Experiments on pocket-type rockfall protective nets at a real slope

著者	Namba Masakazu, Maegawa Koji, Tajima Tomonori, Yokota Tetsuya
journal or publication title	Engineering for Progress, Nature and People (37th IABSE Symposium Madrid 2014, LBSE Madrid Symposium Report)
volume	102
number	2014
page range	815-822
year	2014-01-01
URL	http://hdl.handle.net/2297/43033

Experiments on pocket-type rockfall protective nets at a real slope

Masakazu NAMBA
Graduate Student
Kanazawa University
Kanazawa, Japan
nanba@raiteku.com

Koji MAEGAWA
Professor, Dr-Eng.
Kanazawa University
Kanazawa, Japan
maegawa@staff.kanazawa-u.ac.jp

Tomonori TAJIMA
Civil Engineer, Dr-Eng.
Raiteku Co.Ltd.
Niigata, Japan
tajima@raiteku.com

Tetsuya YOKOTA
Civil Engineer
Raiteku Co.Ltd.
Toyama, Japan
yokota@raiteku.com

Summary

Although pocket-type rockfall protective nets are more economical and easier to install, the amount of rockfall energy they can absorb and the locations where they can be used are limited. Because of this, in recent years, a new rockfall protective net, which has built-in shock absorbers to prevent anchor rods from breaking and to absorb considerable rockfall energy due to their function, has been designed. This study was conducted to determine the effective range of implementation for a new pocket-type rockfall protective net, and to confirm the net's reaction and energy absorption capacity upon the introduction of rotational energy approximating the actual behavior of a rockfall.

Keywords: pocket-type rockfall protective net; impact test; real slope.

1. Introduction

Rockfall mitigation construction can be divided into two types: rockfall prevention construction, in which measures are taken to prevent rockfalls before they occur, and rockfall protection construction, in which measures are taken to catch and stop falling rocks and prevent them from falling further or divert them to the side [1]. In one type of rockfall protection construction called a pocket-type rockfall protective net, the face of the slope is covered with a wire netting that catches and stops falling rocks that enter from a gap at the top of the net. Due to its light weight and widely available construction materials, this type of net is low cost, easily installable, and is widely used in Japan. However, this type of net is only capable of protecting from rockfalls of relatively low energy (50 - 150 kJ), limiting the sites where it can be installed. In recent years, a new type of high-energy-absorption pocket-type rockfall protective net has been under development, with shock-absorbing devices embedded into its mechanical structure. Adoption of this new type of protective net will be possible after evaluating its rockfall protection performance and capability in handling rockfalls of rated energies through performance evaluation experiments and data analyses. In previous research [2], the authors have performed impact experiments with full-scale free-falling masses and verified the performance of the pocket-type rockfall protective nets equipped with two different types of shock-absorption devices. However, due to limitations imposed by the experiment site and experiment setup, the previous experiments were performed with a vertical fall direction, which is different from the real-world case, and did not consider rotational energy because the experiments were free-fall. These issues were left for future research. In this research, the rockfall trapping behaviour of the same types of nets was verified and energy absorption performance was evaluated for the case of rockfalls with rotational energy, through a full-scale impact experiment on a real slope. In addition, the experiments were performed with both the conventional type of zinc-coated low carbon steel wires wire netting (hereafter referred to as "conventional-type wire netting") and a new type of high tensile strength zinc-coated steel wires wire netting (referred to as "new-type wire netting"), and the applicability of the new-type wire netting was verified. Increasing the tensile strength of the wires will make it possible to decrease the size of the wires of the wire netting, resulting in decreased weight and improved ease of installation.

2. Outline of the Experiments

2.1 Experiment method

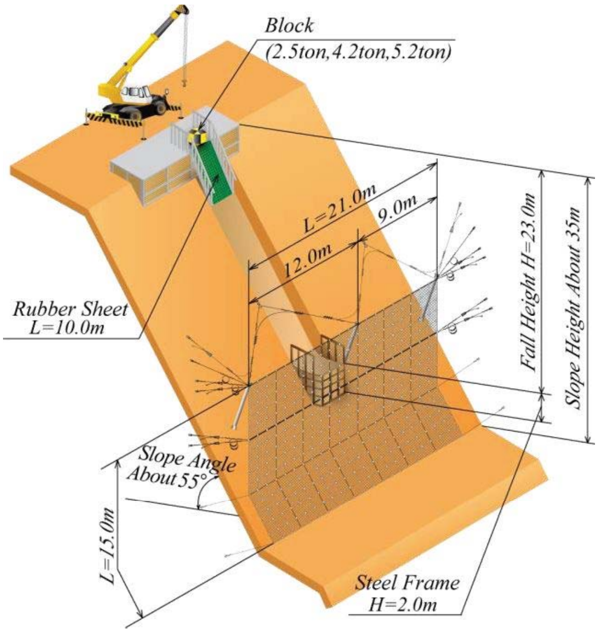


Fig.1: Experiment method schematic view

Figure 1 shows a diagram of the experiment method. In the experiment, a rail was constructed to drop a block from the top of a slope of a height of 35.0 m and a gradient of 55.0 degrees. A runway for the block was excavated into the slope from the top to 25.0 m down the side. A rail of a height of 2.0 m was constructed in the middle of the slope to make the impact direction of the block to be horizontal. A rubber sheet was laid on the runway from the top of the slope for 10.0 m to make the block roll down easily. During the experiment, the block was placed in the rail at the top of the slope, then made to fall by lifting the edge of the rail up with a crane, and made to collide with the test piece at the bottom of the slope.

2.2 Block characteristics

Table 1 lists the masses and dimensions of the blocks used in the experiments. Figure 2 shows the shape of the block. To reproduce the same behavior as in a real rockfall, a shape which easily rolls down slopes was used for the block, as specified in the guideline ETAG27 [3] defined by EOTA. The block was made of reinforced concrete with surfaces covered by iron sheets, and has a cavity in the center for installing a three-axis accelerometer. The 2.5-ton and 4.2-ton blocks were made of a single part, and the 5.2-ton block was made of a top and bottom part, taking transportability into consideration.

Table 1: Mass and the length of the block

Mass(ton)	2.5	4.2	5.2
Length(mm)	1120	1328	1408

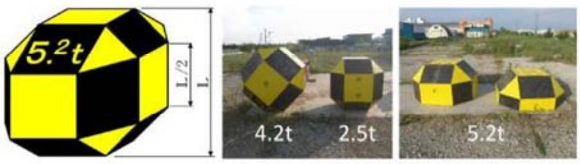
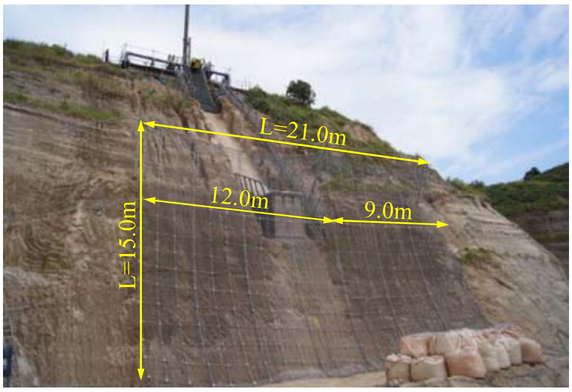


Fig.2: Shape of the block

2.3 Test specimen

Figure 3 shows the shape and dimensions of the test specimen. The net is of a height of 15.0 m, and consists of two non-symmetric spans with supporting post intervals of 12.0 m and 9.0 m, with a total length of 21.0 m. Although it would have been desirable to conduct the experiments with two spans both of the maximum spacing interval of 12.0 m, due to the limitations of the test location, the test specimen was constructed with a combination of a maximum spacing interval of 12.0 m and minimum spacing interval of 9.0 m.



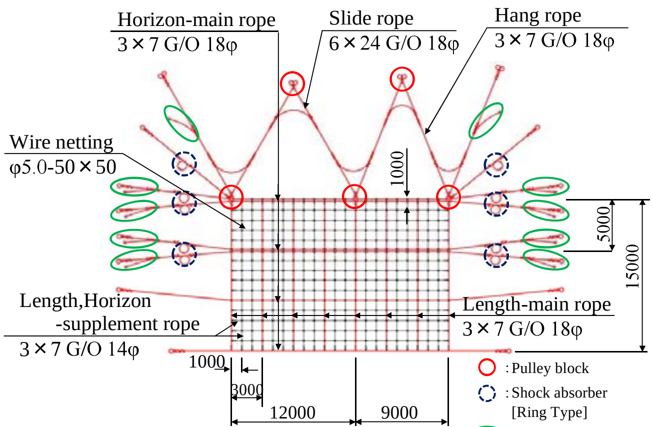
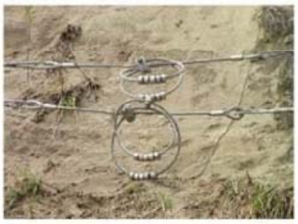


Fig.3: Test specimen setup

The main materials of the test specimen are: supporting posts (SS400, H-150×150×7×10, supporting post height = 4.0 m), wire netting (two types: zinc-coated low carbon steel wires 5.0φ-50×50, and zinc-coated steel wires 4.0ϕ-50×50), hang and main horizontal and vertical wire ropes (3×7 G/O 18ϕ), supplementary wire ropes between the main wire ropes (3×7 G/O 14ϕ), slide ropes on the pulley block (6×24 G/O 18ϕ), anchors (D29-3000), shock-absorber equipment shown in Figure 4 (two types: U-bolt type and ring type), and pulley blocks.



Shock absorber[Ring Type]

Shock absorber[U-bolt Type]

Pulley brock[pillar]

Pulley brock[anchor]

Fig.4: Shock absorber and Pulley block

The main horizontal wire ropes (3×7 G/O 18ϕ) are spaced at intervals of 5 m. In the upper-most and second levels, which are the areas that the block directly impact, two layers of wire ropes are installed, so that the load is distributed more after the block impacts and to increase the total amount of energy absorbed by increasing the shock absorbers. The main vertical wire ropes (3×7 G/O 18ϕ) are spaced at intervals of 3 m. Supplementary wire ropes (3×7 G/O 14ϕ) are spaced at intervals of 1.0 m between the main horizontal and vertical wire ropes. Both the U-bolt-type and ring-type shock absorbers are constructed of two cast metal plates that clamp the wire rope between them. When the tension force in the wire ropes reaches a certain threshold, the wire ropes start to slide, and the friction between the outer surface of the wire ropes and inner surface of the metal plates acts against the movement of the wire ropes and absorbs the energy of the falling rock. In addition, the force exerted on the anchors is decreased because the tension of the wire ropes is lessened by the sliding tension force of the shock absorbers. The average sliding tensions of the shock absorbers are 30 kN (maximum approximately 90 kN) for the U-bolt-type shock absorber and 28 kN for the ring-type shock absorber (maximum approximately 60 kN), as identified in experiments [2]. Depending on the rockfall energy, either a combination of U-bolt-type and ring-type shock absorbers or ring-type shock absorbers alone were used for the horizontal wire ropes. The pulley blocks are installed at the top of the supporting posts and at the anchors behind them, and connect the W-shaped slide rope and hang rope by a single wire rope. This is done to smooth the movement of the hang rope during impact, balance the load, and distribute and absorb the force of the rockfall over the entire structure.

2.4 Measurement item and a method

The measured quantities in this experiment were: amount of slip in the shock absorber (measured with a ruler), tension of ropes shown in Figure 5 (measured by strain gauges put on the U-bolts attached to the ends of the wire ropes), acceleration of the block (measured by an accelerometer installed in the center of the block), movement of the block and deformation of the wire netting (measured by a high-speed camera), and translational velocity and rotational velocity of the block (measured by analysis of images from a high-speed camera).

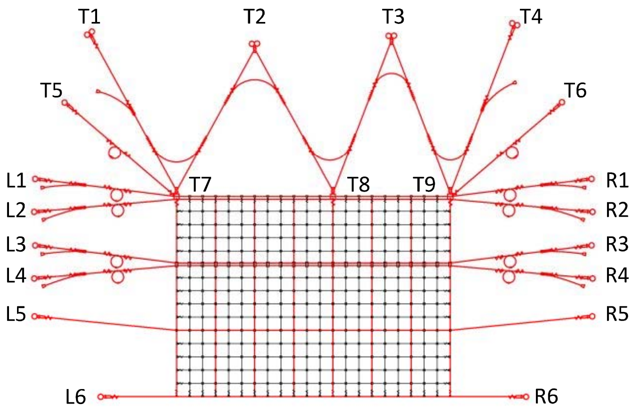


Fig.5: Tension measurement point

2.5 Experiment case

Table 2 lists the parameters of the experiment cases. A total of 6 experiments were performed by using a combination of 3 different blocks and 2 different types of nets (conventional-type wire netting and new-type wire netting). The collision energy was derived analytically from the slope condition parameters and block mass using the formula given in the Rockfall Mitigation Handbook [1]. A combination of U-bolt-type and ring-type shock absorbers on the horizontal wire ropes was used for test case no. 1-3 with the conventional-type wire netting. For the other test cases, only ring-type shock absorbers were used.

Table 2: Setting conditions of the Test cases

Test No.	Wire netting		Hang・Main Rope (Supplement rope)	Type of Shock Absorber	Mass of Block m (ton)	Collision Energy Theory Et (kJ)
	Form	Standard				
1-1	Conventional Wire netting	Zinc-coated low carbon steel wires φ5.0-50×50	3×7 G/O 18φ (3×7 G/O 14φ)	Ring type	2.5	554.5
1-2				Ring type	4.2	931.5
1-3				Ring type and U-bolt type	5.2	1153.3
2-1	New type Wire netting	Zinc-coated steel wires φ4.0-50×50	3×7 G/O 18φ (3×7 G/O 14φ)	Ring type	2.5	554.5
2-2				Ring type	4.2	931.5
2-3				Ring type	5.2	1153.3

3. Test Results and Discussion

3.1 Experimental results summary

Table 3 shows a summary of the experiment results. Except for test case no. 2-3 using the new-type wire netting, in all test cases the block was caught successfully without any damage to the wire netting or supporting posts, severing of the wire ropes, or pulling out of the anchors. In test case no. 2-3, it was observed that the clips at the intersections of the vertical and horizontal wire ropes became loose. As a result, it is hypothesized that the spacing of the vertical and horizontal wire ropes in the area of the impact had widened, and as a result the wire netting bore the entire force of the impact and was ripped, and the block passed through the net. In test case no. 2-3, it is possible that perhaps the clips had not been properly tightened during installation. Therefore, we conducted the experiments a second time (case no. 2-3C). In the second set of experiments, the block was caught by the net; however, some local damage was observed on the net in the area of the impact. It is concluded that the energy and force used in this set of experiments is close to the limit of the new-type wire netting.

The translational velocity was in the range of 14.2 m/s - 15.0 m/s for all cases, and did not vary much between the different block shapes and masses. However, the rotational velocity was 18.1 rad/s and 19.0 rad/s for the 2.5-ton block, 14.8 rad/s and 16.7 rad/s for the 4.2-ton block, and 14.3 rad/s and 15.2 rad/s for the 5.2-ton block. Rotational velocity was faster for blocks of smaller size and mass because the test blocks are not irregularly shaped like natural rocks and do not bounce as they roll down the slope, so the rolling motion is predominant. Based on previous experiments[1], it has been found that in general rotational energy is approximately 10% of translational energy. In this set of experiments, the rotational energy was around 22% - 28% of the translational energy, and was large in proportion to the translational energy. This was because the blocks used were of a shape that easily rolled.

Table 3: Experiment results

Test No.	Mass of Block m (ton)	Translational Velocity V (m/s)	Translational Energy $1/2 \cdot m \cdot V^2$ Ev (kJ)	Rotation Velocity ω (rad/s)	Rotation Energy*1 $1/2 \cdot I \cdot \omega 2$ Er (kJ) (Er/Ev)	Total Energy Test Ev + Er E (kJ)	Max.Tension of Horizontal Rope t1 (kN) (Position)	Max.Tension of Hang Rope t2 (kN) (Position)
1-1	2.5	14.2	252.1	19.0	69.3 (0.27)	321.4	38.0 (R3)	39.4 (T7)
1-2	4.2	14.6	447.6	16.7	126.6(0.28)	574.3	26.8 (R4)	56.6 (T7)
1-3	5.2	15.0	585.0	16.0	161.5 (0.28)	746.5	65.3 (R3)	53.5 (T7)
2-1	2.5	14.6	266.5	18.1	62.9 (0.24)	329.4	44.1 (L5)	53.7 (T8)
2-2	4.2	14.2	423.4	14.8	99.4 (0.23)	522.9	39.9 (L5)	71.5 (T1)
2-3	5.2	14.6	554.2	15.2	145.8 (0.26)	700.0	33.5 (R4)	44.1 (T2)
2-3C	5.2	14.9	577.2	14.3	129.0 (0.22)	706.3	39.7 (R4)	67.6 (T2)

Test No.	Slip Amount of Shock Absorber (Setting length ratio) L (mm)	Max.Deformation of Wire Netting *2 δ (mm)	Max.Resultant Acceleration of Block α (m/s^2)	Observations
1-1	3220 (25.6%)	2379	500.0	Good from collision to capture. No damage to main material.
1-2	7290 (57.9%)	2681	512.4	Good from collision to instruction. Block falls out at the time of capture. No damage to main material.
1-3	8190 (41.4%)	2543	642.4	Good from collision to capture. No damage to main material.
2-1	3310 (26.3%)	2505	368.4	Good from collision to capture. No damage to main material.
2-2	10010 (79.4%)	2700	315.7	Good from collision to capture. No damage to main material.
2-3	6800 (54.0%)	2595*3	272.3*4	Penetrate wire netting. Wire netting is damaged.
2-3C	10210 (81.0%)	2760	230.8	Good from collision to capture. Some wire netting is damaged.

*1 I : The moment of inertia of the block. Calculated by approximating the block as a spherical shape ($2/5 \cdot m \cdot r^2$). *2 Maximum deformation of the wire netting during impact. *3,4 Value before the wire netting was broken.

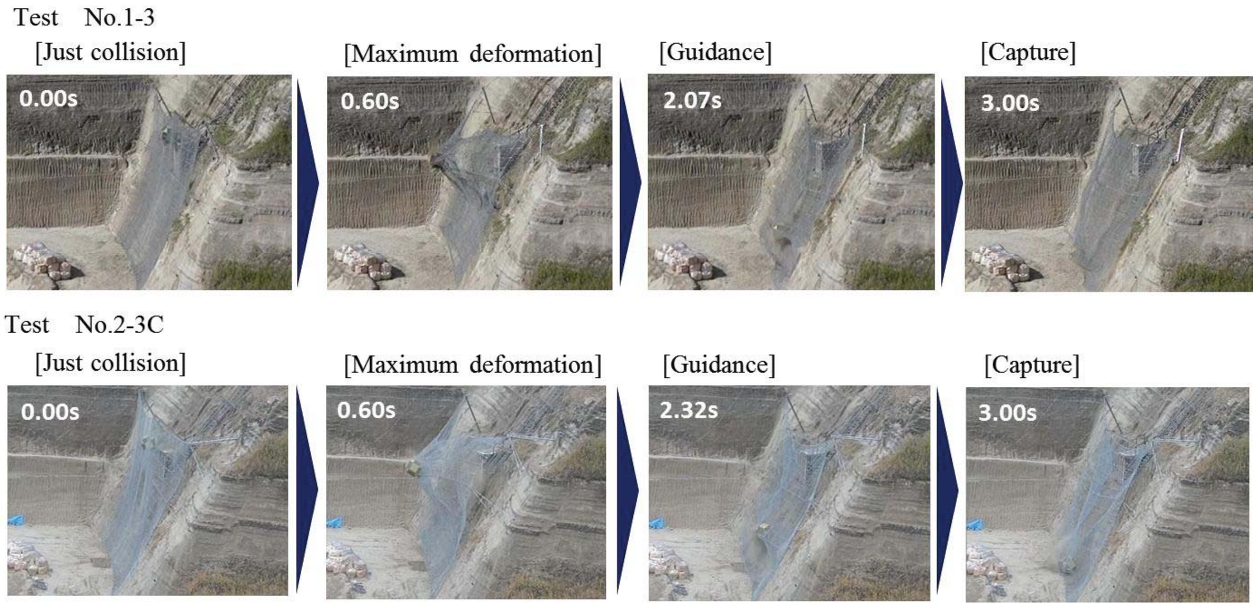


Fig.6: Test No.1-3 and No.2-3C acoording to high-speed photography

Figure 6 shows images captured by the high-speed camera from impact until capture of the 5.2- ton block using the conventional-type wire netting of test no. 1-3 and the new-type wire netting of test no. 2-3C. The instant when the block impacted the wire netting is defined to be 0.00 s. It was confirmed that the net captured the falling block under the wire netting and stopped the rotational movement, and then absorbed the impact energy, dropped the block into the pocket at the lower part of the net and led the block in a controlled fall to the bottom of the slope, and successfully stopped the movement of the block without the block passing through the wire netting. The same behavior was confirmed in the other test cases no. 1-1, no. 2-1, and no. 2-2. Based on these experiment results, it was confirmed that the net using the conventional-type wire netting has the ability to absorb maximum rockfall impact energy of up to approximately 740 kJ. It was confirmed that the net using the new-type wire netting has the ability to absorb maximum rockfall impact energy of up to approximately 700 kJ. In addition, in these experiments, the block impacted the net with both rotational and jumping movement. The rotational movement continued for a short period after the block contacted the net at the impact area, and the rotational movement of the block was stopped after the structure absorbed the impact energy of the block including the rotation energy. After this, the rock fell to the ground and to the bottom of the slope in a controlled fall. This behavior was the same in all test cases. This type of block movement, in which the block has rotational movement, is not reproducible through vertical drop experiments or pendulum experiments, and is unique to experiments in which the block is dropped from a real slope. Real-life rockfalls also roll down the cliff slope so their movement is similar to the one of this experiment. In view of this, to attain high protection performance from pocket-type rockfall protective nets, it is important to choose a structure and materials that can stop the rotational movement of the rock, absorb the impact energy including rotation energy, and withstand friction arising from the rotational movement.

3.2 Wire rope tension forces

Figure 7 shows the measurement results of the tension forces in the main horizontal wire ropes in all test cases. Figure 8 shows the measurement results of the tension forces in the hang ropes in all test cases. The instant the block impacted the wire netting is defined as 0.00 s. In test case no. 1-3, a combination of U-bolt-type and ring-type shock absorbers were installed on the horizontal wire ropes. In the other test cases, only ring-type shock absorbers were installed.

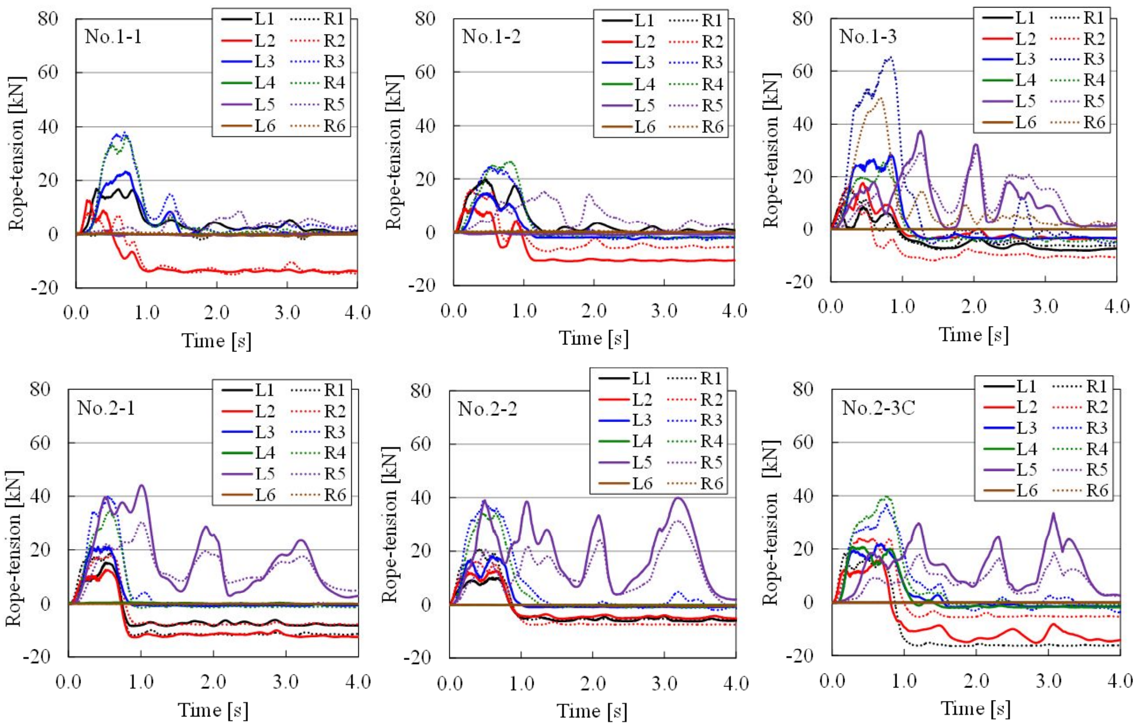


Fig.7: Time course of the length-main rope tension

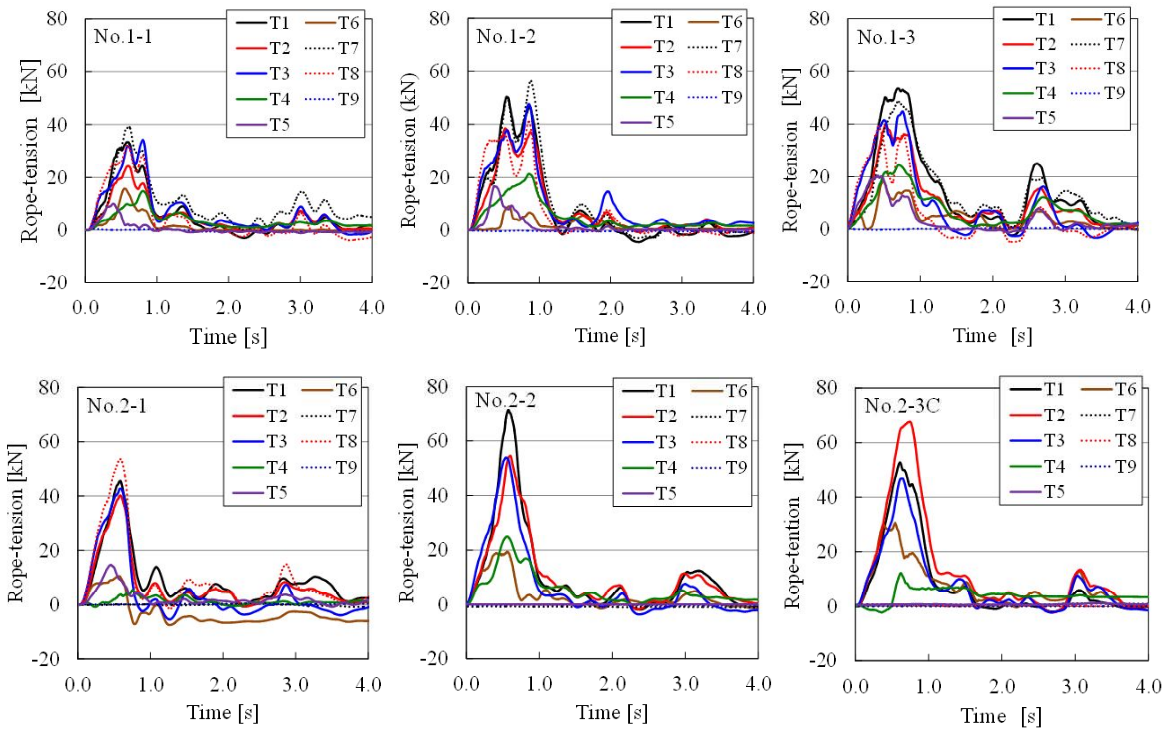


Fig.8: Time course of the hang rope tension

The maximum tension force in test no. 1-3 using the combination of U-bolt-type and ring-type shock absorbers was 65.3 kN, and was under the maximum slipping tension value of 90.0 kN. The maximum tension force in the tests using only the ring-type shock absorbers was in the range of 26.8 kN - 39.9 kN, did not have a large variance, and was under the maximum slipping tension value of the ring-type shock absorber, 60.0 kN. From these results, it can be confirmed that the shock absorber mechanisms of the U-bolt-type and ring-type absorbers were functioning effectively, and that the applied tension forces remained within a constant range regardless of the amount of impact energy. U-bolt-type shock absorber fasteners are installed at both ends of the hang rope (T1, T4). The maximum tension of the hang rope was in the range of 39.4 kN - 71.5 kN, and was under the maximum sliding tension value of the U-bolt-type shock absorber of 90.0 N. It is confirmed that the tension of the hang rope remained within a safe range such that the shock absorbers were functioning effectively to protect the anchors. In addition, the values of the tension in the supporting points of the hang rope, T2 and T3, T7 and T8, and T9, were almost equal. It can be confirmed that the pulley block was functioning effectively.

4. Conclusions

In this research, a rockfall protective net was tested in a full-scale block collision experiment on a real hill-slope. The following results were obtained:
1) It was confirmed that the pocket-type rockfall protective net structure in this research traps rockfalls and has the necessary behavior, including absorbing the rockfall energy in the protective wall, dropping the rockfall down to the slope bottom in a controlled fall, and stopping the rockfall without letting the rock pass through the net.
2) It was confirmed that the rockfall protective net with conventional-type wire netting is capable of handling maximum rockfall energy of approximately 740 kJ. In addition, it was confirmed that the rockfall protective net constructed with the new-type wire netting with higher tensile strength and thinner mesh wires is capable of handling a maximum rockfall energy of approximately 700 kJ. The applicability of the new-type wire netting rockfall protective net was verified for rockfalls within a limited energy range.
3) It was confirmed that the rotational velocity of a block falling down a real slope is high, considering the ratio of rotation energy for translational energy (maximum 28%), and that the impact of the friction force on the impact area arising from the rotational movement is large. It is concluded that to maintain protective capability, it is important for pocket-type rockfall protective nets to have a structure that can stop the rotational movement and withstand friction force from rotational movement.
4) Although this result was not described in detail in the main body of this paper, it was observed that the maximum deformation of the wire netting at the time of block impact was approximately 50% of the spacing interval of 5.0 m of the main horizontal wire ropes. The large deformation is made possible by the slipping function of the shock absorbers. In addition, the amount of deformation was smaller for the conventional-type wire netting with thicker wires, but the new-type wire netting with thinner wires has a higher ability to suppress the impact force.
5) The tension force in the wire ropes installed with U-bolt-type and ring-type shock absorbers was lower than the maximum sliding tension value of the shock absorbers (U-bolt type: 90.0 kN, ring type: 60.0 kN) for the range of impact energies applied in these experiments. The ability of the shock absorbers to absorb energy was confirmed through a full-scale experiment.

5. References

[1] Japan Road Association, *Rockfall Mitigation Handbook* (in Japanese), Maruzen, 2000, pp. 83-96.

[2] Tomonori Tajima, Koji Maegawa, Masao Iwasaki, Koichi Shinohara, Kota Kawakami : *Evaluation of Pocket-type Rock Net by Full Scale Tests*, IABSE SYMPOSIUM BANGKOK 2009, pp466-467, 2009.9.

[3] European Organization for Technical Approvals(EOTA): *ETAG27, GUIDELINE FOR EUROPEAN TECHNICAL APPROVAL OF FALLING ROCK PROTECTIONKITS*, 2008.2.1, p34.