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Full-scale tests on a new type of debris flow trapping fence

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ABSTRACT: Performance of a new type of debris flow trapping fence was examined through a series of full scale tests in which debris flow the trapping fence after traveling a certain distance along a slope of about 5 m high. The fence is essentially a pair of geonet fence designed to prevent the possible traffic accidents by effectively trapping debris flows at the side of motorways. The debris flow trapping fence consists of two fences (0.7 m high × 1.5 m wide) one of which is standing vertically and the other of which is lying on the ground. The standing fence is connected to the lying fence by two hinges at a right angle at the bottom end of a standing fence and is also connected to the lying fence by two bars at the other ends. The debris flow hits the standing fence forcing the standing fence to fall down by rotating around the hinges resulting in the lying fence to stand up vertically. Although the fence is only 0.7 m high and 1.5 m wide, the trapping fence was found to be effective enough to trap 3.0 m^3 of debris flow of wet soil. Liquefied mud of 1.2 m^3 containing more water was also effectively stopped by the trapping fence with splashes of muddy water sprayed 3.5 m beyond the fence while the mud flow reached a distance of 7 m in case that there was no trapping fence at the toe of the slope. The test results ensured that the debris flow trapping fence is an economic measure to prevent the small scale debris flows and to protect the traffic on the motorway.

1 INTRODUCTION

In order to ensure the safety and smooth traffic flow under rainfall condition, the traffic control has been specified for each expressway section. Consequently, any disasters can be prevented when roadways are closed. East Nippon Expressway Company considers the criterion of traffic regulation, for example, taking road strengthening measures such as slope stability and analyzing accumulated disaster data. In low cut slope sections, simple control works are needed to prevent to hold up passing vehicles due to local slope failures.

We developed a debris flow trapping fence to prevent flowing debris from reaching the roadway. The characteristic of the debris flow trapping fence is to dissipate the impact energy of flowing debris by rotating itself and to prevent debris flow reaching roadway. Even when the trapping fence does not rotate, the weight of the trapped debris acts as a counterweight, so that there is no need for a large foundation. This paper reports the characteristics of the debris flow trapping fence and results of full-scale field test.

2 DEBRIS FLOW TRAPPING FENCE

2.1 *Shape of the debris flow trapping fence*

We developed the debris flow trapping fence which consists of an L-shaped frame built with equal-leg angles and polyester netting, and is designed to rotate around an anchor bolt. The bottom is provided with a deformed bar (D35) anchor bolt which anchors the fence to the ground. The fence and bottom are connected together by high-tension bolts (HTB-M24)

Figure 1. Debris flow trapping fence.

Table 1. Specifications of debris flow trapping fence.

Dimensions	700 × 700 × 1500 mm
Frame	Equal leg angle
Net	Polyester raschel net Tensile strength : 30 kN/m
Anchor	Deformed bar, D35 × 500 mm
Connector	High-tension bolt M24
Design impact force	12.02 kN/m

and nuts. Figure 1 shows the structure of debris flow trapping fence, and Table 1 shows its specifications.

2.2 *Design of the debris flow trapping fence*

The impact force of debris flow considered for design of the debris flow trapping fence is calculated (Ministry of Land, Infrastructure and Transport, 2001). As a soil condition, we assume that soil density is $\rho_m = 1.4\,\mathrm{t/m^3}$ (loose cohesive soil), and that the design condition is "debris flow from a height of 0.5 m from the top of a two-stage 45 degree slope" as shown in Figure 2. The impact force of the debris flow is $F = 12.0$ kN/m calculated as follows.

$$F_{sm} = \rho_m g h_{sm}\left[\left\{\frac{b_u}{a}\left(1-e^{\frac{-2aH}{h_{sm}\sin\theta_u}}\right)\cos^2(\theta_u-\theta_d)\right\}e^{\frac{-2ax}{h_{sm}}} + \frac{b_d}{a}\left(1-e^{\frac{-2ax}{h_{sm}}}\right)\right] = 48.08\mathrm{kN/m^2} \quad (1)$$

$$F = \alpha \cdot F_{sm} \cdot h_{sm} = 12.02\mathrm{kN/m^2} \quad (2)$$

where, F_{sm} : moving force of flow debris, ρ_m : density of flow debris, g : gravitational acceleration, h_{sm} : height of debris before flowing, θ_u : gradient of slope, θ_d : gradient of ground, H : height of slope, x : horizontal distance from toe of slope to fence, F : impact force, α : relaxation coefficient of impact force and a,b_u,b_d : calculated by θ_u, θ_d, specific gravity, density, fluid resistance and angle of internal friction of debris.

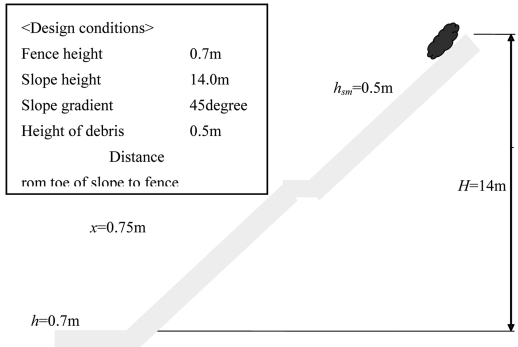

Figure 2. Design conditions and results.

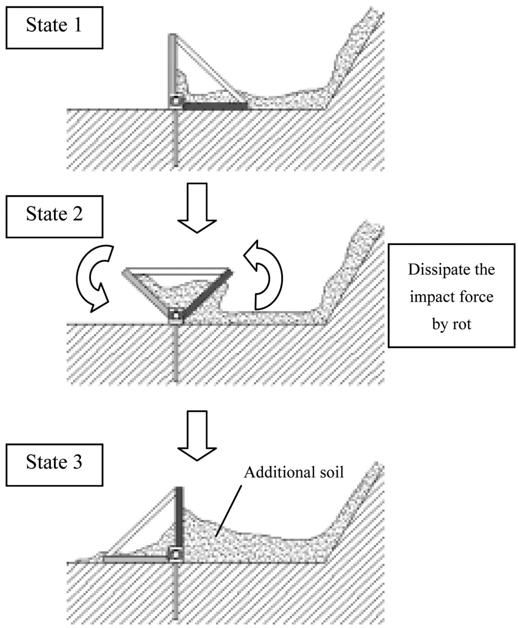

Figure 3. Mechanism of debris flow trapping fence.

2.3 *Rotation mechanism*

Figure 3 shows rotation mechanism of debris flow trapping fence. First, the flow debris hits the upright net of the L-shaped fence (State 1), the fence begins to rotate as it dissipates the impact force of the flow debris (State 2). The fence rotates around the high-tension bolt. After the rotation, the bottom face of the L-shaped fence acts as an upright fence surface as to

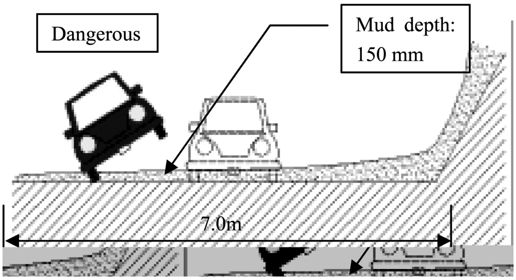

Figure 4. Failure of slope without trapping fence (mud flow directly hitting a passing vehicle).

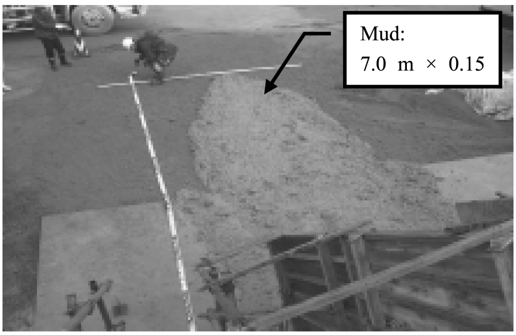

Figure 5. Free flow of mud along slope without trapping.

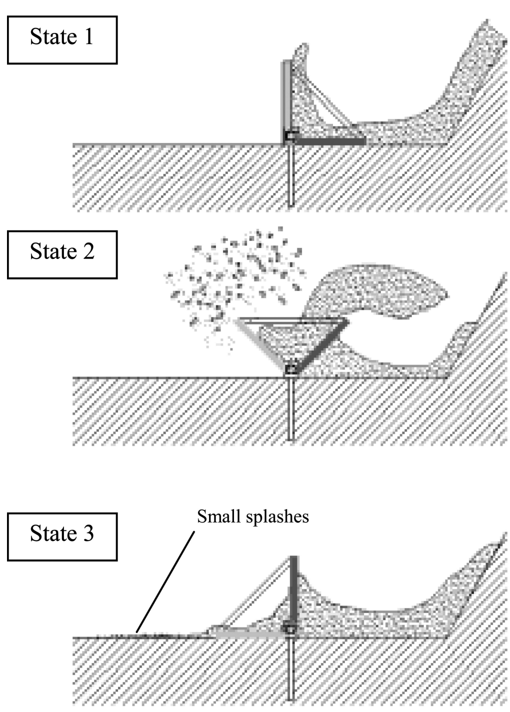

Figure 6. Behavior of mud with trapping fence.

continue to hold back the flow debris (State 3). Characteristic of the debris flow trapping fence is that the fence dissipates the impact force of debris by rotating itself and deflects the direction of energy flow from the horizontal direction to a downward direction, so that it reduces the amount of debris flow toward the road. A second characteristic is that even when it does not rotate, the debris deposited over the bottom net of the fence acts as a counterweight to retain a large volume of debris.

2.4 *Other characteristics*

The debris flow trapping fence has many advantages as follows : 1) After rotating, the fence can retain the flow debris. 2) Inexpensive. 3) Simple structure enables easy installation and removal. 4) Parts of the fence are easy to replace. 5) There is no need for a large foundation, and the amount of construction by-products is small.

3 RESULTS OF FULL-SCALE TESTS

3.1 *Dissipation of impact force by rotation*

In the field test, a 1.2 m^3 of mud mass (0.8 m^3/m) was slid down freely along the slope in the test as shown in Figures 4 and 5. Figures 6 and 7 show that the mud mass was trapped by the trapping fence. In the case that the trapping fence was not used, the mud mass reached the roadway, and the front end of the mud mass was 7.0 m from the toe of the slope and the mud depth was 0.15 m. In the case that the trapping fence was installed and the mud mass was slid down the slope under the same conditions as the fenceless case, when the sliding mass reached the upright net of the

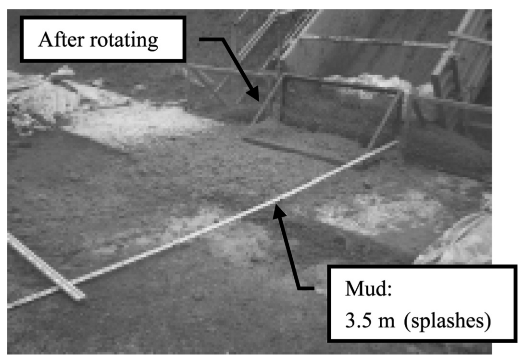

Figure 7. Flow of mud along slope with trapping fence.

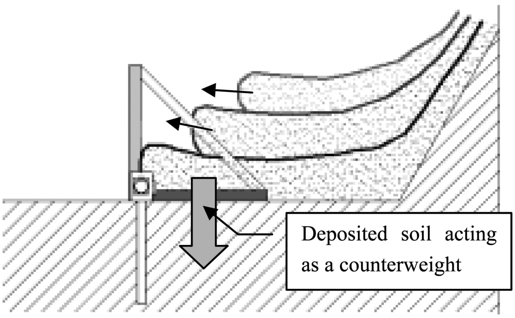

Figure 8. Trapping a flow of field product soil.

Figure 9. Trapping a flow of field product soil.

fence, much of the mud was thrown up (State 1). Part of the mud was thrown backward and the mud flow was prevented from reaching the roadway (State 2). Part of the mud was splashed (State 2) and reached a point 3.5 m from the toe of the slope. Since, however, these splashes were small, their influence on the roadway was considered to be small even if they reached the roadway (State 3). Concurrently, when the trapping fence began to rotate, it dissipates the impact force of the mud (State 2).

3.2 *Retention of debris by self-weight*

In the second field test, a $3.0\,m^3$ soil mass ($2.0\,m^3/m$) of field product soil (sandy gravel containing cohesive soil) was slid down a single-stage cut slope toward the fence. Figures 8 and 9 show that the soil mass was trapped by the fence. The soil mass was retained by the upright net of the trapping fence. The debris deposited on the bottom net, and more debris was deposited on the material deposited earlier. In the test, the fence did not rotate, and the flow debris was successfully retained by the self-weight of the debris.

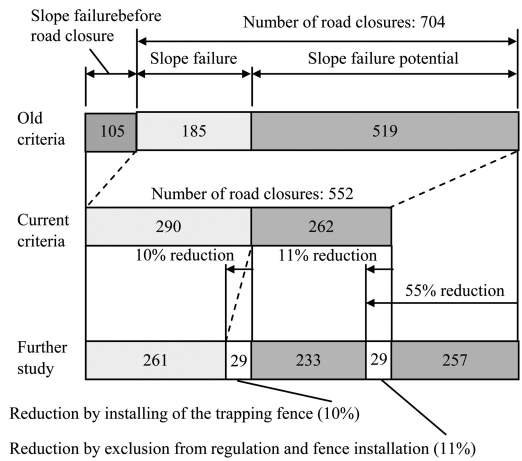

Figure 10. Road-closure-reducing effect.

4 VERIFICATION OF THE EFFECT OF DEBRIS FLOW TRAPPING FENCE

We verify that the closed road due to slope failure can be reduced by installing the debris flow trapping fence as shown in Figure 10. The volume of flowing debris retained by the debris flow trapping fence is assumed to $2.2\,m^3$. Of all cut slope failures in the past 10 years, single-stage cut slope failures account for about 35%. Of the single-stage cut slope failures that necessitated road closure, 28% are small-scale failures that involved $2.2\,m^3$ or less of collapsed soil. It will be possible to prevent road closure at 29 slope failure sites ($0.35 \times 0.28 \times 100 = 10\%$).

When we considered possible reductions in the number of road closures due to slope failure potential, 27% took place in low cut or fill slope sections. About 40% in low cut or fill slope sections can be prevented by installing the debris flow trapping fence. This indicates that it is possible to prevent 29 ($0.27 \times 0.4 \times 100 = 11\%$) road closures in the 262 road closures made because of slope failure potential. If the number of road closures (519) made because of slope failure potential in accordance with the old standards is taken into consideration, about 55% ($=(257 + 29)/519$) can be prevented.

When we consider the number of road closures that can be prevented, we find that 58 road closures made because of slope failure or slope failure potential can be prevented by installing the debris flow trapping fence. Therefore, it can be concluded that the debris flow trapping fences will contribute to better road management and reductions in the number of road closures.

5 CONCLUSIONS

The results of this study can be concluded as follows : 1) The debris flow trapping fence has been developed as a simple means of damage mitigation with the aim of preventing collapsing material from reaching the roadway in the event of a small-scale failure of a low cut slope. 2) The debris flow trapping fence has a number of advantages including its ability to dissipate the impact force of debris by rotation. 3) The advantages of the debris flow trapping fence have been verified through the field test. 4) We predict that better road management can be achieved, and that road closures can be prevented by installing the debris flow trapping fence.

The debris flow trapping fence is a means of damage mitigation based on a completely new concept that have been developed as simple control works following the reconsideration of criteria for road closure due to rainfall. By applying the debris flow trapping fence to actual road, it can be expected to contribute to better road management and reductions in the number of road closures due to small-scale slope failure. We believe that the debris flow trapping fences will contribute to safer and smoother traffic flows expected of expressways. We will continue to work for further improvement under the cold and snowy conditions.

REFERENCES

Ministry of Land, Infrastructure and Transport. 2001. Public Notice No. 332.

Expressway Technology Center. 2003. Study on Traffic Control Due to Rainfall.