Structures under Shock & Impact VI, C.A. Brebbia & N. Jones (Editors)

Prototype impact test on rockfall retaining walls and its numerical simulation

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Abstract

In Japan, rockfall retaining walls as safety facilities of roads are designed as the gravity type with a plain concrete structure. In this paper, in order to investigate impact behavior of the structure, prototype impact tests are conducted by letting a steel weight with a predetermined velocity collide. Elasto-plastic impact analyses on the walls are also performed and an applicability of the proposed method is discussed comparing with the experimental results. From this study, the following results are obtained: 1) using the proposed numerical analysis method, weight impact force wave, rotation of the wall, and crack pattern can be precisely predicted; and 2) this analytical method can be used for establishment of a rational design procedure for rockfall retaining walls.

1 Introduction

In Japan, many rockfall retaining walls (hereafter, walls) are constructed along the national roads near mountainous areas to protect people and vehicles from falling rocks. Now, the wall is designed assuming that it can resist against impact force due to its gravity force and behaves as a rigid body [1]. Then, the wall is basically constructed as a plain concrete structure. However, in practice, severe damage due to falling rocks is observed. An applicability of the present design guideline regarding this type of impact resistant structures has not been confirmed experimentally and numerically.

From this point of view, concerning gravity type rockfall retaining walls, prototype impact tests are conducted by letting a steel weight with a

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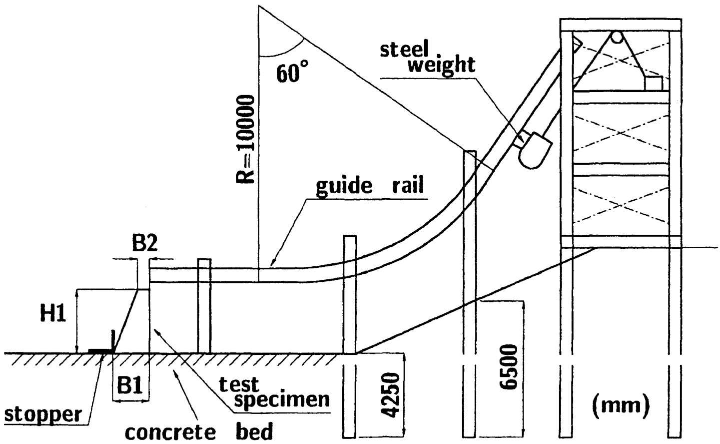


Figure 1: Experimental setup.

predetermined velocity collide onto the wall to investigate the real dynamic behavior and failure mode of wall due to falling rocks. In these experiments, 1.0 ton and 300 kg steel weights are used instead of a falling rock. Measuring items are weight impact force, horizontal displacement of the top of wall, and vertical displacement of the bottom of wall. After experiment, crack pattern is sketched.

And also, elasto-plastic impact analyses are performed taking wall height, loading height, and the mass of steel weight as variables. An applicability of the proposed analytical method is numerically discussed comparing with the experimental results. In these analyses, a simple constitutive law of concrete is applied. Then, energy absorption due to plastic deformation and system damping effects is considered but strain rate effects are ignored. These numerical analyses are performed by using LS-DYNA code[2].

2 Experimental overview

An experimental setup used in this study is shown in Figure 1. Since practically constructed rockfall retaining wall is setup on a good foundation built with compacted gravel and sand, the wall models are set on a concrete foundation and are horizontally restrained at the back-side bottom edge by steel-made stopper. Impact load is surcharged onto the wall by letting a steel weight with predetermined velocity horizontally collide which is introduced along the guide rail made by H section steel beam. Here, two kinds of steel weight are used which are: 1 ton mass with 50 cm in diameter and 300 kg mass with 40 cm in diameter. Based on the experimental results in case of iterative loading with 1 m/s initial and incremental impact velocity to the ultimate state, a steel weight is singly impacted with the maximum impact velocity at the iterative loading test. Here, it is assumed that the walls are in the ultimate state when the wall is

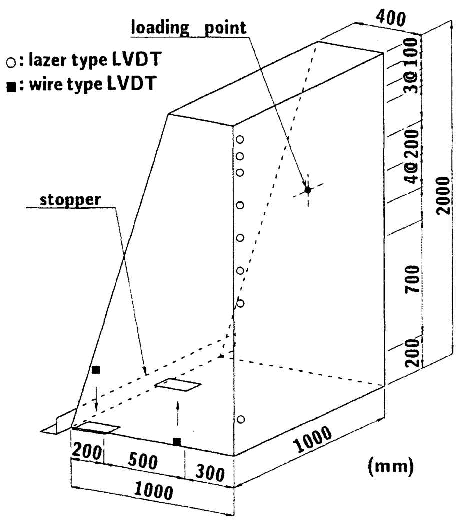
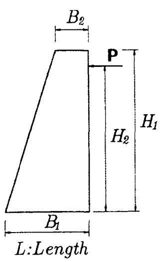


Figure 2: Measuring points of displacement.

Table 1. A list of experimental cases.

<table>
<tr><th rowspan="2">Geometry of wall</th><th rowspan="2">Test ID.</th><th colspan="4">Dimensions (m)</th><th rowspan="2">Loading point H_2</th><th rowspan="2">Steel weight W(ton)</th></tr>
<tr><th>H_1</th><th>B_1</th><th>B_2</th><th>L</th></tr>
<tr><td rowspan="5">
</td><td>W1-0.9-1</td><td>1.0</td><td>0.5</td><td>0.2</td><td rowspan="5">1.0</td><td rowspan="2">$0.9H_1$</td><td rowspan="4">1.0</td></tr>
<tr><td>W2-0.9-1</td><td>2.0</td><td>1.0</td><td>0.4</td></tr>
<tr><td>W3-0.7-1</td><td>3.0</td><td>1.5</td><td>0.6</td><td>$0.7H_1$</td></tr>
<tr><td>W2-0.5-1</td><td rowspan="2">2.0</td><td rowspan="2">1.0</td><td rowspan="2">0.4</td><td>$0.5H_1$</td></tr>
<tr><td>W2-0.9-0.3</td><td>$0.9H_1$</td><td>0.3</td></tr>
</table>

destroyed due to the through cracks being developed and/or is turned over. In this study, horizontal displacement of the front-face, vertical displacement of the bottom side edge, and acceleration caused in the steel weight are measured by using wire type LVDTs, laser type LVDTs, and strain gauge type accelerometers, respectively. These measuring points are indicated in Figure 2. After experiment, crack pattern is sketched and the failure mode is investigated.

Six wall models are used as listed in Table 1. In this Table, test ID. is defined

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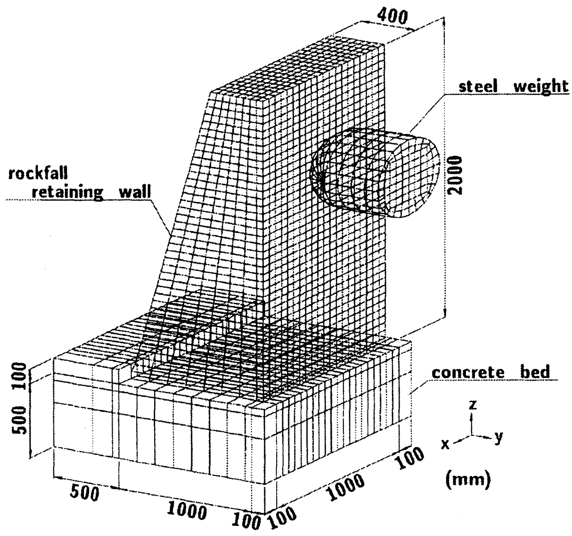

Figure 3: Analytical model example (W2-0.7-1).

hyphening three parameters as: wall height H_1 (m), non-dimensional loading height referring to the wall height H_1, and mass of steel weight (ton). The width at the top and bottom of wall are assuming as $B_1 = H_1/2$ and $B_2 = H_1/5$, respectively, following the present guideline of Japan [1]. Even though usually the walls are designed assuming loading height being $0.9H_1$, here three experimental cases are prepared as: $H_2 = 0.9H_1$, $0.7H_1$, and $0.5H_1$ to investigate the dynamic behavior of wall corresponding to the loading height.

3 Analytical overview

3.1 Analytical model

In this study, LS-DYNA code is used to analyze the impact behavior of prototype rockfall retaining walls due to letting a steel weight with predetermined velocity collide. Figure 3 shows one analytical model example (W2-0.7-1) in which eight-node solid hexahedron and/or six-node solid pentahedron elements are used. Total numbers of nodal points and elements are around 10,000 and 8,000, respectively. The wall is set on the 50 cm thick Reinforced Concrete (RC) foundation with 10 cm high difference of level to prevent it from slide in the backward direction. The bottom and side-surfaces of RC foundation are perfectly fixed. Slide interface model is applied in two contact surfaces between wall and RC foundation, and between a steel weight

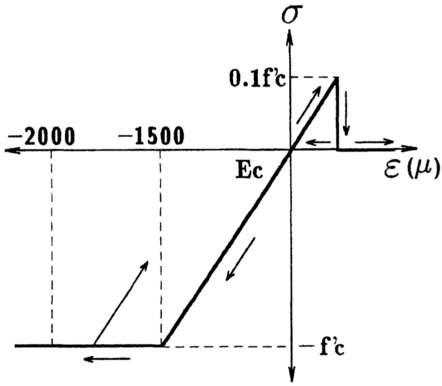

Figure 4: Constitutive model for concrete.

Table 2. Material properties.

Material	Young's modulus (GPa)	Compressive strength (MPa)	Poisson's ratio
Concrete	20.6	21.1	0.18
Steel	205.8	–	0.30

and front-surface of wall to precisely estimate the rotation of wall and the rebound of steel weight. A steel weight with predetermined velocity is horizontally impacted onto the front-face of wall and its vertical and side-sway motions are always prohibited. In these analyses, one-point integration method in Gaussian quadrature is applied for estimation of volumetric integration to save the computer time. Here, in order to accurately analyze the rotation of wall, the initial stress and displacement of wall due to gravity force are considered which are pre-analyzed by means of dynamic relaxation method first.

3.2 Material model

In this study, soil-crushable foam model installed in the code is applied to represent the constitutive law of concrete, in which stress-strain relation in the compression region is assumed as perfectly elasto-plastic material (bi-linear model) with von Mises yielding criterion and tension cutoff is considered. This model is defined that if stress reaches the tension cutoff, tension stress is decreased to zero level and can not be transmitted in any direction. Figure 4 shows stress-strain relation of concrete used in this study. Here, it is assumed that concrete is yielded when stress reaches compressive strength accompanying with 0.15 % strain and tension cutoff stress is equal to one-tenth of the yielding

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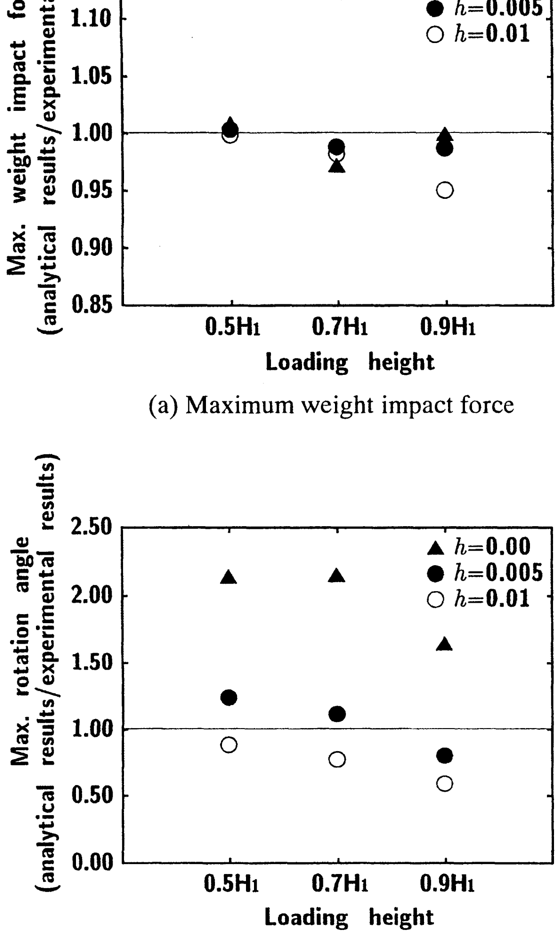

(a) Maximum weight impact force

(b) Maximum rotation angle of wall

Figure 5: Comparison of numerical and experimental results
in cases of W2-0.5/0.7/0.9-1

3.3 Determination of damping factor *h*

In elasto-plastic dynamic response problems, two damping effects must be considered which are: energy dissipation effect due to cyclic inelastic deformation and system damping effect. The former is automatically considered by using elasto-plastic constitutive model for concrete and the latter can be considered assuming a given dynamic problem as a viscous damping vibration system.

In order to properly determine the damping factor h, dynamic response analyses on three experimental cases with different loading height are executed inputting three assumed damping factors: h = 0.00, 0.005, and 0.01. Comparison of these analytical results on the values of maximum weight impact force and maximum rotation angle of wall to those of experimental ones are shown in Figure 5, in which these values are normalized with reference to the experimental values. From these figures, it is seen that analytical results assuming h = 0.005 are the best correspondence with the experimental ones among those obtained assuming three damping factors. Then, hereafter numerical simulations are performed assuming the system damping factor h = 0.005 for all experimental cases considered here.

4 Comparison between analytical and experimental results

4.1 Weight impact force

Figure 6 shows the comparison between the analytical impact force excited in the steel weight and that of observed one. The force is evaluated multiplying an excited acceleration in the weight by its mass. In these figures, numerical results on the duration time of impact force for the cases of W2-0.9-1, W3-0.9-1, W2-0.7-1, and W2-0.5-1 are estimated a little longer than those of observed ones. However, the maximum weight impact forces obtained from the experimental results for all cases are precisely predicted by this numerical analysis.

4.2 Crack pattern

Based on the assumption of soil and crushable model applied as material constitutive law of concrete, when a deviatoric stress in the element exceeds the tension cutoff level, it is defined that the failure is occurred in the element and the stress is zeroed. It implies that if the maximum principal stress of the element is equal to zero value, a crack has been developed in the element. Here, it is tried to evaluate the crack pattern developed in the wall by applying this concept.

Figure 7 shows the comparison between crack patterns developed in each surface of the wall and the color contour on the maximum principal stress at the time when the maximum weight impact force is excited. The time is estimated as about 7 ms after a steel weight being collided onto the front-surface of wall

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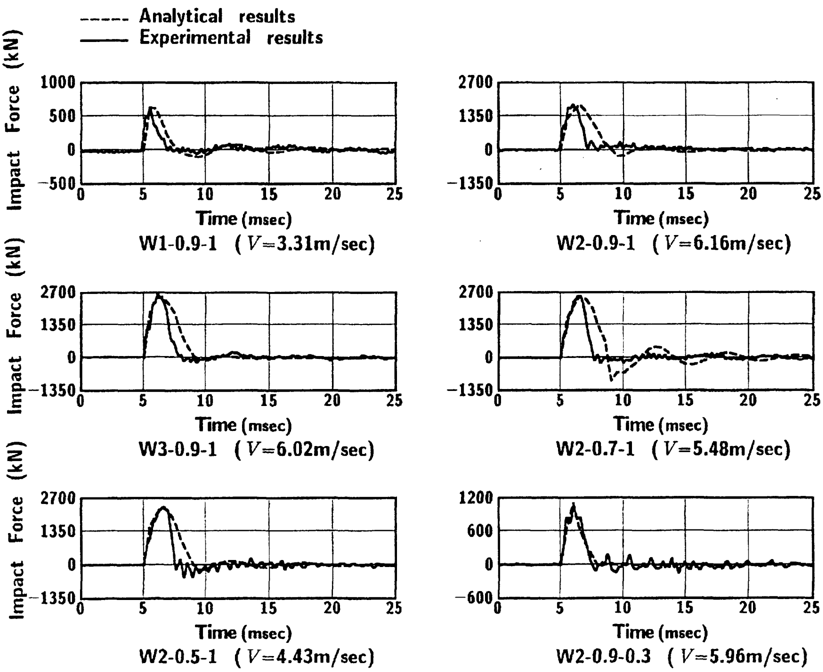

Figure 6: Comparison of weight impact force between analytical and experimental results.

for all cases. In this figure, the element with the zero maximum principal stress is drawn with green color. The results on three experimental cases of W1-0.9-1, W2-0.9-1, and W2-0.7-1 are shown. From these comparisons, green color distributions obtained from numerical analyses give a fairly good agreement with bending crack patterns developed in the front and back surfaces and shear crack patterns in side-surfaces. Then it is seen that the crack pattern developed in the wall due to a steel weight impact loading can be rationally predicted by using LS-DYNA code with soil and crushable foam model as the material constitutive law of concrete.

5 Conclusions

In this paper, in order to investigate the impact behavior of rockfall retaining wall due to falling rocks, prototype impact tests are conducted by letting a steel weight with a predetermined velocity singly collide. And, the elasto-plastic impact analyses on the walls are also performed and an applicability of the proposed method is discussed comparing with the experimental results. From this study, following results are obtained:

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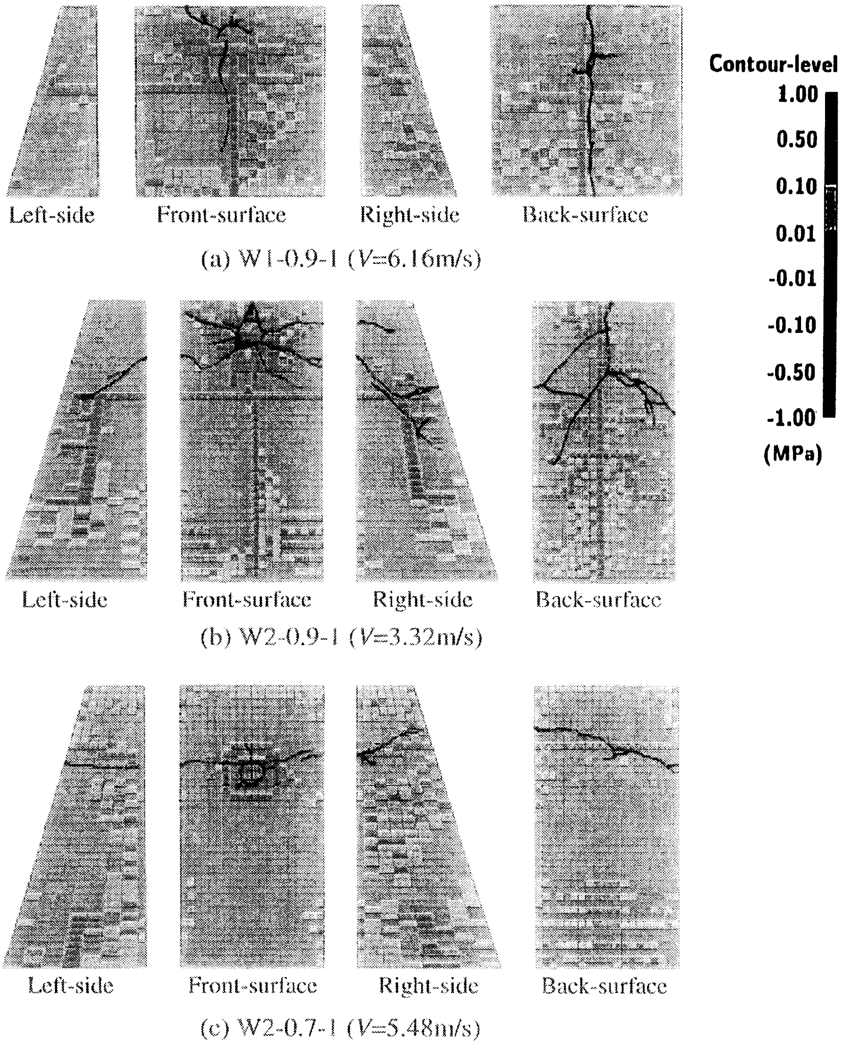

Figure 7: Comparison between maximum principal stress distribution and crack pattern.

1) using the proposed numerical analysis method, weight impact force wave and the maximum impact force can be precisely predicted;

2) using color contour distribution of the zero maximum principal stress obtained from numerical analysis applying soil and crushable foam model as material constitutive law of concrete, crack pattern and failure mode of wall can be rationally predicted; and

3) this proposed analytical method can be used for establishment of rational

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design procedure for rockfall retaining walls.

References

[1] Japan Road Association, Manual for impact resistant structures against falling rocks, 1983.
[2] Hallquist, J.O. LS-DYNA user's manual, Livermore Software Technology Corporation, 1997.