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A study on dynamic load model on precast SRC rock-shed

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ABSTRACT

To perform dynamic analysis of the rock-shed, it is necessary to model the input wave of impact force into a simple shape. This study found that there is a proportional relationship between the impulse and the input energy. Using this relationship and the proposed trapezoidal model for a time-impact force, 3-D framework analysis could obtain the displacements corresponding to the experimental results of a SRC rock-shed.

Keywords: Rock-shed, Impact waveform, Impulse, Nonlinear dynamic framework analysis

1 INTRODUCTION

The high risk of falling rocks is existing along the mountain and coast roads in Japan, Taiwan and other countries that have narrow national lands. Rock-sheds are constructed to protect such roads from falling rocks. Rock-shed should have high toughness even in the plastic zone. In the case of the SRC structure made by H-shaped steel and reinforced concrete, the strength does not suddenly decrease even after the maximum load. The authors focused on the high toughness performance of the SRC structure and applied it to rock-shed.

Fig. 1 illustrates a rock-shed in which the roof consists of precast SRC girders, precast SRC slab and cast-in place concrete slab. This study focused on the roof. First of all, the precast SRC girder is installed in the direction crossing the road, and then on the girder, the precast SRC slab member is installed in the road direction. Then, install reinforcing bars on the precast slab, placing of concrete, and a unified slab is completed. Also, the girders and the slabs each have been covered with outer steel plates.

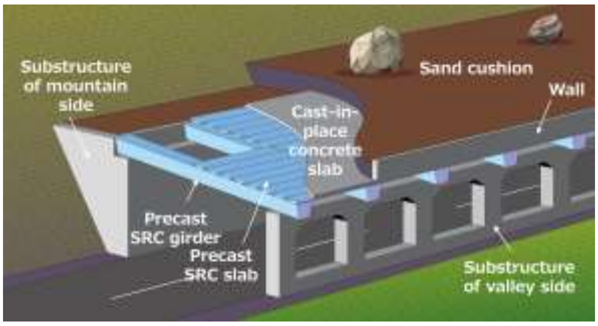

Fig. 1. SRC Rock-shed

Based on the above background, Matsuta et al. (2017) first conducted a static bending test and FEM analysis of the girder and the slab segment of SRC members. Next, Kitajima et al. (2018) carried out a weight drop test on the real scale roof part of a rock-shed. In addition, Kitajima et al. (2017) conducted 3-D dynamic framework analysis using the measured transmitted impact force. In this research, the time-impact force model for the analysis is created to simulate the behavior of a SRC rock-shed and to aid the design work.

2 REAL SCALE EXPERIMENT

2.1 Outline of experiment

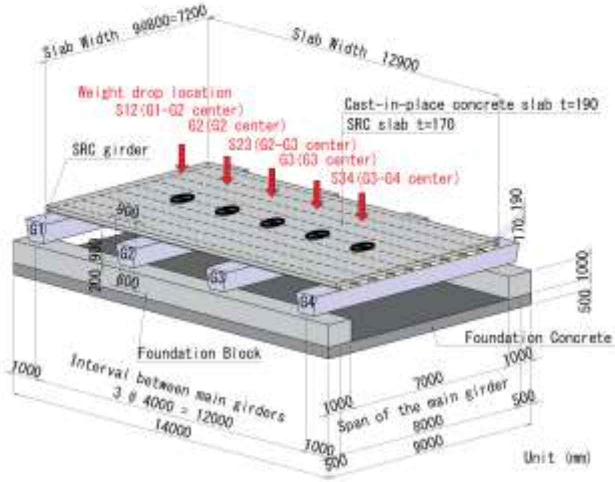

Fig. 2. Specimen dimensions

Fig. 2 shows a real sized specimen. A span length and a cross-section height of the SRC girder is 8.0 m and 0.9 m, respectively. Three sets of nine SRC slabs arranged in the direction of the span of the girder, a total of 27 slabs. The thickness of the precast slab was

0.17 m. Cast-in-place concrete was cast over the installed precast slabs to form a unified structure. The thickness of the cast-in-place concrete slab was 0.19 m. The thickness of the unified slab was 0.36 m. The main girder is a simple beam supported by the base block.
The details of the experimental specimens are the same as those of Kitajima et al.(2018)

In the test, a weight was suspended at the specified height from the boom of a crawler crane before being dropped in free-fall. The shape of the weight was based on the regulation of the ETAG27(2008) designated by EOTA.

The river-sand cushion of 4 m square and 0.9 m in thickness was set below the impact point on the slab surface. The properties of the sand were as follows: A maximum dry density (1.75 g/cm^3); an optimum water content ratio (13.0%); a maximum particle size (4.75 mm); and an equalizing coefficient (3.65). Therefore, it was gravel mixed sand. In each experimental case, the sand cushion was subjected to vibrating plate compactor every 30 cm in thickness. Table 1 shows cases of the test.

Table 1. Cases of the test

No	Test cases	Weight drop location (Fig.2)	Weight (ton)	Weight Height (m)	Input energy (kJ)
1	S12-E60	S12	5.2	1.22	62
2	S12-E320			6.22	317
3	S12-E1060			20.72	1,056
4	S12-E1390			27.22	1,387
5	S12-E2030		10.1	20.52	2,031
6	S12-E3000		15.0	20.38	2,996
7	G3-E320	G3	5.2	6.22	317
8	G3-E470			9.22	470
9	G3-E730			14.22	725
10	G3-E1060			20.72	1,056
11	S34-E4390	S34	15.0	29.88	4,392
12	G2-E4390	G2			

2.2 Measurement item and measurement method

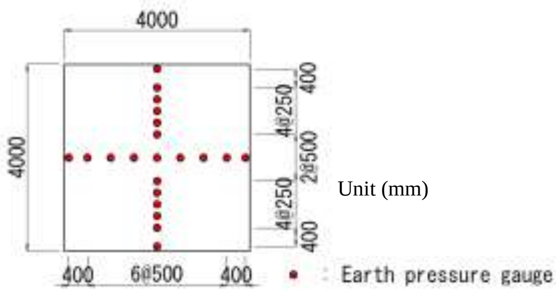

Fig. 3. Arrangement of the earth pressure gauges

As shown in Fig. 3, 21 earth pressure gauges were placed on the cast-in-place concrete slab and its central point was coincident with the center of an impact-loading. Values between each earth pressure gauge were approximated by a straight line, then the transmitted impact force to the concrete slab was obtained by surface-integrating the values in the circumferential direction. Displacement was measured by a displacement gauge just under the loading point. The output from each sensor was sampled to the recorder at 0.2 ms intervals.

3 CONSIDERATION OF TIME-IMPACT FORCE WAVEFORM MODELING

3.1 Background of the study

Since the impact load acts on the rock-shed, it should be designed by dynamic analysis. Therefore, the simple modeling for a time-impact force waveform is necessary for the analysis. Figure 4 shows an example of a model of a trapezoidal waveform shown in Rock-fall countermeasure handbook (2017). The duration of loading is 35 ms. However, the load duration obtained in our experiment was in the range of about 70 ms to 200 ms. This duration is different from that of Fig. 4, because Fig. 4 has come from the waveform obtained from the experiments on a solid foundation but not a flexible slab like this study. Therefore, a rational time-impact force waveform for designing a rock-shed is considered in the following sections.

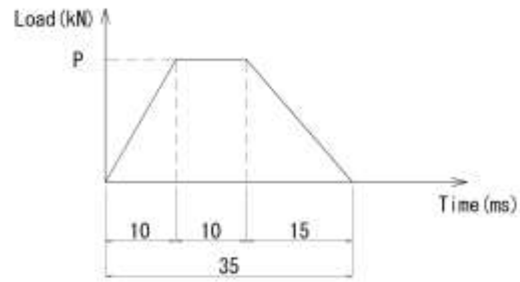

Fig. 4. Example of time-impact force waveform model

3.2 Impulse of rock fall impact

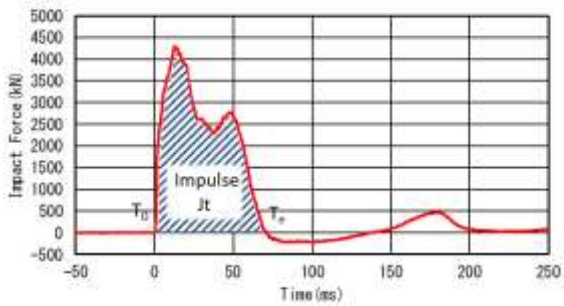

Fig. 5. Concept of impulse

In Fig. 5, T_o is the rise time of the impact force and T_e is the time the impact force returns to zero. The impulse J_t is evaluated by integrating the impact forces from T_o to T_e. Fig. 6 shows the relation between the impulse J_t and the input energy E. The data came from Nos. 1-4 and Nos. 7-9 in Table 1.

It seems that the impulse is in proportion to the input energy regardless of the differences in weights or drop positions. Since the number of test cases is not enough. Therefore, as a similar experimental example, the impulse of the weight drop test on PC girder performed by Nishi et al. (1995) is indicated by a red cross dots for reference. In their tests the mass of a weight was 3.0 ton, and its bottom shape, i.e. the collision surface was spherical. Although the energy range is low, the correlation is consistent with our test result.

The linear correlation Eq. (1) was obtained from these 11 data.

$$J_t = 0.1696E \tag{1}$$

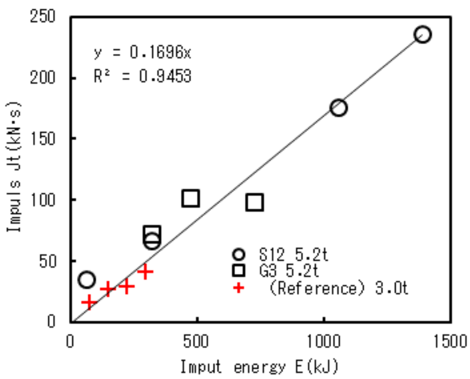

Fig. 6. Relationship between impulse and input energy

3.3 Modeling time-impact force waveform

If the time-impact force waveform can be determined as illustrated in Fig. 7, it is greatly able to contribute to the design works of a rock-shed. In Fig. 7, *T* is the total loading time, *T1* (=10 ms) is the 1st interval of load increasing, *T2* (=10 ms) is the 2nd interval of peak load retaining and *T3* is the 3rd interval of load decreasing.

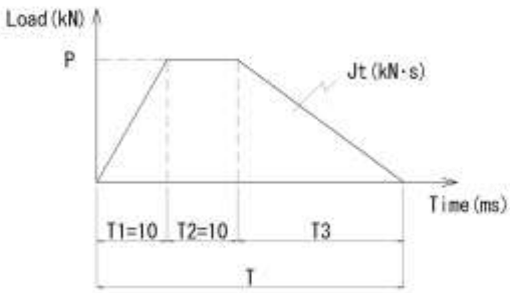

Fig. 7. Proposed time-impact force waveform model

The peak impact-load, P, can be predicted by Eq. (2) of Rock-fall countermeasure handbook (2017)

$$P = 2.108 \cdot (m \cdot g)^{2/3} \cdot \lambda^{2/5} \cdot h^{3/5} \cdot \alpha \tag{2}$$

where P : peak impact load (kN), m : mass of a falling rock (ton), g : gravitational acceleration 9.8 m/s^2, λ : Lamé's constant of 1,000 kN/m^2, h : falling height (m), α : extra factor determined from the ratio of sand cushion thickness and falling rock diameter $=\sqrt{(D/T)}$, D : falling rock diameter (m), T : sand cushion thickness of 0.9 m.

When the rock-fall conditions are given, the impulse *Jt* and the peak load *P* are calculated by Eq. (1) and Eq. (2), respectively. Then assuming that the impulse *Jt* is equivalent to that of Fig. 7, the interval *T3* in Fig. 7 can be found. Fig. 8 shows the time-impact force waveforms obtained from experiments and modeling of test Nos. 3, 4 and 9.

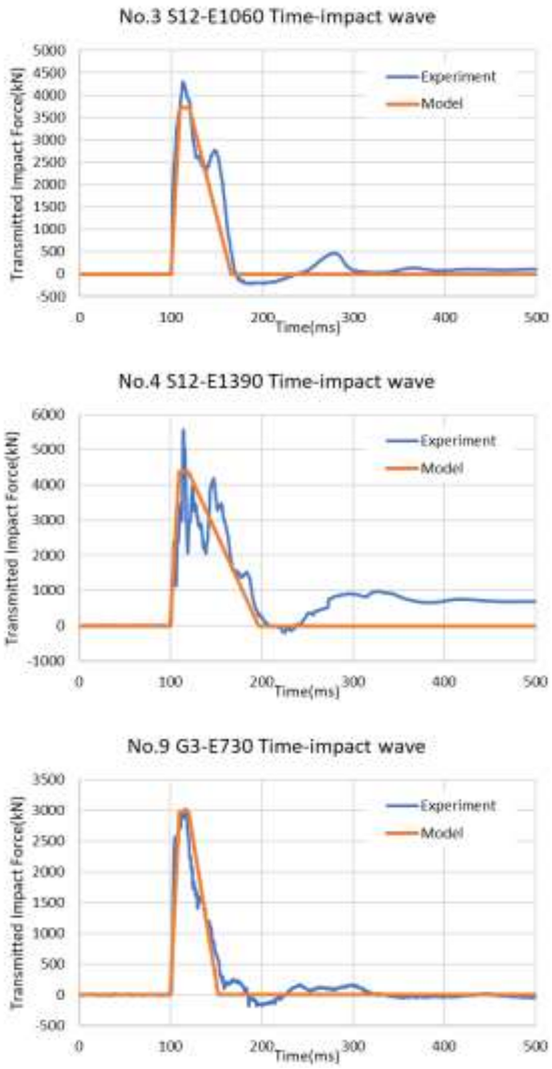

Fig. 8. Time-impact force waveform

In the first two cases of Fig. 8. the peak transmitted impact force obtained in experiment exceeds that of model significantly. There are two reasons for that. Firstly, since the experimental impact force was calculated by the surface integration using the values of 21 earth pressure gauges, the error is large. Secondly, Eq. (2) is the estimated equation based on Hertz's theory of impact. However, the waveform model could well approximate the experimental waveform.

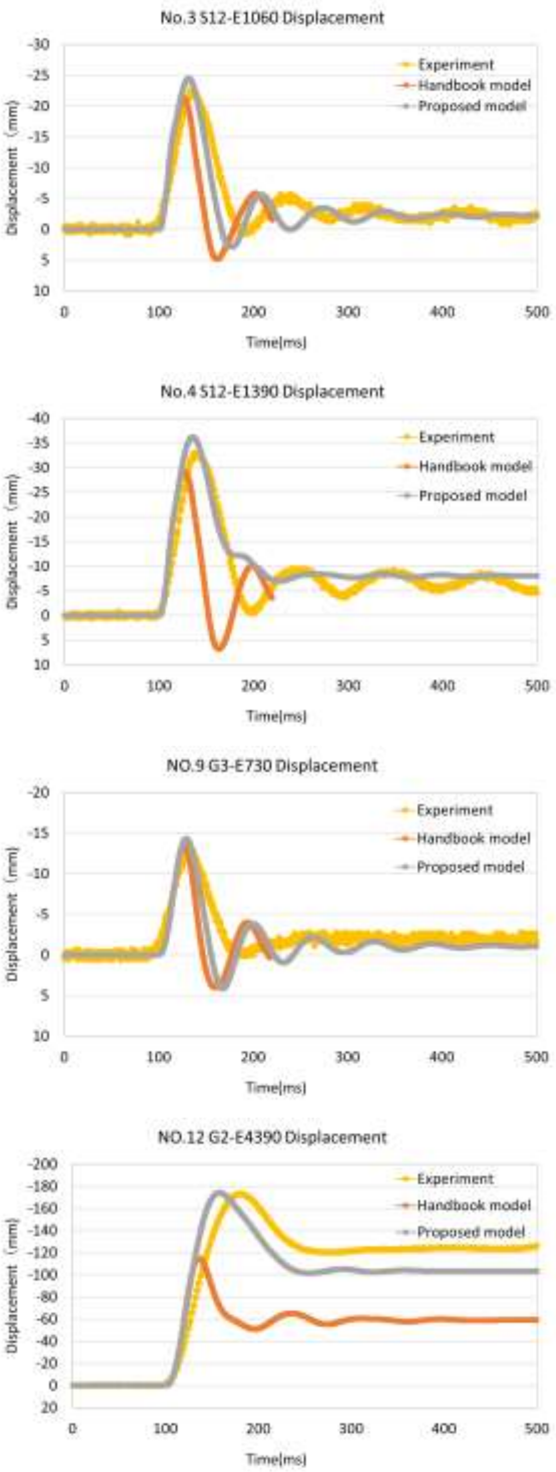

Fig. 9. Time-displacement waveform of loading point

3.4 Analysis using modelized waveform

Dynamic analysis was carried out using modelized time-impact force waveform. It is important to understand and analyze plastic behavior in designing a rock-shed. FEM analysis can reproduce the structural behavior to some extent. However, the model of a SRC rock- shed becomes complicated, and it takes a huge time to build and analyze the model. It is not practical. Therefore, nonlinear 3-D dynamic framework software (Engineer's Studio Ver. 7.2.2) using a fiber model was used. Other analysis conditions are the same as those of Kitajima et al. (2017: 39th IABSE Symposium).

In order to compare the effect of waveform models of the time-impact force on the analytical results, the handbook's model shown in Fig. 4 and the proposed one in Fig. 7 were applied to nonlinear 3-D dynamic analysis. Fig. 9 indicates the time-displacement waveform of a slab or a girder just under a loading point. Although the maximum displacement by the analysis using the proposed model is somewhat larger than that of the experiment, it is reproduced well compared with that using a handbook model. The residual displacement at the time of 500 ms is also successfully reproduced. The handbook model cannot reproduce the experimental behavior, especially when the energy increases. When the influence of the plastic behavior of a structure becomes greater, the loading duration should be set closer to reality.

4 CONCLUSION

There was a proportional relationship between the impulse and the input energy. This study proposed the modeling method of the time-impact force waveform for the 3-D dynamic framework analysis of a rock-shed, and the waveform model was effective for reproducing experimental values. This proposed model will be able to make dynamic framework analysis of a rock- shed accurate and simple.

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