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Experimental research of reinforced soil wall for rock-fall protection

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ABSTRACT: The soil wall reinforced with geosynthetics for rock-fall protection has been developed in 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 . 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 its top. This paper describes the experimental research of the reinforced soil wall for rock-fall protection. We perfomed two types of model tests, the miniature size model (wall height 1.5m) and actual size model (wall height 6.0m). The experiment of miniature size model confirmed the efficiency of geosynthetics. The experiment of actual size model demonstrated the behavior of the wall and confirmed its safety against a huge scale rock fall.

1 INTRODUCTION

Recent years, rock-fall protection techniques have been 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, we 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 earth reinforcement 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 reports the results of the actual size experiment conducted for a pocket type wall. The impact force acting upon the pocket type wall is discussed to propose a simplified design method.

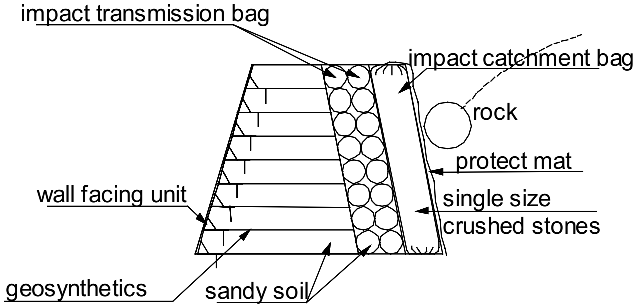

Figure 1. Bank type rock-fall protection retaining wall (conventional type).

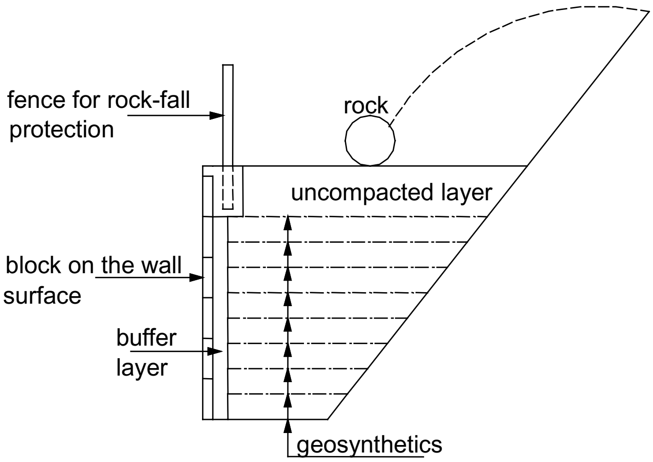

Figure 2. Pocket type rock-fall protection retaining wall.

2 ACTUAL SIZE EXPERIMENT

2.1 *Methods of experiment*

An actual size model shown in Figure 3 was fabricated and a weight falling experiment was conducted. The embankment material applied had the parameters as shown in Table 1. In the model, geosynthetics were laid out in intervals of 500 millimeters which have a tensile strength of 32 kN/m (strain 5%). For the wall surface material, concrete blocks were used, with a 300 millimeters thick buffer layer (crushed stone) provided on the back. In addition, a 1.4 meters thick uncompacted 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 include the weight acceleration, vertical earth pressure, wall surface displacement and the penetration of the weight. To determine the vertical earth pressure, pressure meters were buried after being secured onto a 300 x 300 millimeters steel plate.

Table 1. Properties of soil.

wet unit weight γ_t	16.0 kN/m^3
angle of shear resistance φ	36.0 °
cohesion c	0.0 kN/m^2

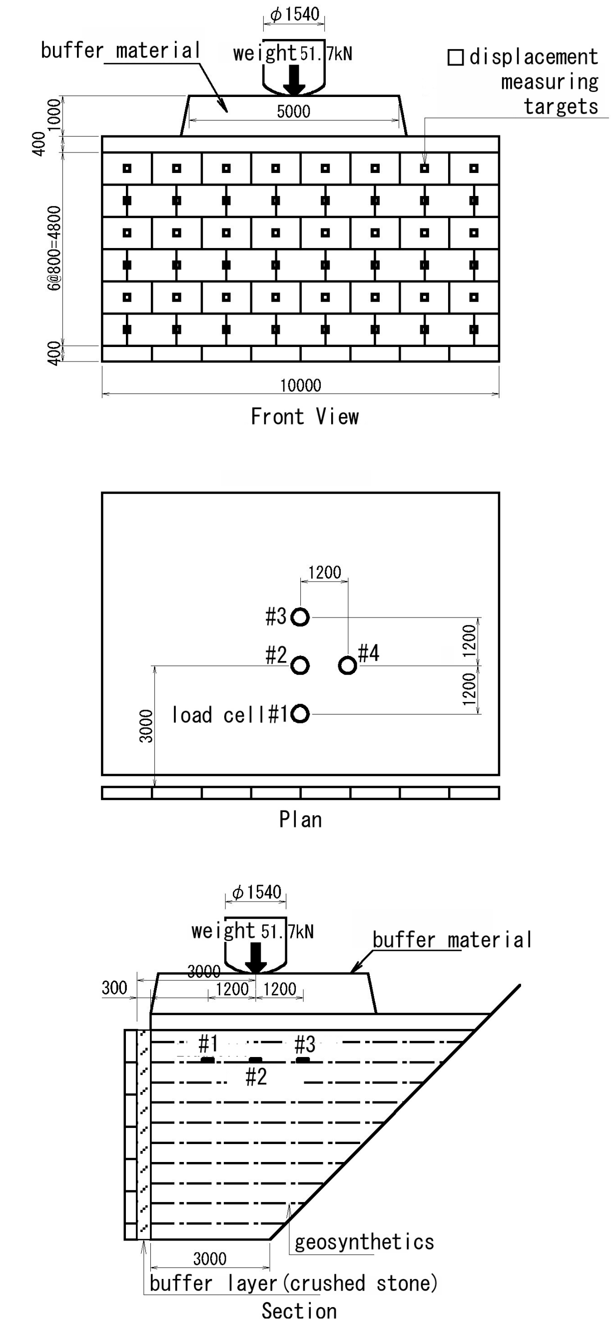

Figure 3. Actual size experiment.

Figure 4. Weight falling (1).

Figure 5. Weight falling (2).

Figure 6. Wall surface deformation.

Table 2.Wall surface displacement.

ROW / LINE	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	0.059	0.065	0.064	0.061	0.066
4	0.026	0.046	0.052	0.056	0.053	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	0.051	0.052

unit : m

2.2 *Results*

Figures 4,5 and 6 show the conditions of the experiment. Figure 7 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 8 shows a time series of changes in the vertical earth pressure measured with pressure meter. Pressure Meter 2, located just under the weight drop point, a maximum vertical earth pressure of 355.6 kN/m^2 in 67 msec. Table 2 shows the displacement of concrete block on the wall surface. A wall surface displacement of 97 millimeters was recorded in front of the weight drop point, with a penetration of

950 millimeters. The weight stopped in the uncompacted layer while the geosynthetics at the uppermost stage broke down. The maximum weight impact force of 2,417 kN was recorded. Based on this value, the rock-fall impact force assumption formula given in Equation 1(e.g. Obata et al.) was used to calculate the Lame's constant that expresses the rigidity of an impact recipient.

$$P = 2.455^{2/3} \cdot \lambda^{2/5} \cdot H^{3/5} \quad (1)$$

where P : a weight impact force, H : a drop height, λ : Lame's constant. As a result, the impact recipient was found to have about 700 kN/m^2. The Lame's constant for usual buffer material has 1,000 kN/m^2 in general. The impact force measured in this experiment may fall nearly within a range of reasonable values. A weight penetration may be expressed by Equation 2(e.g., Obata et al.) .

$$y = \left(\frac{45 \cdot W \cdot H}{64 \cdot \lambda} \right)^{2/5} \cdot r_1^{-1/5} \quad (2)$$

where У : a penetration , W : a weight load , r_1 : a converted radius of the weight. From Equation 2 , a penetration of 929 millimeters was obtained subject to the actual size experiment conditions. And it was found to agree well with the experiment result.

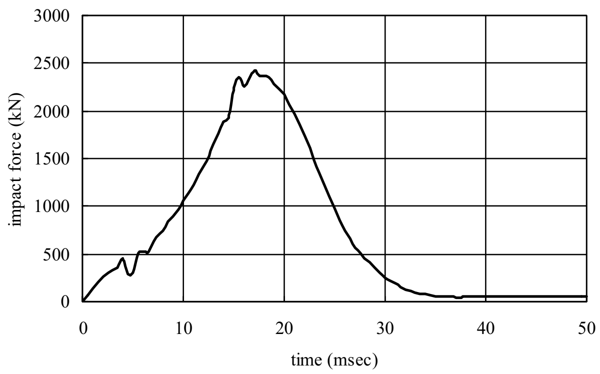

Figure 7. Weight impact force.

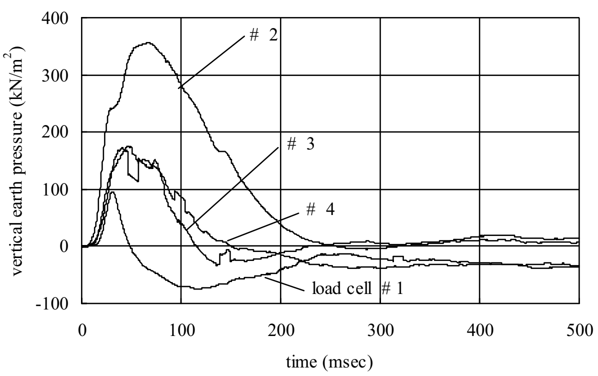

Figure 8. Vertical earth pressure.

3 SIMPLIFIED DESIGN METHOD

Based on the weight impact force obtained from the actual size experiment an attempt was made to check out the model by examining the internal stability of the reinforced earth retaining wall. Figure 9 shows a model for simplified calculation. To examine the internal stability , it was assumed that the impact force would act as an additional load on the reinforced earth retaining wall at the ceiling end. The impact earth pressure is assumed to distribute by 1: 0.5 as measured in 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 wall. The soil parameters used in the calculations, are given in Table 1. 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 kN/m. The weight had an impact force of 2,417 kN experimentally determined. And it was really loaded in the experiment. In the experiment, the pocket type 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 against a rock-fall impact force. We must assume load sharing width by trial and error method. The term, load sharing width means an extension of the width by which the geosynthetics would resist an impact load. The examination gives the load sharing width of 5.0 meters and a minimum safety factor of 1.030. Figure 10 shows the slip surface with the safety factor minimized. Figure 11 shows the shared width. As shown in Figure 11, a distribution gradient of 1: 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 slip surface 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. In the experiment, the wall surface displacement was found to increase upwards from a position of about 1.0 meter at the bottom end of the wall. From this, it may be gathered that the slip surface was located almost reasonably. Table 3 shows the results of checking out each geosynthetics for tensile force. Consequently, the geosynthetics at the uppermost stage only have an acting tensile strength exceed the geosynthetics tensile strength. In the experiment, the uppermost geosynthetics broke down, showing an agreement between the experimental results and predicted results.

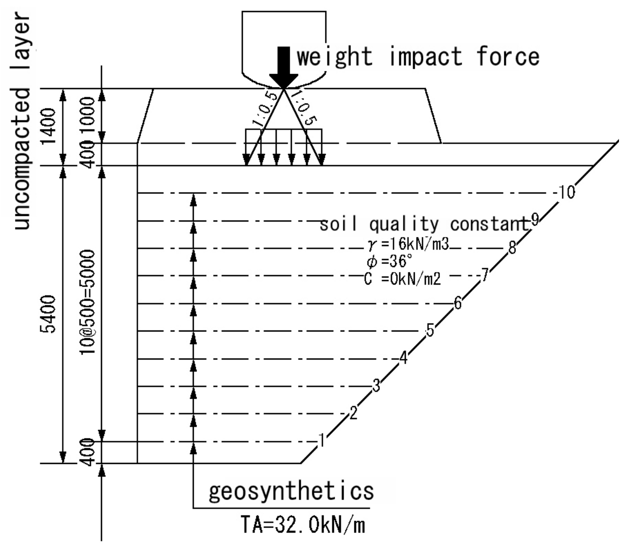

Figure 9. Simplified calculations.

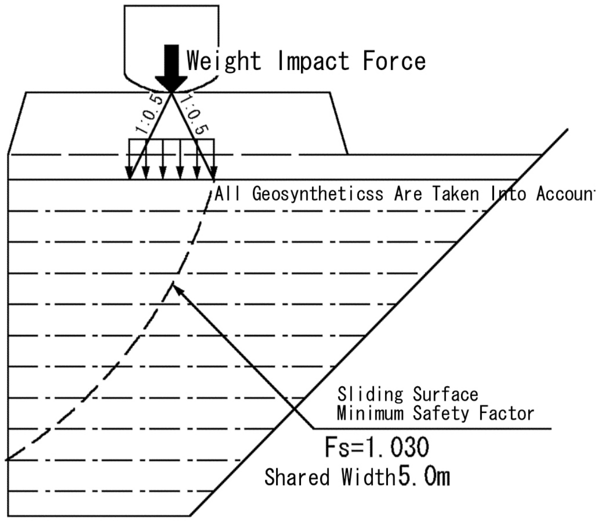

Figure 10. Assumed failure mode.

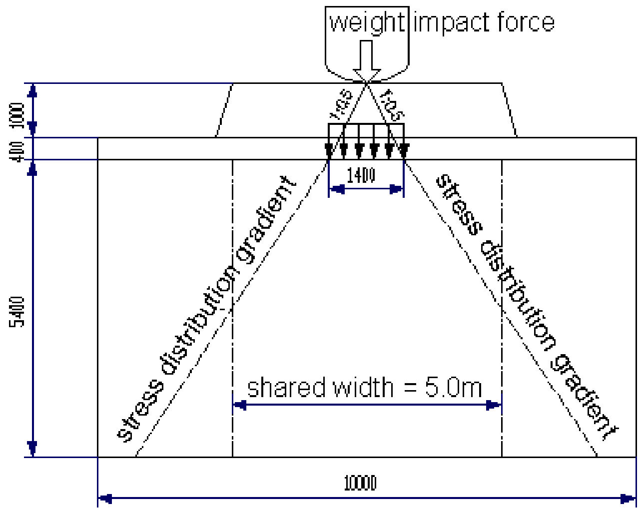

Figure 11. Assumed distribution of strss.

Table 3 Tensile force acting on geosynthetics.

No.	Distance from he top (m)	Tensile force to act (kN/m)	Tensile strength T_A (kN/m)	Judgment
10	0.5	51.096	32.0	×
9	1.0	28.222	32.0	○
8	1.5	24.753	32.0	○
7	2.0	22.609	32.0	○
6	2.5	21.282	32.0	○
5	3.0	20.492	32.0	○
4	3.5	20.075	32.0	○
3	4.0	19.928	32.0	○
2	4.5	20.452	32.0	○
1	5.0	27.326	32.0	○

4 SUMMARY

The results obtained are summarized as follows.

(1) It is possible to enhance the safety of a retaining wall against a vertical load by the geosynthetics in stalled in backfill.

(2) An actual size experiment verified 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 assumed formula would give the 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 enables to make a design, using the reinforced earth retaining wall stability checkout method commonly used. 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. We have to establish a simplified calculation technique in the future. Our experiment 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 behavior of a reinforced earth retaining wall.

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