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Experimental research of reinforced soil wall for rock-fall protection

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ABSTRACT: The retaining reinforced soil wall for rock-fall protection has been developed recent years. It needs appropriate spaces to construct the wall due to its structural shape. However, there is often insufficient space to construct the wall where needs such a protection structure. Therefore the pocket type reinforced soil wall for rock-fall protection was developed. It can be constructed in narrow space at a roadway side and it can catch a rock by it's top. This paper describes the experimental research of the reinforced soil wall for rock-fall protection. The test was performed two models of prototypes, the miniature size model (wall height 1.5m) and actual size model (wall height 6.0m). The experiment of miniature size model confirmed the effect of geosynthetics. The experiment of actual size model demonstrated behavior of the wall, when at the moment of clashing of the rock and confirmed it's safety against a huge scale rock fall.

1 INTRODUCTION

Recent years, rock-fall protection techniques have been being researched and developed in U.S.A. (e.g., Hearn et al. 1995). Rock-fall countermeasures have been improved technologically and the rock-fall protection engineering has been diversified far more than ever. Under such circumstances, the first author, et al. developed the "bank type rock-fall protection retaining wall", which was constructed into a bank out of a geosynthetics-applied reinforcement embankment as shown in Figure 1. Such retaining wall has been put into some practical uses. On the route where a rock-fall is likely to take place, however, it is often impossible to secure the space enough to install a protection facility on the roadside. As a solution to this problem, a "pocket type rock-fall protection retaining wall" was designed, which has a function of preventing a falling rock from reaching the road, with a flat place located on the roadside by the reinforced earth engineering method as shown in Figure 2. The bank type wall is designed to catch a rock at the lateral side, while the pocket type wall is used to stop a rock at the upper surface. This paper, deals with the results of the actual size experiment conducted for a pocket type wall. The impact force acting upon the pocket type wall is to be discussed to propose a simplified design method.

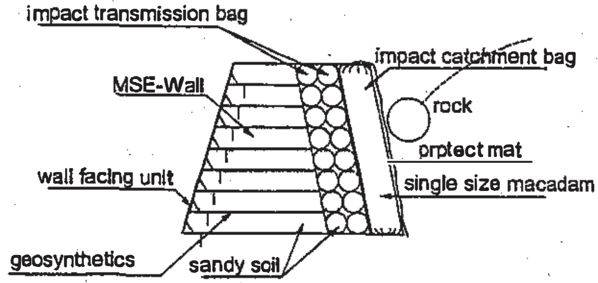

Figure 1. Bank type rock-fall protection retaining wall (conventional type).

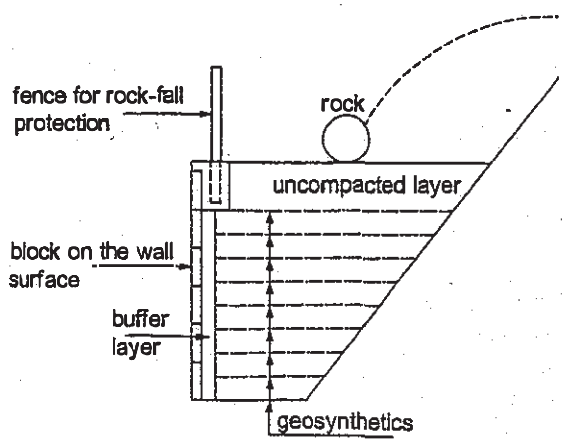

Figure 2. Pocket type rock-fall protection retaining wall.

2 ACTUAL SIZE EXPERIMENT

2.1 *Experiment method*

A actual size model shown in Figure 3. was fabricated and a weight falling experiment was conducted. The embankment material applied had parameters as shown in Table 1. On the model, geosynthetics were laid out height wise in intervals of 500 millimeters as a geosynthetics with a tensile strength of 32 kN/m (strain 5%). For the wall surface material, a wall block was used, with a 300 millimeters thick buffer layer (one-size crushed stone) provided on the back. In addition, a 1.4 meters thick non-rolled layer of sand was provided at the ceiling end of the wall as rock-fall buffer material.

To carry out the experiment, a cylindrical weight, which had a diameter of 1.54 meters, weighing at 51.7 kN, was dropped from a height of 20 meters onto the model at the center as shown in Figure 3.

Measurement items included weight acceleration, a vertical earth pressure, a wall surface displacement and a penetration of the weight. To determine an intra-earth value of the vertical earth pressure, however, a load meter was buried after secured onto a 300 x 300 millimeters steel plate.

2.2 *Results*

Figure 4 shows a time series of changes in the weight impact force obtained by multiplying the measured weight acceleration by the weight mass. It shows a weight impact force of 2,417 kN at the maximum in 17 msec. Figure 5 shows a time series of changes in the vertical earth pressure measured with a load meter. Load Meter 2, located just under the weight drop point, read a maximum vertical earth pressure of 355.6 kN/m^2 in 67 msec.

Table 1. Properties of soil.

Unit weight γ_t (kN/m^3)	16.0
Angle of shear resistance ϕ'(°)	36.0
Cohesion c'(kN/m^2)	0.0

Table 2. Wall surface displacement.

(in meters)

LINE \ ROW	1	2	3	4	5	6	7	8
1	0.002	0.005	0.027	0.074	0.097	0.076	0.072	0.075
2	0.006	0.007	0.028	0.064	0.077	0.068	0.066	0.068
3	0.011	0.025	0.029	0.069	0.065	0.064	0.061	0.066
4	0.026	0.046	0.062	[illegible]	0.056	0.053	0.061	0.060
5	0.028	0.050	0.051	0.053	0.052	0.052	0.054	0.058
6	0.029	0.050	0.051	0.050	0.051	0.050	0.061	0.052

Table 2 shows the displacements by block on the wall surface. A maximum wall surface displacement of 97 millimeters was recorded in front of the weight drop point, with a penetration of 950 millimeters observed. The weight stopped in the non-rolled layer while the geosynthetics at the uppermost stage broke down.

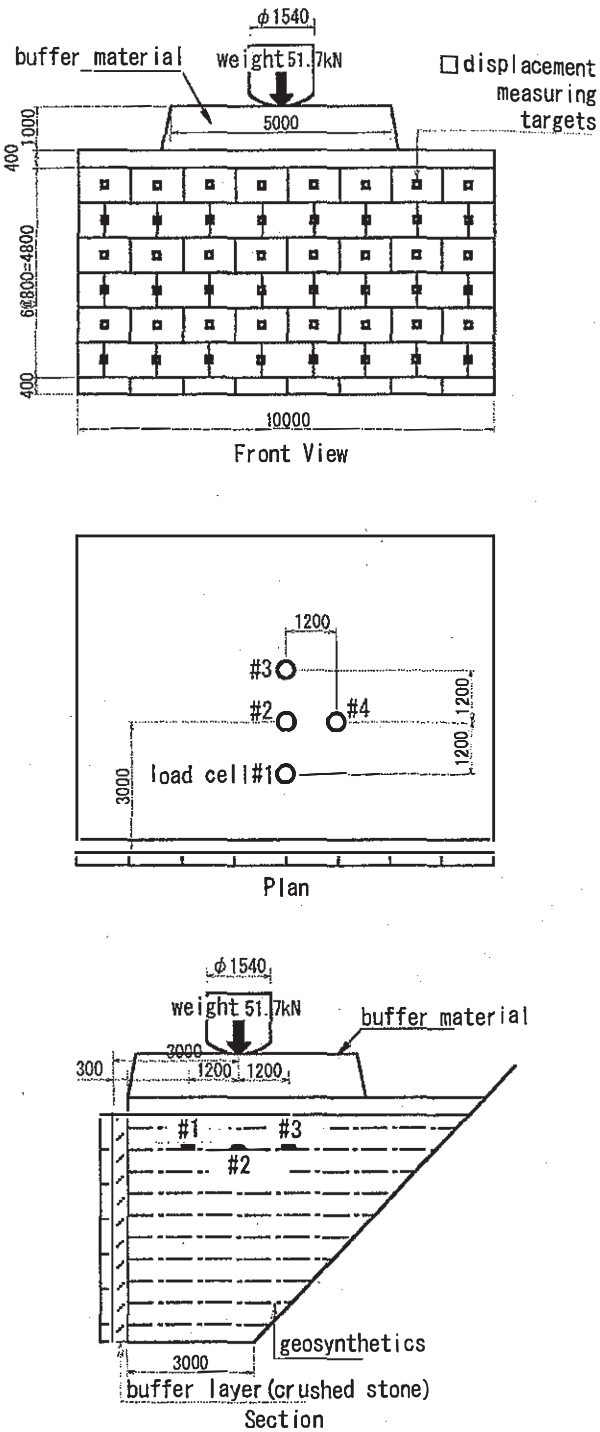

Figure 3. Shape of actual size experiment.

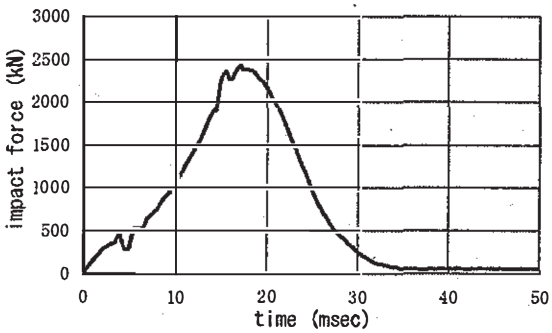

Figure 4. Weight impact force vs. time.

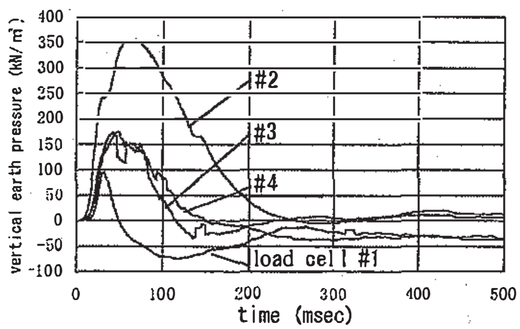

Figure 5. Vertical earth pressure vs. time.

The actual size experiment recorded a maximum weight impact force of 2,417 kN. Based on this value, the rock-fall impact force assumption formula given in Expression 2.1 was used to calculate the Lame's constant that expresses the rigidity of an impact recipient. As a result, the impact recipient was found to have approximately 700 kN/m^2. The buffer material used in the design by Lockshed, et al. reportedly Lame's constant have 1,000 kN/m^{2}in general. The impact force measured in the experiment reported herein may be deemed to fall nearly within a range of reasonable values. A weight penetration relative to the rock-fall impact force assumption formula, moreover, may be expressed in Expression (2.2).

$$P = 2.455W^{2/3} \cdot \lambda^{2/5} \cdot H^{3/5} \qquad (2.1)$$

$$y = \left(\frac{45\,WH}{64\,\lambda} \right)^{2/5} \cdot r_1^{-1/5} \qquad (2.2)$$

where, P is a weight impact force, ya penetration, W a weight load, H a drop height, λLame's constant and γ_1 a converted radius of the weight. From Formula 2.2, a penetration of 929 millimeters was obtained subject to the actual size experiment conditions. And it was found to agree nearly with the experiment result.

3 SIMPLIFIED DESIGN METHOD

Based on the weight impact force obtained from the actual size experiment results, a design impact force was assumed while an attempt was made to check out the model by examining the internal stability of the reinforced earth retaining wall. Figure6 is a schematic of simplified calculations. To examine the internal stability of the pocket type rock-fall protection reinforced-earth retaining wall, it was assumed that the design impact force would act as an additional load on the reinforced earth retaining wall at the ceiling end.

For a possible distribution of the impact earth pressure is concerned, the vertical earth pressure was eventually found to distribute by I: 0.5 or more as measured during the actual size experiment. The rock-fall impact force, therefore, was made to act as a distributed load on the top surface of the reinforced earth retaining wall where the rock-fall impact force had was distributed at 1: 0.5 in the non-rolled layer as shown in Figure 6. For the earth quality constant used in the calculations, refer to the conditions given in Table I. It was assumed, moreover, that the geosynthetics would not have its strength affected by its own creep and that it had a tensile strength of 32

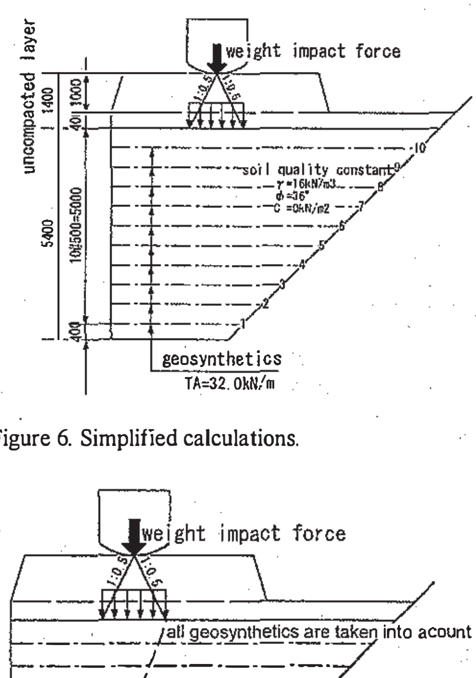

Figure 6. Simplified calculations.

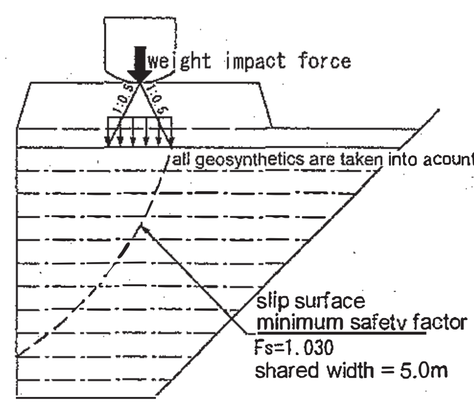

Figure 7. Slip surface and minimum safety factor.

kN/m. The weight, moreover, had an impact force of 2,417 kN experimentally determined. And it was really loaded in the experiment.

In the experiment reported herein, the pocket type rock-fall protection retaining wall did not come to break down. It was assumed, therefore, that the retaining wall had a safety factor of 1.0% or more relative to a rock-fall impact force. And the reinforced earth retaining wall with a safety factor of more than 1.0 had its shared width obtained on a trial and error basis. The term, load's shared width, as used herein, means an extension of the width by which the geosynthetics would resist an impact load. The examination resulted in a load's shared width of 6.0 meters and a minimum safety factor of 1.030. Figure 7 shows the sliding surface with the safety factor minimized. And Figure 8 shows the shared width. As shown in Figure 8., moreover, a distribution gradient of approximately I: 0.7 was obtained by connecting the distributed load at the end with the center of the wall height at the end of the shared width. The sliding surface, moreover, appeared from the load-acting point at the end to a position of 1.0 meter above the reinforced earth retaining wall at the bottom end. During the experiment, moreover, the wall surface displacement was found to increase upwards from a position of approximately 1.0 meter at the bottom end of the wall. From this, it may be gathered that the sliding surface was located almost reasonably.

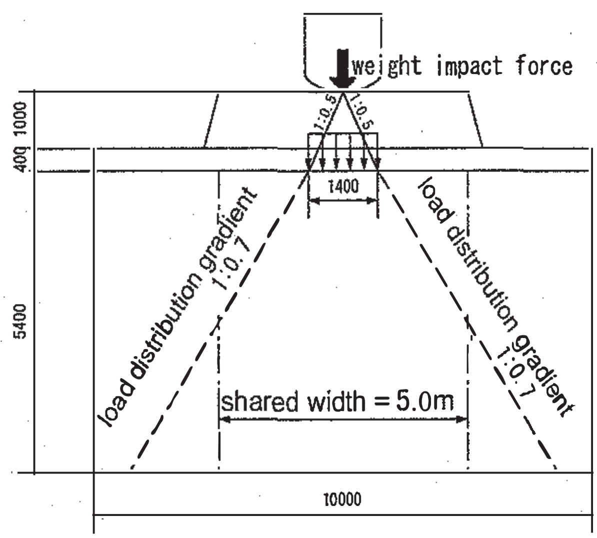

Figure 8. Stress distribution.

Table 3. Tensile force acting on geosynthetics.

No.	Distance from the top (m)	Tensile force to act (kN/m)	Tensile strength T_A (kN/m)	Judgment
10	0.5	51.096	32	×
9	1.0	28.222	32	○
8	1.5	24.7[illegible]	32	○
7	2.0	22.609	32	○
6	2.5	21.282	32	○
5	3.0	20.492	32	○
4	3.5	20.075	32	○
3	4.0	19.928	32	○
2	4.5	20.452	32	○
1	5.0	27.326	32	○

Table 3 shows the results of checking out each geosynthetics for tensile strength. Consequently, the geosynthetics at the uppermost stage only was found to have an acting tensile strength exceed the geosynthetics tensile strength. During the experiment, the uppermost geosynthetics broke down, showing an agreement with the experimental results.

4 SUMMARY

The results obtained in the study reported herein could be summarized as under.

(1) It is possible to enhance the safety of a retaining wall against a vertical load by installing a geosynthetics on the retaining wall body.

(2) A actual size experiment allowed the author et al. to make certain that a pocket type rock-fall protection retaining wall would be safe enough as tested under the conditions of 51.7 kN in weight and 20 meters in drop height.

(3) An assumption formula would permit us to obtain weight impact force acting upon the pocket type rock-fall protection retaining wall at the ceiling end, including a penetration.

(4) Replacing the impact force with a static additional load would permit us to make a design, using the reinforced earth retaining wall stability checkout method commonly used.

From the above, the author et al. think that the pocket type rock-fall protection retaining wall is satisfactorily applicable as a rock-fall protection work unless a flat space is available alongside the road. The author et al. would like to establish a simplified calculation technique in the future. To this end, it is planned that the experiment reported herein will be reproduced analytically to grasp the transfer and distribution behaviors of internal stresses, thereby making certain of the load's shared width and deformation behaviors of a reinforced earth retaining wall.

REFERENCE

George. H., Robert K.B., & Henrie. H. (1995) *Transportation research record 1504*.