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Concrete Spalling Damage Evaluation to Third-Party for Rational Design and Maintenance of Concrete Structures

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Abstract

Recently, the deterioration of infrastructure becomes obvious in Japan, and also will more obvious in the future. Focusing on the concrete structures, deterioration causes spalling. In Japan, there is a problem of damage to third-party by concrete spalling like the accident of Sanyo Shinkansen in 1999, and the main cause of concrete spalling is steel bar corrosion which is one of the deterioration of concrete caused by chloride attack and carbonation. Hence, the number of concrete spalling will increase in the future, and then it is expected that the damage to third-party caused by concrete spalling will also increase. Therefore, it is essential to evaluate the damage to third-party by concrete spalling for the rational design and maintenance.

In this study, the impact experiment was conducted in order to investigate how each parameter affects the damage to third-party on spalling accident. Concrete specimens which had various mass, surface area and hardness dropped from different heights, and then clashed to some materials. When concrete specimens clashed, the impact force was measured. The obtained data were compared with the damage criteria proposed in the previous research. From this experiment, it is made clear that the maximum impact force is almost proportional to mass of concrete, square root of drop height and negative three-fourth power of surface area. And, the clashed material also affects the maximum impact force. On the other hand, there is little correlation between hardness of concrete and the maximum impact force. From this study, damage to third-party when spalling concrete clashes can be estimated.

1. Introduction

Recently, the deterioration of infrastructures in Japan becomes obvious. In the future, the ratio of infrastructures which have been used for more than 50 years will increase. Therefore, it is important to manage and maintain all of the deteriorated infrastructures. However, it is expected to be severe because of limited budget and labor by rapid population decrease.

Focusing on the concrete structures, they suffer from deterioration by steel bar corrosion with time, and deterioration causes spalling. This fact implies that the number of concrete spalling will increase and also the damage to third-party will increase in the future. Therefore, it is important to evaluate the damage to third-party by spalling. However, few studies about the damage estimation has been reported.

In this paper, the impact experiment was conducted in order to obtain how each parameter of concrete spalling affects damage to third-party. Concrete specimens which have various mass, shape and hardness dropped from different heights and clashed to some materials. When the concrete clashed, the impact force was measured. And, the maximum impact force obtained from the experiment was compared with the human damage criteria proposed by Nahum[1].

2. Outline of experiment

The experiment was conducted in order to make clear how each parameter of spalling concrete affects the damage to third-party. The outline of experiment is shown in Figure 1. Dropped specimens is controlled to clash on specific surface, and load cells measured the impact force. The set parameters of this experiment are mass, surface area and hardness of concrete, drop height of spalling and the clashed material hardness which are thought to affect impact force. Figure 2 shows the example of measurement result. In this experiment, the maximum impact force when clashing was focused on because it is appropriate to evaluate whether third-party is damaged or not[2]. In order to investigate the effect of clashed surface hardness, steel and wood plates were used (Figure 3). Table 1 shows the outline of specimens in this experiment.

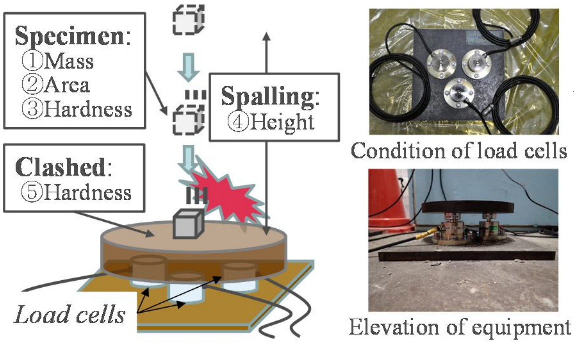

Figure 1: Outline of experiment

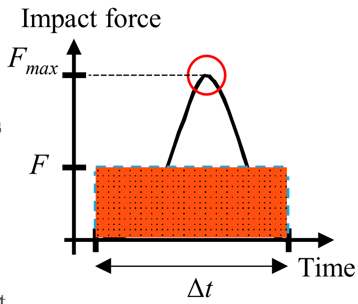

Figure 2: Impact force

Figure 3: Clashed material

Table 1: Outline of specimens

Parameter	*Shape*	*Size (mm)*	*Mass (g)*	*Clased Area (mm^2)*	*Dynamic elastic modulus (GPa)*	*Drop height (m)*	*Clashed material*	*Results of maximum impact force* Average (kN)	Standard deviation (kN)
①Mass	Column	Φ50×100	398	1963	-	1.00	Steel	6.11	1.41
		Φ50×67	264	1963	-	1.00	Steel	3.85	0.94
		Φ50×50	197	1963	-	1.00	Steel	2.79	0.30
		Φ50×33	126	1963	-	1.00	Steel	1.68	0.34
②Area	Prism	40×40×160	559	1600	-	0.50	Steel	7.84	2.11
		50×70×70	555	3500	-	0.50	Steel	4.00	1.28
		50×70×70	555	4900	-	0.50	Steel	3.33	0.42
		40×40×160	559	6400	-	0.50	Steel	2.89	0.54
③Hardness (concrete)	Sphere	Φ40	60	-	29	1.00	Steel	1.87	0.22
		Φ40	60	-	30	1.00	Steel	1.79	0.12
		Φ40	69	-	40	1.00	Steel	2.04	0.11
		Φ40	69	-	43	1.00	Steel	1.98	0.04
④Height	Prism	40×40×160	400	6400	-	0.25	Steel	2.98	0.52
		40×40×160	400	6400	-	0.50	Steel	4.85	1.10
		40×40×160	400	6400	-	1.00	Steel	7.11	0.32
⑤Hardness (the clashed)	Prism	50×70×70	555	4900	-	0.50	Steel	2.61	0.26
		50×70×70	555	4900	-	0.50	cedar	1.62	0.28
		50×70×70	555	4900	-	0.50	walnut	3.29	0.57

3. Results of experiment

The results of this experiment are shown in Figure 4. The impact experiment was conducted 3-5 times for each specimen, and data of these results were averaged. The bars and red lines in the figure show the standard deviation and damage criteria in terms of skull collapse proposed by Nahum (2.45kN)[1]. Dot lines show the regression curve drawn based on the obtained data. As shown in these graphs, mass, square root of height and negative three-fourth power of area were almost proportional to the maximum impact force (Figure 4 ①, ②, ④). And, the clashed material also affected maximum impact force (Figure 4 ⑤). On the other hand, there was little correlation between concrete's elastic modulus and the maximum impact force (Figure 4 ③).

4. Discussion

From the result of experiment, the following equation was obtained.

$$F_{max} \propto M \times h^{1/2} \times A^{-3/4} \tag{1}$$

Then, F_{max} means the maximum impact force when clashing, M means mass of concrete specimens, h means drop height and A means clashed surface area. On the other hand, elastic modulus (hardness) of concrete does not affect the maximum impact force. It is made clear that the effect of hardness of concrete will be ignored when the spalling concrete clashes.

Red lines: damage criteria of skull's collapse proposed by Nahum / **Dot lines**: regression line

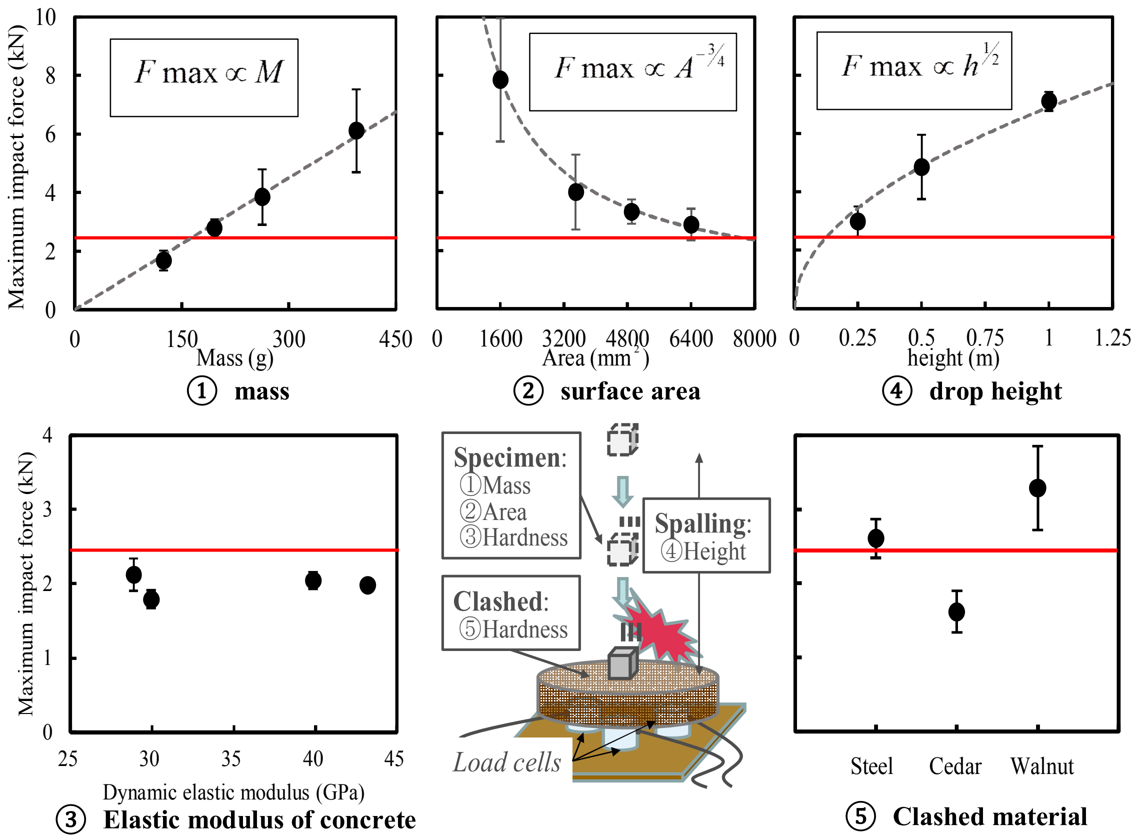

Figure 4: Results of experiment for each parameter

Focusing on the material which are clashed, the maximum impact force of steel is bigger than that of cedar, and smaller than that of walnut. In contrast, the elastic modulus of both wood material is obviously smaller that of steel. It seems that there is no apparent relationship between elastic modulus of the clashed material and the maximum impact force. The difference of this result may be explained as follows.

The impulse is expressed by the following equation by considering objective's speed before and after clashing.

$$I = \vec{F} \cdot \Delta t = M(\vec{v}^{'} - \vec{v}) \tag{2}$$

Then, I means the impulse when clashing, $\vec{F}$ means the impact force, Δt means duration of clashing and $\vec{v}^{'}$ and $\vec{v}$ means speed of specimens after and before clashing. If the specimen bounds after clashing, so $\vec{v}^{'}$ is more than zero, the impulse is bigger than the impulse when the specimen does not bound. In the experiment, the bound of specimens was observed in cases of the steel and walnut material, however, not observed in case of the cedar material. The fact shows that the maximum impact force when cedar was used is less than the maximum impact force when walnut or steel is used. In order to verify the above hypothesis, the speed after clashing will be measured for each material in the future.

5. Conclusion

From the impact experiment, it is made clear that mass, square root of height and negative three-fourth power of area are almost proportional to the maximum impact force, and the clashed material also affects the maximum impact force. On the other hand, there is little correlation between concrete's elastic modulus and maximum impact force.

6. Future work

Now, the authors are constructing the system to predict when and how big concrete spalls and how often spalling concrete clashes to third-party. From this study, it is made clear how each parameter of concrete spalling affects the maximum impact force, and the damage to third-party. In the future, the knowledge obtained from this study will introduce the above system, and the system to evaluate the damage risk to third-party by concrete spalling will be developed.

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8. References

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