Upgrading of existing stone guard fence by use of high-energy absorption net

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ABSTRACT: This paper proposes a new technique which can upgrade the performance of existing stone guard fence by use of high energy absorption net that made from synthetic fibers. In this technique, large rockfall impact energy beyond the design one for the existing fence can be damped by the high energy absorption net installed in the mountainside of the existing fence. In order to confirm the applicability of the proposed technique, a field test and its numerical simulation were carried out. This paper describes the results of the field tests and numerical simulations as well as the design example of the proposed technique.

1 INTRODUCTION

A great number of stone guard fences that protect the traffic of mountainous roads from rockfalls have been constructed in Japan. However, there are many cases, in which a new stone with larger rockfall impact energy than the initial design one for the existing stone guard fence is found during the periodic site investigation, hence, many existing stone guard fences do not satisfy the performance requirements of the rockfall protection fence.

Therefore, in order to upgrade the existing fences lacking the performance requirement, a new technique, which uses the high energy absorption net consisted of several members made from synthetic fiber, have been proposed by authors. In this technique, the high energy absorption net is installed in the mountainside of the existing fence, and the large rockfall impact energy can be reduced to smaller one than the design one for the existing fence before the collision between the falling rock and the existing fence. Two field-tests were carried out, in which one is to model the deformable characteristic of the high energy absorption net installed in slack state for numerical analysis and another one is to confirm the efficiency of the proposed technique. Numerical simulations were also carried out in this study. This paper describes the results of the field tests and numerical simulations as well as the design example of the proposed technique to upgrade the performance of the existing stone guard fence.

2 HIGH ENERGY ABSORPTION NET

2.1 *Structural characteristics*

The structure of the high energy absorption net is illustrated in Figure 1. The net consists of several members made from synthetic fiber which are knitted net, outer circumferential rope of the net, belt and rope arranged in a double cross. The major characteristic point of the net is that; the net can absorb the large rockfall impact energy from its high deformable ability. Although the synthetic fiber is considered that it is susceptible to the ultraviolet, the ability of the synthetic fiber treated by anti-ultraviolet shielding, which the net can possess 70% tensile strength after 25 years passed, has been confirmed from a series of accelerated weathering test.

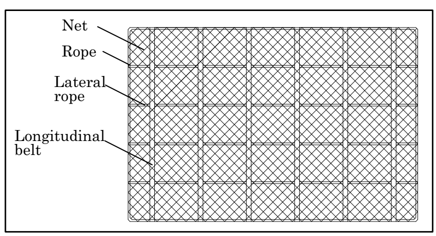


Figure 1. High energy absorption net.

2.2 *Modeling for numerical analysis*

In order to study the modeling of the high energy absorption net for numerical analysis, a field test was carried out in advance. Figure 2 summarizes the field test in which the high energy absorption net was adopted as a member of an independent rockfall protection net system. In this test, the target absorptive rockfall energy for the net system is 150kJ. According to the test, it was confirmed that the net system absorbed the target energy of 150kJ by the deformation of the high energy absorption net of about 4.0m as shown in Photograph 1 (Yoshida *et al.* 2008).

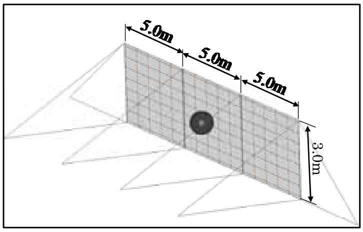
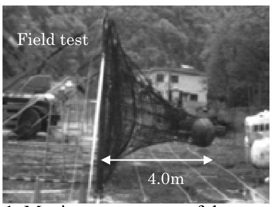


Figure 2. Field test on high energy absorption net



Photograph 1. Maximum response of the net system.

A numerical simulation was carried out to study the performance of the deformable characteristics of the net consisting of several members made from synthetic fiber, which are installed in slack state. The numerical tool LS-DYNA was used for the simulation in this study. All members constituting the net are modeled by the cable elements, which only resists against the tensile force. Table 1 presents parameters to simulate the response of the high energy absorption net, where elastic modulus of the members constituting the net are set as 0.2 times of the original parameters of each members. Figure 3 shows the maximum response deformation of the net system obtained from the numerical analysis. According to the result, the analysis is found to reproduce well the response of the net system observed in the field test. Therefore, the parameters of the net adopted in the simulation will be used as the basic parameters of the net in this study.

Table 1. Parameters of the members constituting the net

	Elastic modulus kPa	Sectional area m^2
Rope of net	4.27×10^4	6.36×10^{-6}
Longitudinal belt	5.56×10^5	2.40×10^{-4}
Lateral rope	2.12×10^5	3.14×10^{-4}
Stay	2.78×10^6	1.20×10^{-4}

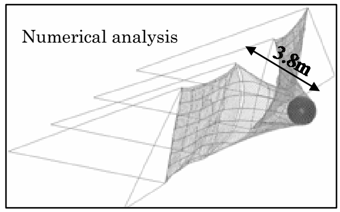


Figure 3. Deformation of the high energy absorption net.

3 UPGRADE TECHNIQUE OF EXISTING STONE GUARD FENCE

3.1 *Upgrade technique*

Photograph 2 shows the target existing stone guard fence in this study. This type of fence is one of popular rockfall protection facilities in Japan. The fence consists of wire mesh, wire rope and steel post. Figure 4 shows the upgrading technique of existing stone guard fence using high energy absorption net, which is proposed in this study. The high energy absorption net is installed in the mountainside of the existing fence by using rope made from synthetic fiber. Upper and lower ropes are connected in the anchor installed in the back slope. The purpose of the technique is to reduce large rockfall impact energy to smaller one than the design one for the existing fence by the absorbable ability of the high energy absorption net before the collision between the falling rock and the existing fence.


Photograph 2. An existing stone guard fence

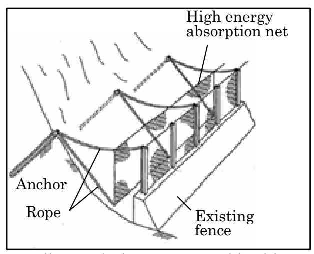


Figure 4. Upgrading technique proposed in this study.

3.2 *Field test*

A field test to confirm the effectiveness of the proposed upgrading technique for existing stone guard fences was carried out. Figure 5 shows the summary of the test. The frame structure constructed by H steel members, H200×200×8×12, was adopted to model an existing fence and the back slope of the fence. The existing fence was modeled by a wire mesh (mesh size: 50mm square, diameter of wire: 3.2mm) on the frame structure. The high energy absorption net was set in front of the existing fence by using upper and lower ropes. In this test, two cases were carried out, in which Case 1: a steel ball with the energy of 100kJ hits the wire mesh directly (the case without the high energy absorption net), and Case 2: the steel ball hits the wire mesh through the high energy absorption net (the case with the high energy absorption net; the proposed technique).

Photograph 3 shows the actual responses of the wire mesh, the steel ball and the high energy absorption net after the collision between the steel ball and the wire mesh. According to the results, in Case 1, the steel ball broke the wire mesh and jumped out of the wire mesh. In contrast, in Case 2, the high energy absorption net set in front of the wire mesh reduced the energy of the steel ball before the collision between the steel ball and the wire mesh, consequently, the wire mesh could catch the steel ball without any damage. The applicability of the upgrading technique proposed in this study was confirmed from the results.

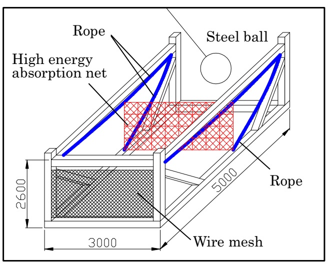


Figure 5. Summary of a field test


(a) Case 1: without the net (b) Case 2: with the net
Photograph 3. Responses obtained from the field tests

3.3 *Reproducibility of the numerical analysis*

In order to design the proposed technique, the reproducibility of the numerical analysis with the basic parameters of the net presented in Table 1, was confirmed from the comparison between the results of the field test and simulated one. Figure 6 shows the simulated responses of the high energy absorption net, the steel ball and the wire mesh. Figure 7 shows the comparison between the observed time history of the acceleration of the steel ball and simulated one. According to the results, the numerical analysis using the basic parameters of the net is found to reproduce well the observed response in the field test.

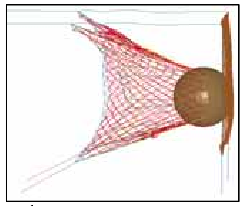


Figure 6. Simulated responses.

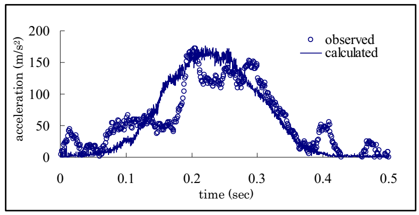


Figure 7. Time history of the acceleration of the steel ball.

4 AN EXAMPLE OF DESIGN ON UPGRADING TECHNIQUE FOR EXISTING STONE GUARD FENCE

4.1 *Modeling of existing stone guard fence*

Figure 8 shows the finite element model of the target existing stone guard fence in this example. The design absorbable rockfall energy of the target fence is 56kJ when the rockfall hits the wire mesh and is 70kJ when the rockfall hits the post (Japan Road Association 2008). In this example, the case of the collision between the falling rock and the part of the steel post is targeted. From the view point of practical design, simple elastic analysis was adopted in this example.

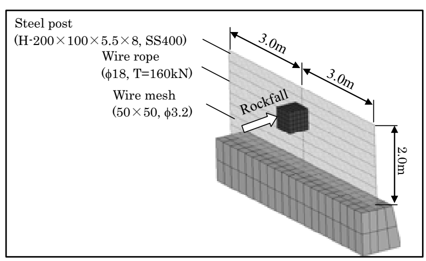


Figure 8. Modeling of an existing stone guard fence.

The deformable characteristics of the each member constituting the existing fence are modeled based on the design deformation of the fence when the falling rock hits the post, as shown in Figure 9 (Japan Road Association 2008). More specifically, equivalent flexural stiffness (EI) of each member based on equivalent absorption energy with respect to each elasto-plastic behaviors (Newmark et al. 1960) as shown in Figure 10 is adopted in this analysis.

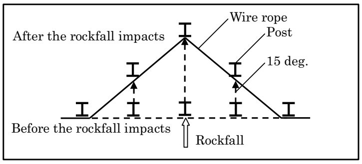


Figure 9. Design deformation of the existing stone guard fence.

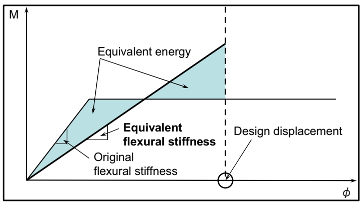


Figure 10. Equivalent flexural stiffness.

4.2 *Results of the numerical analysis*

Figure 11 shows the maximum responses of the center post of the target existing fence, displacement and bending moment with respect to the design rockfall impact energy of 70kJ. In this study, the performance of the target existing fence is discussed based on a criterion measure of the limit state.

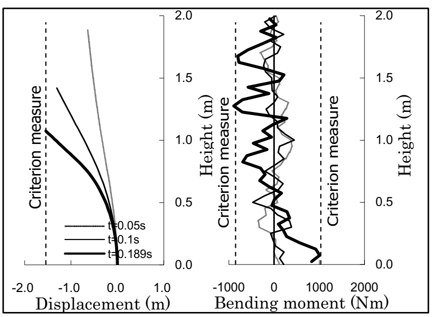


Figure 11. Response of the post (70kJ, without the net).

Figure 12 shows the maximum responses of the center post of the target existing fence with respect to new rockfall impact energy of 135kJ which is about 2 times of the design one. Since the responses of the existing fence are larger than the criterion measure, it is considered that the performance of the fence cannot satisfy the requirements as the rockfall protection fence with respect to the new target rockfall impact.

In contrast, the maximum responses of the center post of the target existing fence with respect to the new rockfall impact energy of 135kJ with the proposed technique are smaller than the criterion measure as shown in Figure 13. Therefore, the performance of the existing fence could be upgraded against the new rockfall impact by the proposed technique in which the high energy absorption net was set 2.0m back of the existing fence in this example.

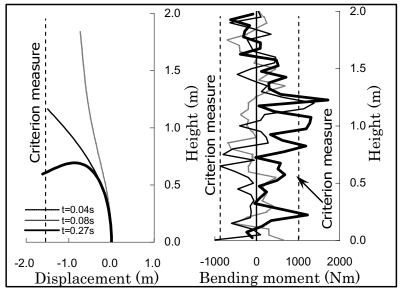


Figure 12. Response of the post (135kJ, without the net).

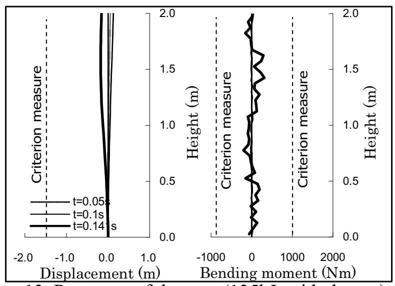


Figure 13. Response of the post (135kJ, with the net).

5 CONCLUSION

This paper can be concluded as follows; 1) a new upgrading technique of the existing stone guard fence which uses the high energy absorption net was proposed, 2) the effectiveness of the proposed technique was confirmed from a field test, 3) a design method which can reproduce the results of the field test was proposed, and 4) a design example of application of the proposed technique to an existing stone guard fence was introduced.

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