한국지반환경공학회 논문집 제6권 제3호 2005년 9월 pp. 35~45

Development and Performance Evaluation of the Expanded Metal Rockfall Protection Fence

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Abstract

The rockfall protection fence is one of the most common rockfall protection methods in Korea. The typical rockfall protection fence consists mainly of three parts; H-beam supports, wire meshes, and wire ropes. The design of the rockfall protection fence is made such that the total energy absorbing capacity of the fence. Therefore, resulting from the combined energy absorbing capacity of the three parts is larger than the falling energy of rocks. In present study, a new rockfall protection fence, constructed using expanded metals instead of the existing wire rope and wire mesh for the typical type of rockfall protection fence, was evaluated on its performance by conducting both laboratory and field tests. Also, for a comparison, the same tests were performed on the typical rockfall protection fence. The test results revealed that the expanded material is an economic alternative to the existing protection materials and the expanded metal rockfall protection fence exhibits the higher energy absorbing capacity compared to that of the typical rockfall protection fence.

Keywords : Rockfall protection fence, Energy absorbing capacity, Wire rope, Expanded metal

요 지

낙석방지울타리는 국내에서 가장 보편적으로 사용되는 낙석방지공법의 하나로 일반적으로 H형강, 와이어메쉬 및 와이어로프의 세 부분으로 구성되며 이들에 의해 발휘되는 낙석방지울타리의 총 흡수가능에너지가 낙석에너지보다 커야한다는 것을 기본적인 설계개념으로 한다. 본 연구에서는 기존 낙석방지울타리의 와이어메쉬와 와이어로프 대신, 새로운 재료인 팽창메탈을 사용한 낙석방지울타리의 성능을 평가하고 기존의 낙석방지울타리와 비교하였다. 이를 위하여 팽창메탈 낙석방지울타리와 기존 방식의 낙석방지울타리에 대하여 실내 및 현장시험을 실시하였으며, 그 결과 팽창메탈 낙석방지울타리의 흡수가능에너지는 기존 낙석방지울타리와 비교해 높은 것으로 나타나 팽창메탈은 성능 및 경제적인 면에서 기존 재료에 비해 우수한 재료임을 보였다.

주요어 : 낙석방지울타리, 흡수가능에너지, 와이어로프, 팽창메탈

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1. Introduction

A main function of the rockfall protection facility installed on road slopes is to prevent rockfalls or falling stones from getting into roads, protecting road users and road facilities. Such rockfall protection facility is classified into two types, according to its usage purpose; 1) reinforcement type and 2) protection type. The protection type facility includes the rockfall protection netting, rockfall protection fence, rockfall retaining wall, and rock evasion tunnel etc., according to the protection method.

The rockfall protection fence is one of the most common rockfall protection methods in Korea. The design of the rockfall protection fence is usually made such that the energy absorbing capacity of the fence. A typical type of the rockfall protection fence used in Korea is composed mainly of three parts; 1) poly vinyl chloride(PVC)-coated wire mesh, 2) steel supports and 3) wire rope. It is known that for the typical type, the maximum energy absorbing capacity of the fence results from the combined energy absorbing capacities of each part. A recent study on the typical type of rockfall protection fence, however, revealed that in some cases, the falling rocks with the energy much less than the total energy absorbing capacity of the fence are not supported efficiently(Hwang, 2003).

In present study, investigations were carried out on the performance of the rockfall protection fence using expanded metals, developed as an alternative to the existing wire mesh and wire rope used for the typical rockfall protection fence. Both laboratory and field tests were conducted to evaluate the performance of the material and the behavior of the expanded metal rockfall protection fence. Also, for a comparison, the performance of the typical type of rockfall protection fence was investigated.

2. Typical Rockfall Protection Fence

2.1 Basic Structure

In Korea, the rockfall protection fence is generally designed to resist the rock falling energy of 50kJ, equivalent to the energy of a 0.4-ton rock falling from the height of 12.5m. The 0.4-ton is an average weight of the rocks observed in 275 rockfall sites along the national roads for the past one year. A typical rockfall protection fence has a structure with the H-beam supports to which the wire rope and wire mesh are attached (Fig. 1). The top end of the support is usually bent toward roads. Since both the wire rope and wire mesh usually carry very high tensile forces, all the three parts of the fence, supports, wire rope and wire mesh, behave as a unit when resisting falling rocks.

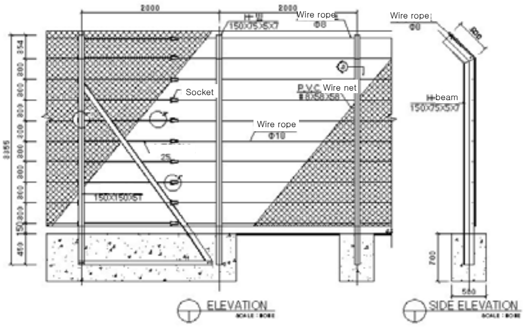


Fig. 1. Typical "H-beam + wire rope + wire mesh" rockfall protection fence

2.2 Energy Absorbing Capacity of the Fence

According to the Standards of the Ministry of Construction and Transportation(MOCT) of Korea (2000), the total energy absorbing capacity of the rockfall protection fence and the falling energy of rock are obtained by Eqs. (1) and (2). When calculating the rock falling energy, the location of rock collision is assumed to be 2/3 of the height of the fence at the center of both supports and the direction of the collision at a right angle to the fence.

Total absorbing energy of fence :

$$E_T = E_R + E_P + E_N \quad (1)$$

where, E_T : total absorbing energy(kJ)
E_R : absorbing energy of wire rope(kJ)
E_P : absorbing energy of support(kJ)
E_N : absorbing energy of wire mesh(kJ)

Rock falling energy :

$$E_i = \left(1 - \frac{\mu}{\tan\Theta}\right) \cdot (1+\beta) \cdot m \cdot g \cdot H \quad (2)$$

where, E_i : rock falling energy(kJ)
θ : angle of slope(deg.)
μ : equivalence friction coefficient of rockfall
β : coefficient of rotating energy(typically 0.1)
m : weight of falling rock(ton)
H : height of falling rock(m)
g : acceleration of gravity(9.8m/sec^2)

As the design value for the total energy absorbing capacity of the fence, currently a value of 50kJ is used, which was calculated based on the assumption of the maximum allowable displacement angle of the support of about 15° and the allowable elongation rate of the wire rope of about 2~4% (Table 1). For the energy absorbing capacity of the wire mesh, however, the value of 25kJ, selected based on the results of the experiment by Shinho University in Japan, is assumed due to the difficulties in its estimation.

2.3 Field Performance of the Fence

Hwang(2003) conducted a series of the field rockfall test on the typical "H-beam + wire rope + wire mesh" rockfall protection fence to examine its field performance. The fence was constructed as prescribed by the Standard of Korea Ministry of Construction and Transportation(Standard of Korea Ministry of Construction and Transportation, 2000).

The cut of the slope where the tests were conducted had the maximum height of 45m and slope gradient of 1:0.5. Five concrete balls with different weights, 50, 100, 250, 500,1000kg, were used in the test to simulate rockfalls. A crane was used to drop them from four different heights, 5, 10, 15, and 20m. A total 49 tests was conducted in the sequence of applying small to large falling energy. The fence was separated from the bottom part of the slope, so that the falling energy of the concrete balls could be considerably reduced prior to the impact to the fence.

The test results showed that of the total 49 tests, (ie., free fall of 49 concrete balls), 6 balls penetrated the fence(1 case for 50kg-ball and 5 cases for 100kg-ball), which was about 12% of the total number of free fall. Of 100kg-balls only, penetrated numbers were 42% of the total. For all cases, the falling energy of each concrete ball was less than 25kJ, which was only the half of the value of design absorbing energy(ie., 50kJ). Moreover, considering the energy loss due to the collision of the concrete ball with slope surface when falling along the slope, even smaller energy may have exerted to the fence.

Table 1. Standards of rockfall protection fence(MOCT in Korea)

Wire rope		Steel Support			Fence end	Absorbing Energy(kJ)
Diameter	Spacing(mm)	Section Size(mm)	Embedded length(mm)	Standard Spacing(mm)		
∅18	200~300	H150×75×5×7	over 700	2000~3000	H150×150×7/10 □150×4.5	48
∅18	200~300	H200×100×5.5×8	over 700	2000~3000	H175×175×7.5/11 □175×5.0	56
∅18	200~300	H200×100×5.5×8	over 700	2000~3000	H200×200×8/12 □175×5.0	61

3. Proposed Rockfall Protection Fence Using Expanded Metal

In this study, an attempt was made to develop a new rockfall protection fence with higher performance, compared to the typical "H-beam + wire rope + wire mesh" protection fence. The new rockfall protection fence is made by connecting expanded metals to H-beam supports. Here, the expanded metal refers to a mesh shaped-material made by making cut incisions in a given interval in a thin metal plate and pulling the plate in perpendicular to the direction of the cut incisions (Fig. 2).

To investigate the performance of the rockfall protection fence using expanded metal, both laboratory and field tests were performed. The test results and discussions, including the methods of the tests, are described in succeeding sections.

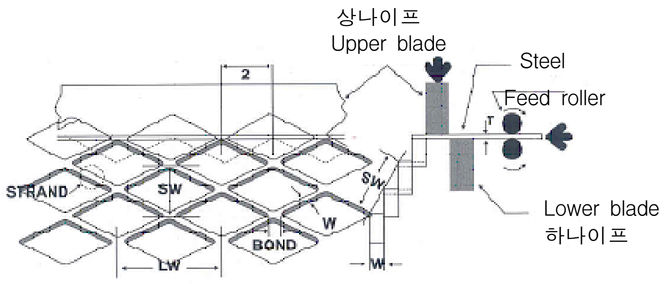


Fig. 2. Expanded metal

3.1 Laboratory Performance Tests of Expanded Metal

3.1.1 Test Method

The expanded metal with 1200×2400(H×V)mm in size was tested in a laboratory to examine its load resistance and deformation characteristics. As shown in Figs. 3 and 4, the expanded metal with a circular plate attached in its center was bolted to both H-beam supports and a winch was connected to the circular plate through a wire cable. A 5-ton load cell and a line gage were installed in the wire cable and the plate, respectively, to measure the loads applied to the metal by the cable winch and the corresponding displacements of the metal.

Three expanded metals with different thickness, 6T(t=6mm), 4.5T(t=4.5mm), and 3.2T(t=3.2mm), were used in the test. For each, two or three tests were conducted to examine the influence of the manufacture direction of the expanded metals(i.e., pulling direction of the cut incisions on the metal) by changing the manufacture direction(see Fig. 6). Also, the same tests were conducted on the PVC coating net used in the typical rockfall protection fence for a comparison.

Details on the test of the expanded metal are as follows:

(1) Installation of supports : Two H-beam supports were fixed to a support plate on the laboratory floor by bolting.

(2) Installation of expanded metal : An expanded metal was bolted to the supports. The bolt interval was 300mm(2 bolts for 1 set, CTC=300mm)

(3) Load application : Loads were applied through the cable winch to allow a large displacement of the metal. To simulate a falling rock, the circular plate, connected with the cable, was attached to the metal.

(4) Measurements of load and displacement : The applied load was measured by the tension load cell installed on the winch cable. The measurement of the metal displacement was achieved by using the cable gage with the measurement range of 5m. The measurement interval was one per second.

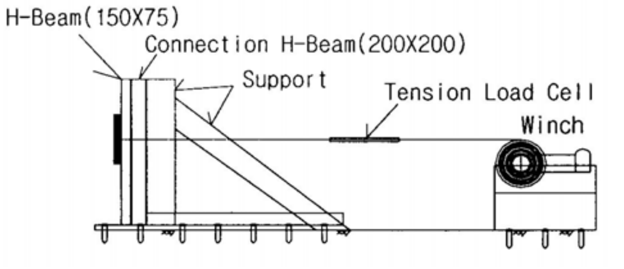
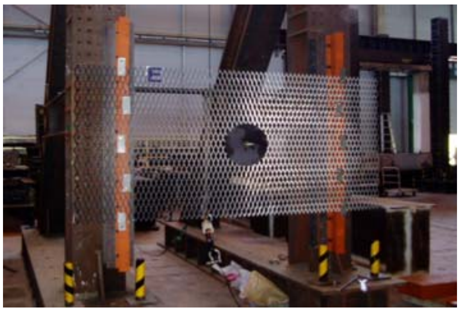
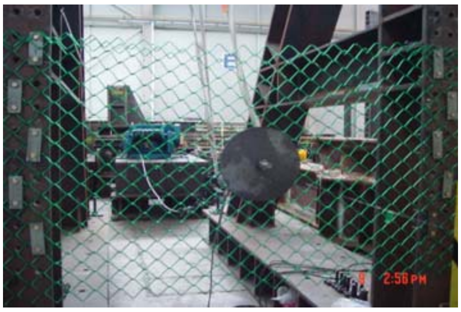


Fig. 3. Schematic of laboratory test on expanded metal



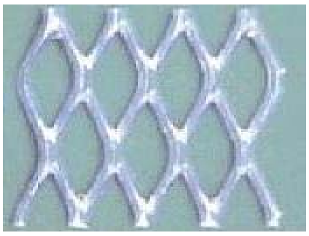
(a) Expanded metal



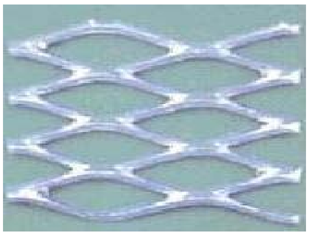
(b) PVC coating net

Fig. 4. Expanded metal and PVC coating net for test

Fig. 5. Connection between support and expanded metal



(a) Manufacture direction



(b) Perpendicular manufacture direction

Fig. 6. Expanded metal direction

3.1.2 Test Results and Discussion

Fig. 7 through Fig. 10 show the results of the laboratory test. The breakage of the tested expanded metals occurred in the load ranging from 3.0 to 3.5ton for 6T and 4.5T-metal and 3.5 to 4.0 ton for 3.2T-metal, respectively. The location of the breakage was different between different types of loads. For the 6T-metal, the breakage occurred mainly around its center under interval loads, whereas under sustained loads, the breakage occurred around the connection between the metal and the supports. The reason for the breakage in the metal center for the interval loads appears because the load applied to the connections became dispersed between the load applications, resulting in the maximum load applied to the center where the cable load is applied directly. On the other hand, the breakage in the connections under the sustained load may be because in the connection the metal was fixed not to allow any displacement, therefore, the load dispersion did not occur.

For the 4.5T and 3.2T-metals, the breakage load and displacement curves were similar to those for the 6T-metal. The maximum displacements occurred prior to the breakage, however, were larger by about 20cm and 30 to 35cm than that of the 6T-metal, respectively, indicating elongation increased with the decrease in metal thickness.

The test was also conducted on the expanded metals installed horizontally. For the 3.2T-metal, the breakage load ranged from 3.3 to 5.7ton and the maximum displacement was 24.5cm. The breakage load increased with the increase in the connection strength between the supports and the metal. The breakage load for the 4.5T-metal could not be measured due to the limit in the capacity of the load cell. The measured maximum displacement was 23cm when the load of 4.7ton was applied.

As shown in Fig. 10, the load-displacement relationship of the PVC coating net was distinctly different from those for the expanded metal, although the magnitudes in the maximum resistance load were similar between them.

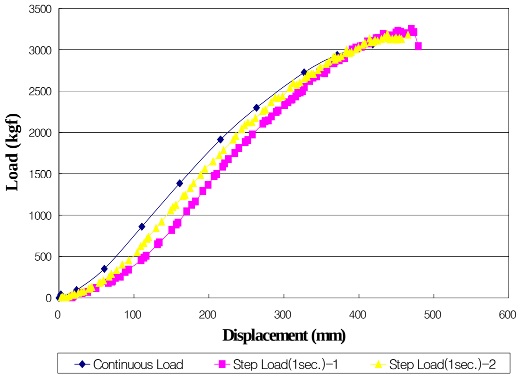


Fig. 7. Test results of 6T-expanded metal

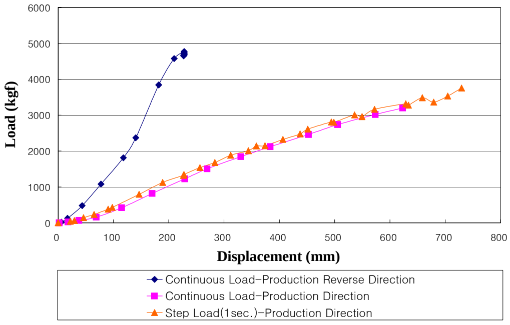


Fig. 8. Test results of 4.5T-expanded metal

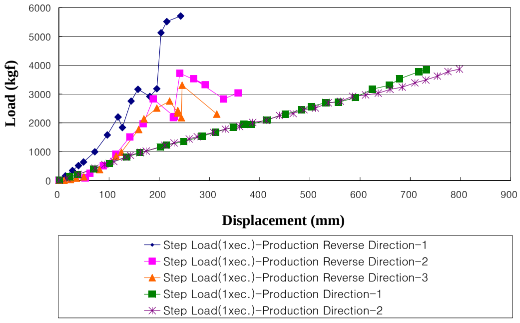


Fig. 9. Test results of 3.2T-expanded metal

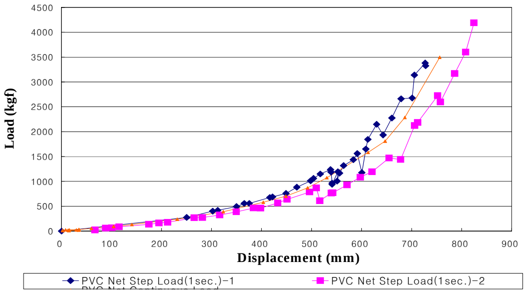
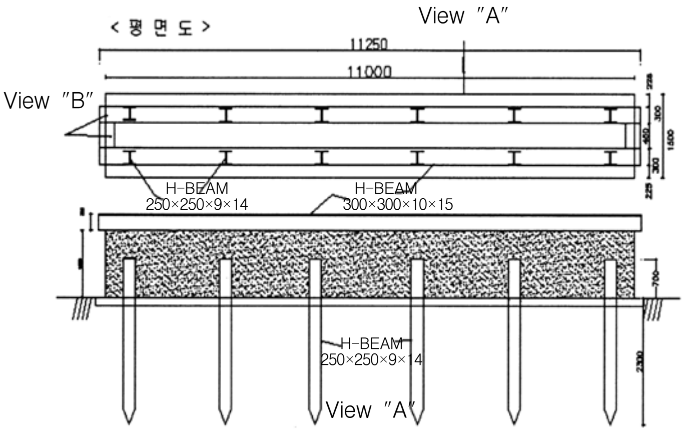
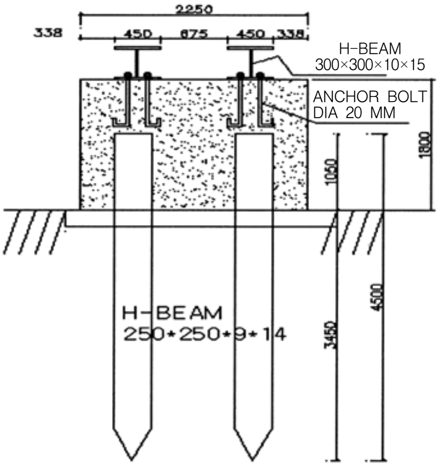


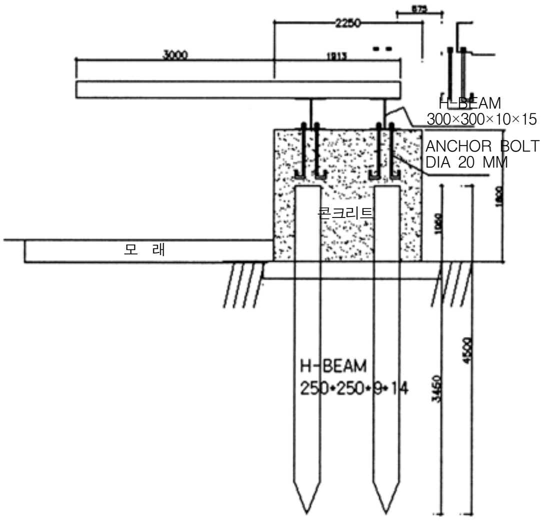
Fig. 10. Test results of PVC coating net



(a) Plan view of expanded metal protection fence field test device



(b) View "A"



(C) View "B"

Fig. 11. Plan and side views of expanded metal rockfall protection fence for test

3.2 Field Performance Tests of Expanded Metal Rockfall Protection Fence

3.2.1 Test Method

In order to investigate the field performance of the expanded metal rockfall protection fence, field rockfall tests were performed on the expanded metal fence with 5 spans. Fig. 11 displays the plan and side views of the expanded metal protection fence constructed for the field tests. Four types of expanded metal, Ex-Metal XS-62(3.2T), XG-21(4.5T), XG-22(6T), and XG-23(6T), were used in the tests. Also, the typical "H-beam + wire rope + wire mesh" rockfall protection fence with the same spans (span CTC=2.0m) and the PVC coating net were tested for comparisons.

A commonly used field rockfall test is done by rolling rocks or concrete balls along a cut slope. The test, however, has a shortcoming that the falling energy of rocks can not be accurately measured since the falling rocks, in many cases, hit a ground first and roll to the fence. Moreover, the cut slope usually has an irregular surface.

In present study, therefore, the test was carried out by using a crane and falling a concrete ball from a given height directly to the protection fence to measure the impact energy and the location of the falling concrete ball as accurate as possible (see Fig. 12). Total 14 tests were planned and the details on the tests are shown in Table 2.

(a) Installation of typical rockfall protection fence

Table 2. Outline of field rockfall tests

Type	Test No.	Conc. ball weight(ton)	Falling height(m)	Falling method	Falling energy(kJ)	Remark
Existing rockfall protection fence	1	0.4	12.5	Fee fall	50.0	Tests for the Ex-Metal(XG-22 and 23)are not conducted, If the Ex-metal(XG-21, 4.5T)is not damaged or penetrated
	2	0.1	12.5	Fee fall	12.3	
PVC coating net	3	0.1	10.0	Fee fall	9.6	
	4	0.4	6.5	Fee fall	25.5	
Ex-Metal(XG-21)	5	0.1	12.5	Fee fall	12.3	
	6	0.4	12.5	Fee fall	50.0	
Ex-Metal (XS-62), 5mm	7	0.4	12.5	Fee fall	50.0	
	8	0.4	12.5	Fee fall	50.0	
Ex-Metal (XS-62), 4mm	9	0.25	22	Fee fall	50.0	
	10	0.4	12.5	Fee fall	50.0	
Ex-Metal(XG-22)	11	0.4	12.5	Fee fall	50.0	
	12	0.4	12.5	Fee fall	50.0	
Ex-Metal(XG-23)	13	0.4	12.5	Fee fall	50.0	
	14	0.4	22.0	Fee fall	90.0	

(b) Installation of expanded metal rockfall protection fence

(c) Concrete balls

(d) Free fall of concrete ball

Fig. 12. Field performance tests

3.2.2 Test Results and Discussion

Table 3 shows the results of the field rockfall test on the typical "H-beam + wire rope + wire mesh" rockfall protection fence, the PVC coating net, and the expanded metal rockfall protection fence. For the typical rockfall protection fence and PVC coating net, breakages or penetrations occurred by the falling energy of 50kJ (i.e., the 0.4ton-concrete ball falling from 12.5m height). This may be due to mainly the breakage of the splices which help the wire rope keep tensioned. The splice breakage may have resulted in the loss of tension in the wire rope and the up-and-down deformations. Also, it was observed that the fence penetration occurred by the falling energy of 12.3kJ(Fig. 13).

The test results on the expanded metal rockfall protection fence, however, indicated that overall no severe damages occurred by the falling energy of 50 kJ. For the XG-21(4.5T) expanded metal fence, the distortion of the H-beam supports was observed while no breakage or penetration occurred in the metal. It seems that the support distortion occurred because the expanded metal has a relatively high load transfer capacity, which led to the falling energy transferred to the supports and consequently, a unified behavior between the metal and supports.

Since no breakage occurred for the XG-21(4.5T) expanded metal, the expanded metals with higher rigidity(i.e., Ex-Metal XG-22and 23) were not tested.

For the XS-62(3.2T) expanded metal, which has a lower rigidity compared to the XG-21(4.5T), no metal breakage and much less support distortion were observed. Also, it was seen that the 0.25 ton-concrete ball falling from 22m height(i.e., falling energy = 50kJ) was fully resisted by the expanded metal fence(i.e., the concrete ball did not touch the ground(see Fig. 14)).

(a) Splice damage

(b) Rockfall protection fence damage(rockfall energy=50 kJ)

(c) Rockfall protection fence damage(rockfall energy=12.3kJ)

Fig. 13. Test results for the typical "H-beam + wire rope + wire mesh" rockfall protection fence

Table 3. Field performance test results

Type	Test No.	Conc. ball weight(ton)	Falling height(m)	Falling method	Falling energy (kJ)	Remark
Existing rockfall protection fence	1	0.4	12.5	Fee fall	50.0	Fence damaged, support distorted, wire rope breakage, wire net breakage, splice breakage, concrete ball penetration
	2	0.1	12.5	Fee fall	12.3	Wire rope breakage, concrete ball penetration
Ex-Metal (XG-21)	3	0.1	12.5	Fee fall	12.3	No metal breakage, support distorted
	4	0.4	12.5	Fee fall	50.0	No metal breakage, support distorted
	5	0.4	12.5	Fee fall	50.0	No metal breakage, support distorted
PVC coating net	6	0.1	10.0	Fee fall	9.6	Support distorted, concrete ball penetration
	7	0.4	6.5	Fee fall	25.5	Support distorted, concrete ball penetration
Ex-Metal (XS-62), 5mm	8	0.4	12.5	Fee fall	50.0	Partly breakage at connection between support and metal, support distorted
	9	0.25	22	Fee fall	50.0	Partly breakage at connection between support and metal, support distorted
Ex-Metal (XS-62), 4mm	10	0.4	12.5	Fee fall	50.0	Partly breakage at connection between support and metal, support distorted

(a) Rockfall energy 50KJ(Weight : 0.4ton, Height : 12.5m)

(b) Damage at bolting section

(c) Rockfall energy 50KJ(Weight : 0.25ton, Height : 22m)

Fig. 14. Test results for the expanded metal rockfall protection fence

5. Conclusions

In this study, the expanded metal rockfall protection fence was investigated on the performance by conducting both laboratory and field tests. The conclusions drawn from the study are as follows:

(1) The test results indicated that the breakage load of the expanded metals ranged from 3.0 to 4.0ton and the corresponding displacements were about 400 to 800mm, exhibiting the higher energy absorbing capacity compared to the materials used for typical rockfall protection fences.

(2) The expanded metal was found to exhibit distinctly different load-displacement behaviors for different manufacture directions(i.e., pulling directions of cut incisions on the metal). The breakage load was about 40% higher for the expanded metal made by pulling the cut incisions in the metal in its length direction (i.e., perpendicular to the manufacture direction) than that for the expanded metal made in its

width direction(i.e., the manufacture direction). Also, the magnitude of the displacement for a given load was about 3 times larger for the expanded metal made in the manufacture direction than that for the expanded metal in made in the perpendicular manufacture direction. However, the expanded metal made in the perpendicular manufacture direction exhibited a very irregular load and displacement relationship, compared to that in the manufacture direction.

(3) Field rockfall test on the typical "H-beam + wire rope + wire mesh" rockfall protection fence showed that the breakages and penetrations occurred by the falling energy of concrete ball of 50kJ(i.e., 400kg in concrete ball weight and 12.5m in falling height). Moreover, the fence was penetrated by the much lower falling energy of 12.3kJ(i.e., 100 kg in concrete ball weight and 12.5m in falling height). Accordingly, it appears that the current standards of the energy absorbing capacity of 50kJ may need to be changed for the typical type of rockfall protection fence.

(4) For the expanded metal rockfall protection (i.e., using EX-Metal XG-21(4.5T) and XS-62(3.2T)), however, no severe damage was observed for the falling energy of 50kJ, revealing its enough energy absorbing capacity to meet the current standard for the rockfall protection fence.

(5) Comparing the costs of construction between the typical "H-beam + wire rope + wire mesh" and the expanded metal rockfall protection fence with 50 or 100m in length, the construction costs for the EX-Metal XG-21(4.5T) and the XS-62(3.2T) fences were found to be lower by about 37% and 46%, respectively, than that of the existing type.

(6) From this study, it appears that for the materials for the rockfall protection fence, the expanded metal is an economic alternative to the wire rope and PVC coating net. It exhibits a greater energy absorbing capacity while allowing a large displacement, compared to the existing materials. A large deformation of the expanded metal, however, may allow rocks getting into roads through it, although no breakage occurs. Therefore, it may be desirable that the current standard for the rockfall protection fence prescribe the criteria on its allowable displacement.

Acknowledgements

This research was supported by Sangji University Research Fund, 2003.

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