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Current impact problems and progress in civil engineering in Japan

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ABSTRACT

This paper presents the current impact problems concerning the civil engineering structures in which I have been recently investigated. That is, (1) the prototype impact test and analysis of prestressed concrete rock-shed structures in the mountainous road by falling rocks, (2) the model tests and the computational approach for the steel check dams by the huge rocks in the debris flow.

INTRODUCTION

The members of the subcommittee of impact problems, committee of the structural engineering, Japan Society of Civil Engineering (JSCE) have been investigated the rational method on the impact resistant design of the rock-shed structure, the check dams and the protective structures against the aircraft, car and ship crash. Current impact problems for the civil engineering structures in Japan are listed as follows :

(a) The impact onto the rock-shed structure in the mountainous road or railway by falling rocks.

(b) The impact onto the concrete or steel check dams (so called Sabo dams) by huge rocks in the debris flow or avalanches.

(c) The impact onto the guardfense or handrail by a car.

(d) The impact onto the bridge pier or harbour facilities by a ship.

(e) The impact onto the nuclear power plant facilities by a projectile including an aircraft.

(f) The impact onto the protective structures by explosions of gunpowder or gas.

(g) The failure of buried pipes by impact external force due to strong earthquake.

This paper presents current impact problems concerning the above items (a), (b) in which I have been recently investigated. That is, (1) the prototype impact test and analysis of the prestressed concrete rock-shed structure, (2) the model impact test and the computational approach for the steel check dams.
The feature of impact problems on the civil engineering structures is in general to be the low speed (e.g. $V = 1 \sim 20m/sec$) and the heavy weight of impacting body (e.g. $W = 1tf \sim 10tf$). Therefore, the elastic-plastic deformation of structure member by impact energy seems to be more predominant than the stress wave in the impact phenomenon.

IMPACT PROBLEM OF ROCK-SHED STRUCTURE

(1) Object of this research

On July 16, 1989 the collapse accident of the prestressed concrete (PC) rock-shed structure has occurred at Echizen seashore of Fukui Prefecture and 15 people in the microbus were died by the structural collapse of rock-shed by falling rocks [1]. Taking this opportunity the safety assessment of rock-shed structure has become more important from the viewpoint of load carrying capacity. In general the rock-shed structures have been constructed at mountainous roads as the safety facilities against falling rocks. The PC rock-shed is currently designed by the allowable stress design method by elastic analysis in which the impact load is replaced into static load [2]. However, little attempts have been made so far on the load carrying capacity or the safety assessment of he PC rock-shed from the viewpoint of the structural failure under impact loading [3,4]. Herein, the impact test was performed by dropping the weight onto the prototype PC rock-shed in order to examine the load carrying capacity [5]. Then, the impact response analysis is performed by connecting the distinct element method (DEM) [6] with rigid body spring model (RBSM) and is compared with the experimental results.

(2) Impact test of PC rock-shed

Figure 1 shows the new specimen of the prototype PC rock-shed which is designed at the design load level ($P = 40tf$) of the rock weight $W = 1tf (= 9.8kN)$ and the dropping height $H = 5m$ [5]. The specimen has columns with height $3.0m$ and the girder with the width $1.5m$ and the length $9.8m$. The sand cushion $90cm$ is laid on the girder in order to absorb the impact load.
The measurement items are as follows : the acceleration of the weight ; the vertical and horizontal reaction forces at the supporting point of the No.3 girder ; the displacements at the center of the girders. The test results are as follows:
(a) The crack was occurred at the lower side of the No.3 girder in the load level ($P = 130tf$) of [$W = 3tf$ and $H = 10m$] .

(b) The No.3 girder was failed at the collapse load level ($P_c = 371tf$ as the maximum acceleration is $74.2g$) of $[W = 5tf\ ,\ H = 20m]$ and the collapse mechanism was formed as the beam mechanism.
(c) The load carrying capacity of PC rock-shed is considered from the two points of view. One is the collapse load ($P_c = 371tf$) which is about 9 times of the design load ($P = 40tf$) and the other is the energy absorption capacity $[W = 5tf\ ,\ H = 20m]$ which is about 20 times of the design load level $[W = 1tf\ ,\ H = 5m]$.

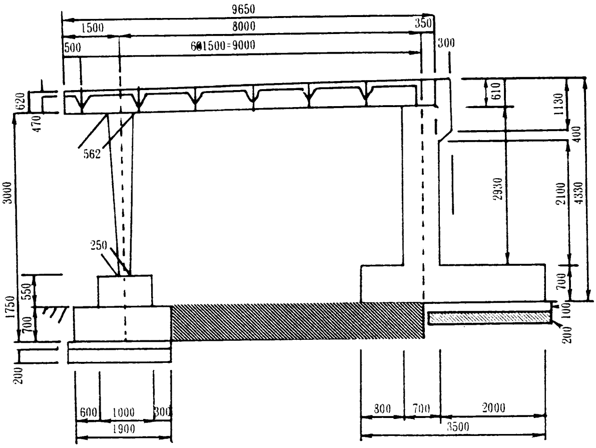

Figure 1 : Prototype PC rock-shed

(3) Impact response analysis
The impact response analysis is developed by combining the distinct element method (DEM) with the rigid body spring model (RBSM) in order to take into account for the interaction between the rock-shed and sand cushion [6].
Herein, the PC rock-shed is modelled into the circular rigid PC beam elements and sand cushion is transformed into the circular rigid sand elements with normal and tangential spring and dashpots, respectively, as shown in Figure 2. In order to examine the load carrying capacity of the PC rock-shed, the impact response analysis has been performed by increasing the weight W and the height H.
The computational results of impact response analysis are found to be as shown in Table 1. It is found that the load carrying capacity of this shed is $[W = 5tf\ ,\ H = 15m]$ which are conservative values compared with the experimental results $[W = 5tf\ ,\ H = 20m]$. This may be the reason why the failure of PC rock-shed has been defined as the section failure of PC members [7] in this analysis. Figure 3 shows the yielding process of this shed under $[W = 5tf\ ,\ H = 15m]$. It is found that the impact point of the No.3 girder has failed at the displacement $10cm$ which was almost the same as the test result.

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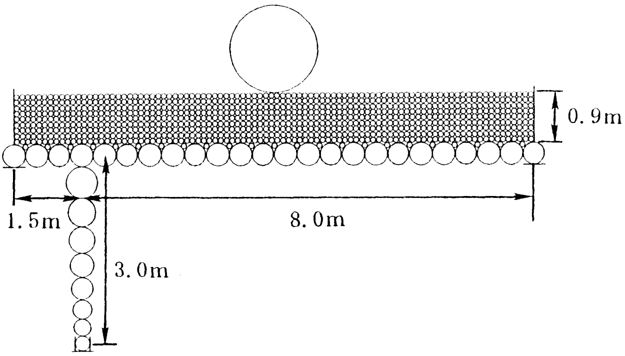

Figure 2 : Analytical model

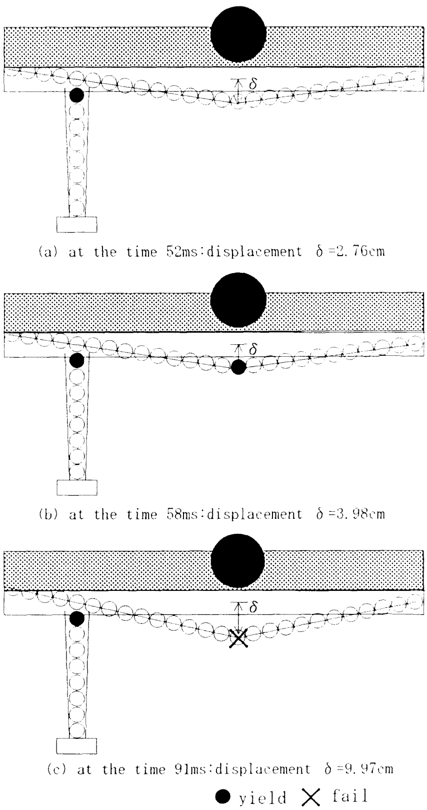

Figure 3 : Yielding process of PC rock-shed
($W = 5tf, H = 15m$)

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Table 1 : Computational results of PC rock-shed

Weight W(tf)	Height H(m)	Safety assessment of PC rock shed response curvature ultimate curvature
3.0	20.0	$0.139 \times 10^{-3} \leq 0.192 \times 10^{-3}$ Safe
5.0	10.0	$0.142 \times 10^{-3} \leq 0.192 \times 10^{-3}$ Safe
	15.0	$0.192 \times 10^{-3} \leq 0.192 \times 10^{-3}$ Fail

IMPACT PROBLEM ON STEEL CHECK DAM UNDER DEBRIS FLOW

Recently many steel check dams (Sabo dams) have been constructed in many mountainous places as the counter-measure structures against the debris flow from the viewpoint of rapid construction and easy maintenance [8]. Photo 1 shows the B-type slit dam which is made by steel pipe members. This type of structure can prevent the huge rocks in the debris flow by the absorption energies due to both local and global deformations. At first, the impact test of the fixed steel pipe beam [9] is performed in order to evaluate the local and global absorption energies. Secondly, the impact response deformations are calculated by an analytical approach in which the local deformation is assumed as the shape of a gourd [10]. Finally, the computational results are compared with the experimental results.

The impact test is performed by dropping the weight until the failure is occurred at the beam. The impact load is obtained by multiplying the mass of the weight by the acceleration. The total displacement which is the sum of local and global displacements as shown in Figure 4. The global (beam) displacement can be measured by the optical displacement sensor, and, therefore, the local displacement is obtained by subtracting the global displacement from the total one.

Figure 5 shows the load - total displacement relation obtained by the impact test. It is found that the load increases but the total displacement reduces as the weight dropping time grows in number.

Figures 6 and 7 show the load - local displacement relation and the load - global (beam) displacement relation, respectively. It is observed that the local displacement reduces, but the global displacement increases as the number of weight dropping times increases. Therefore, it is confirmed that the mode of the impact response transfers from the local response to the global one. In general the velocity of debris flow is said to be about the maximum $10m/sec$ and is usually $4 \sim 6m/sec$, but the weight of huge rock in debris flow is about $1tonf \sim 10tonf$. Herein, the impact problem may be treated as the quasi-static rigid-plastic analysis [10] is adopted in order to examine the impact response of steel pipe beam.

The analysis procedure is performed by giving the increment local deformation of the dented cross section assuming as the shape of a gourd shown in Figure 4 and is terminated at when the sum of local and global absorption energies is equal to the kinetic energy E of the weight.

The load - total displacement relation calculated by the analysis is good

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agreement with the experimental result as shown in Figure 5. Therefore, the impact absorption energy by this analysis coincides with the experimental one.
Figure 8 shows the failure deformation process computed by the guasi-static rigid-plastic analysis. The maximum response displacement is good agreement with the experimental one as shown in Photo 2. Therefore, this approach will be also applied to the estimation of the impact response of actual steel pipe members used in the steel check dams.

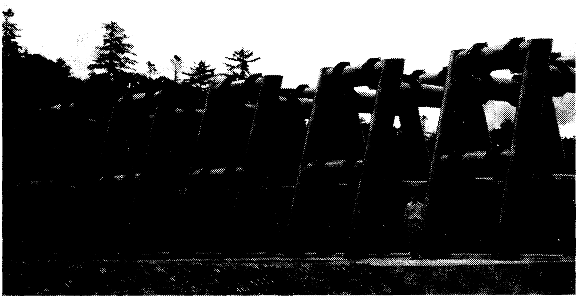

Photo 1 : B-type slit dam

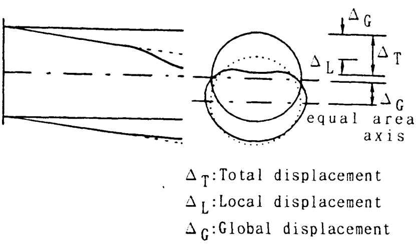

Figure 4 : Deformation profile

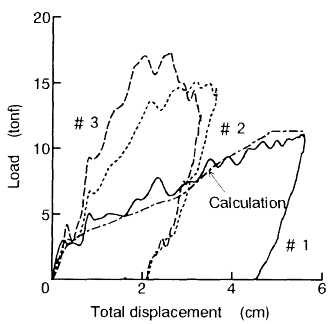

Figure 5 : Load ~ total displacement relation

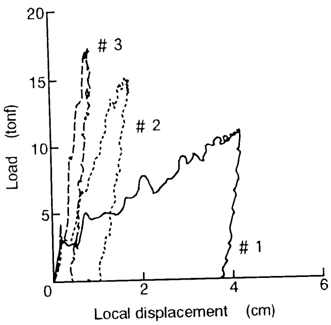

Figure 6 : Load ~ local displacement relation

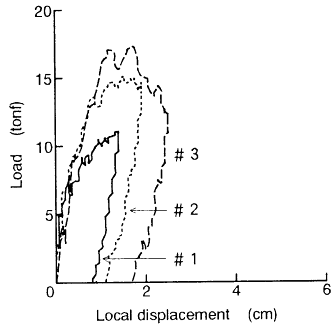

Figure 7 : Load ~ global displacement relation

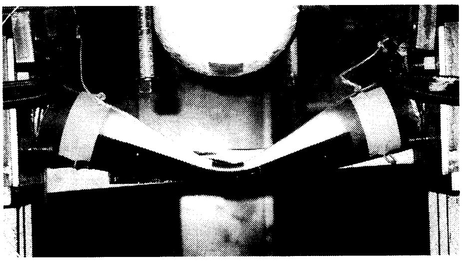

Photo 2 : Failure mode

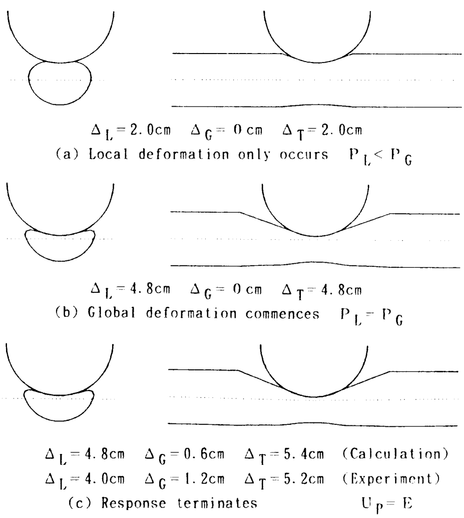

Figure 8 : Failure mode

CONCLUSIONS

The two impact problems on rock-shed and steel check dam have been mainly introduced by experimental and computational approaches. In general, the studies on impact problems in civil engineering field in Japan are very slow comparing with the studies on the earthquake resistant problems. Especially, it is quickly hoped to establish the safety assessment of the rock-shed and check dam structures from the viewpoint of energy criterion. For instance, how much the sand-cushion can absorb the impact energy as the impact absorption system ? That is, it is necessary to determine the dynamic ultimate limit states of the rock-shed and check dam structures against the huge rocks. Furthermore, it is required to establish the experimental approach, for example, the standard impact loading test, the measurement method of impact force and the safety assessment method of the impact resistance, e.g., strength or deformabiliy or energy absorption, etc.. It should be also required to develop the computational approach from the viewpoints of the quantitative analysis as well as the qualitative analysis.

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