope. Figure 10d shows

Figure 8. Non-frame stabilizing Izuinatori slope.

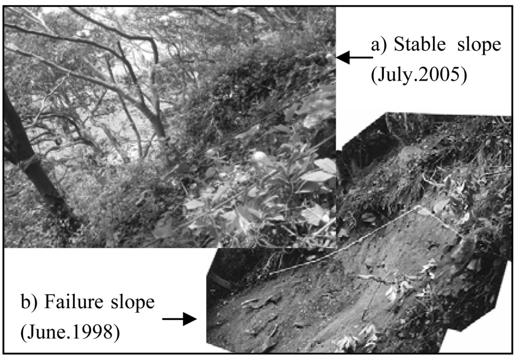

Figure 9. Izuinatori slope before and after rein-forcing by Non-frame.

slope failure at Kawazu tunnel very close to the Non-frame field and Figure 10c shows other landslide in upstream area of Izu peninsula. Such a good example of Non-frame application, Izuinatori slope is perfectly stable, Figure 9a.

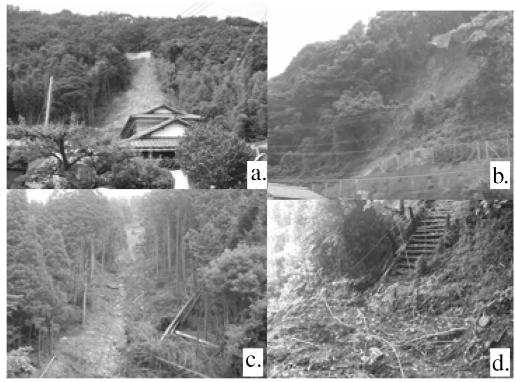

Figure 10. Four shallow landslides occurred near the Izuinatori slope (12nd. Jul. 2005).

4 CONCLUSION

By innovative method of steel nail flexibly, it nails top-soil into the bedrock in combining with block efficient of wire net to avoid the partial failure and thus keep slope more stability, Non-frame can protect vegetation while stabilizing slope. It fulfills the complicated requirements of conservation works for a cultural or landscape heritages. Three fields in Japan show Non-frame preserving the forest slopes that is successfully under effects of typhoons and earthquakes.

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