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DAMAGE OF STEEL OPEN SABO DAMS BY ROCK IMPACT

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Abstract. *There have been recent damaged examples of steel open-type Sabo dams (hereafter, steel open dams) which illustrate protective structures against debris flow. This was caused due to large rocks carried in the debris flow resulted from torrential rainfall of abnormal weather. This paper presents a computational approach to investigate the damage of a steel open dam by a fluid load and rock impact in the debris flow. First, the field survey after disaster was performed in order to examine the damage of steel open dams and the remaining rocks. Second, the impact FEM analysis of a steel open dam against a large fluid load and huge rocks was conducted by using the software of ANSYS AUTODYN.*

Keywords: Steel open Sabo dam, rock impact, impact FEM analysis, ANSYS AUTODYN

1 INTRODUCTION

In order to prevent debris flow and sediment-related disasters, many steel open dams have been constructed in Japan, as shown in Figure 1. However, a steel open dam has partially collapsed due to rocks in the debris flow, as shown in Figure 2. These disasters may have resulted due to torrential downpour as a result of unusual weather conditions [1, 2] .

Figure 1: Steel open dam trapped rocks in debris flow

Figure 2: Steel open dam was partially collpased by large rocks

A steel open dam is composed of steel pipe components, which usually allow water, soil and small pieces of gravel to flow downstream through gaps in the steel structure. However, it functions to block rocks and woody debris during debris flow. In Japan, the design guidelines for Sabo dams were revised such that a steel open dam should be basically constructed as a countermeasure against debris flow and woody debris.

Many studies on the damage the concrete dam against the impulsive fluid load or impacting rocks have been investigated thus far [3-9]. As for the studies of steel open dams, the trapping mechanism have been mainly conducted [10,11]. However, the damage of steel open dam against fluid load or rock imapct has not been sufficiently examined so far.

To this end, this paper presents a computational approach relevant to the failure mechanism of a steel open dam, in order to examine the effects of the impulsive fluid load and the size and the velocity of a rock in debris flow.

First, the site survey after disaster was performed in order to investigate the size and velocity of rocks and examine the failure mechanism of a steel open dam at Nagiso, Nagano Prefecture,Japan on July 2014[12,13] .

Second, an impact FEM analysis was conducted to examine the damage behavior of a steel open dam against impulsive fluid load and impacting rocks in the debris flow by using the software of the ANSYS AUTODYN [14,15].

2 FIELD SURVEY

After the debris flow disaster on July 2014, the site field survey was conducted to investigate the trapping mechanism of steel open dams and the size and velocity of rocks, as shown in Figures1-5 [12,13].

Figure 1 illustrates an actual trapping case of a steel open dam against abnormally large rocks (diameters greater than 3m). Figure 2 shows a further example in which the upper part of the dam experienced partial collapse, although this dam was able to trap large rocks.

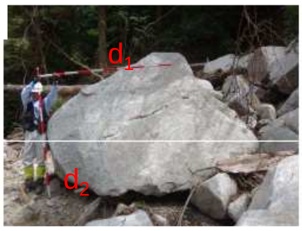
Figure 3 shows many rocks found downstream after debris flow at Nagiso. Figure 4 illustrates the largest rock with a width of 10m and a long of 3.5m and, therefore, an average diameter of 6.7m. Therefore, it is necessary to locate abnormally large rocks in the field survey prior to the design process, as shown in Figure 5.

Figure 3: Rocks found at downstream

Figure 4: The largest rock with diameter of 6.7m

(a) Point A: D=(d1+d2)/2=375cm

(b) Point B: D=(d1+d2)/2=335cm



(c) Point C: D=(d1+d2)/2=265cm

(d) Point D: D=(d1+d2)/2=450cm

Figure 5: Measurement of rock size

3 IMPACT FEM ANALYSIS

Following this, it is necessary to conduct an impact FEM analysis against the large fluid load and huge rocks in order to confirm the integrity of a steel open dam, as shown in Figure 6. A steel open dam model with the height of 8m and the width of 5.2m which was connected by the joints between the thick pipe of 508mm with the thin pipe 318mm or joints between thick pipes is shown in Figures 6 and 7. The properties of steel pipe are the density of 7.85t/m^3, Young's modulus of 206GPa, Poisson's ratio of 0.3, yield stress of 315Mpa and tensile strength of 593Mpa. The foots of pipes were fixed into the footing. Pipe diamenter and thickness were modeled as shell elements.

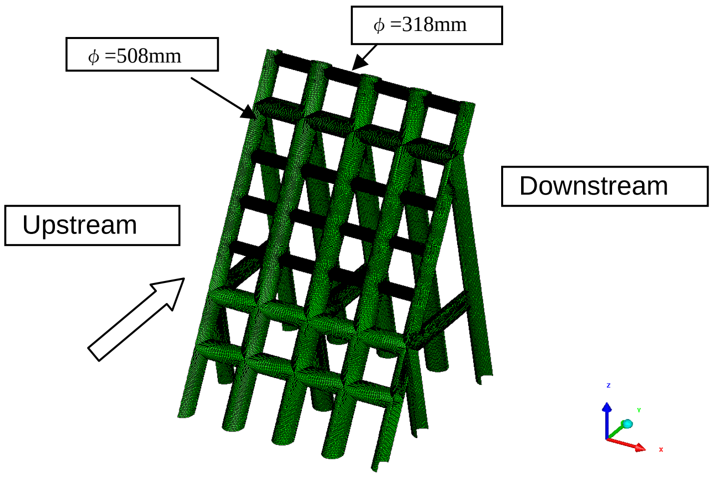
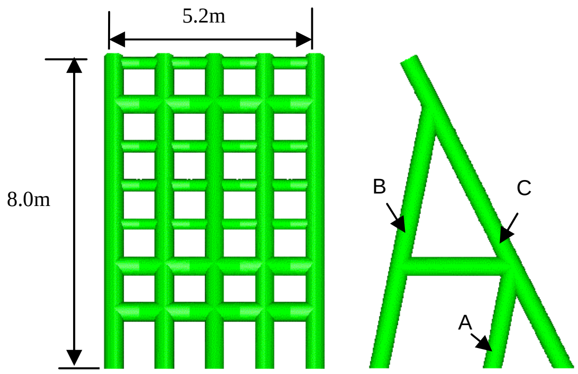


Figure 6: Steel open dam model (3-dimennsion)

3.1 Fluid load

A FEM impact analysis was conducted using the software of ANSYS AUTODYN [14,15] to examine the impact response against large fluid load F=583.5kN/m with velocity of 8.45m/s which was found by the extreme conditions of the stable analysis, as shown in Figure 8.



(a) front (b) side

Figure7: Steel open dam model (2-dimension)

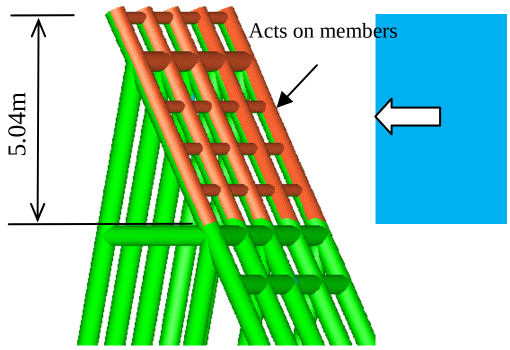
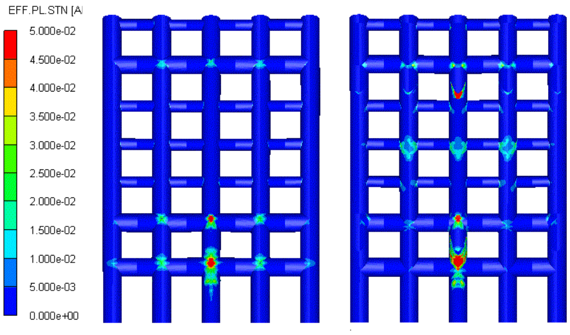


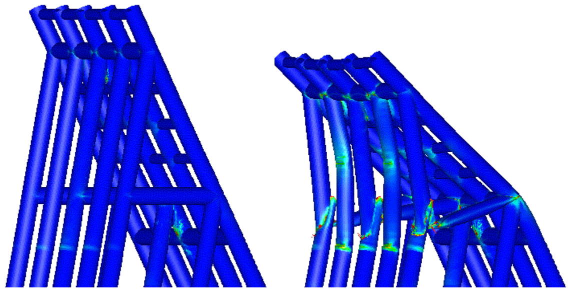
Figure 8: Fluid load acts on dam

The computational result shows that the steel open dam was only damaged due to flexural action in which the palstic strains occurred at the upstream and downstream, as shown in Figure 9. Figure10 (a) shows the final deformation profiles which was not so damaged at F=583.5kN/m which was the stable limit load of structure, but Figure10 (b) illustrates the severely deformation profile at F=722.9kN/m which was the ultimate deformable limit load of the structure. Therefore, it was confirmed that this steel open dam can resist until the ultimate deformable limit fluid load of 722.9 kN/m. Figure 11 represents the pipe reaction-time relation responded by fluid load of F=583.5kN/m. It was found that the reactions of pipes A and B were pushed, but the pipe C was pulled at about 3000kN, respectively. Therefore, it should be noted that the footing strength has to be resisted more than 3000kN.



(a) upstream (b) downstream

Figure 9: Plastic strains by fluid load of F=583.5kN/m



(a) F=583.5kN/m (b) F=722.9kN/m

Figure10: Final deformations by fluid loads

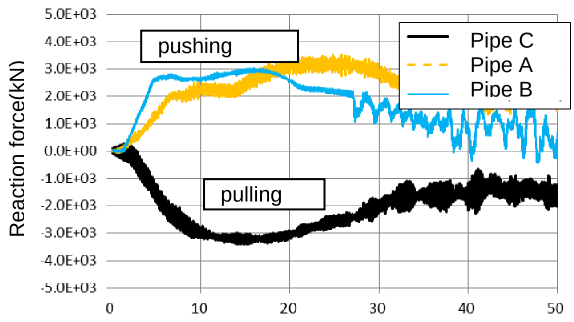


Figure11: Reaction force-time relation by fluid load

3.2 **Rock impact**

The rock impact FEM analysis was performed against two rocks of the Cases 1 and 2, as shown in Table 1. These rocks dimensions were determined by the field survey.

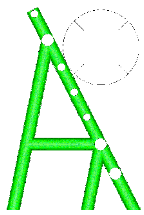
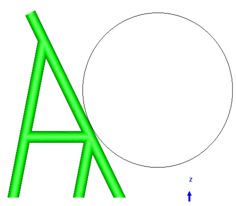
Case 1	Case 2
	
Rock diameter =3.0m	Rock diameter =6.7m
Rock mass=36.7 ton	Rock mass=409ton (11 times larger than Case1)
Rock velocity=8.45m/sec	Rock velocity=9.7m/sec
Rock kinetic energy=1.3MJ	Rock kinetic energy=19.2MJ (15 times larger than Case1)

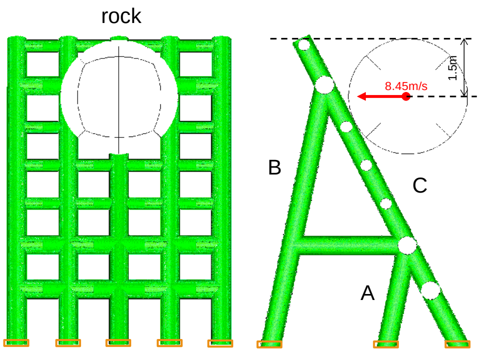
Table 1: Comparison of rocks of Cases 1 and 2

3.2.1 CASE 1: Rock with diameter of 3.0m and velocity of 8.45m/s

Figure 12 shows a case 1 in which a steel open dam is struck by a rock with a diameter of 3.0m and a velocity of 8.45m/s. A rock is assumend as an elastic body with the density of 2.60t/m^3 , the Young's modulus of 49Gpa and Poisson's ratio of 0.23.

Figure 13 illustrates the local deformation of the pipe members at the impact point. It was obviously recgonized that the rock impact energy was only absorbed by the limited pipe members at the impact point and the steel open dam was not entirely collapsed against a rock impact with diameter of 3.0m and velosity of 8.45m/s, as shown in Figures 14 and 15.

Figure 14 (a) shows the damage process of the front of the steel open dam against Case 1. It was found that large plastic strains were only limited at the impact point. Figure 14 (b) is the damage of the back side of the dam in which the plastic strains were occurred at the joints between diagonal members and columns.



(a) front (b)side

Figure 12: Rock impact of Case 1

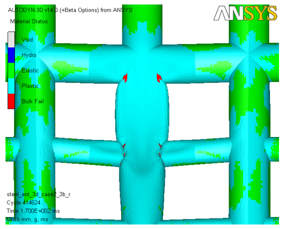
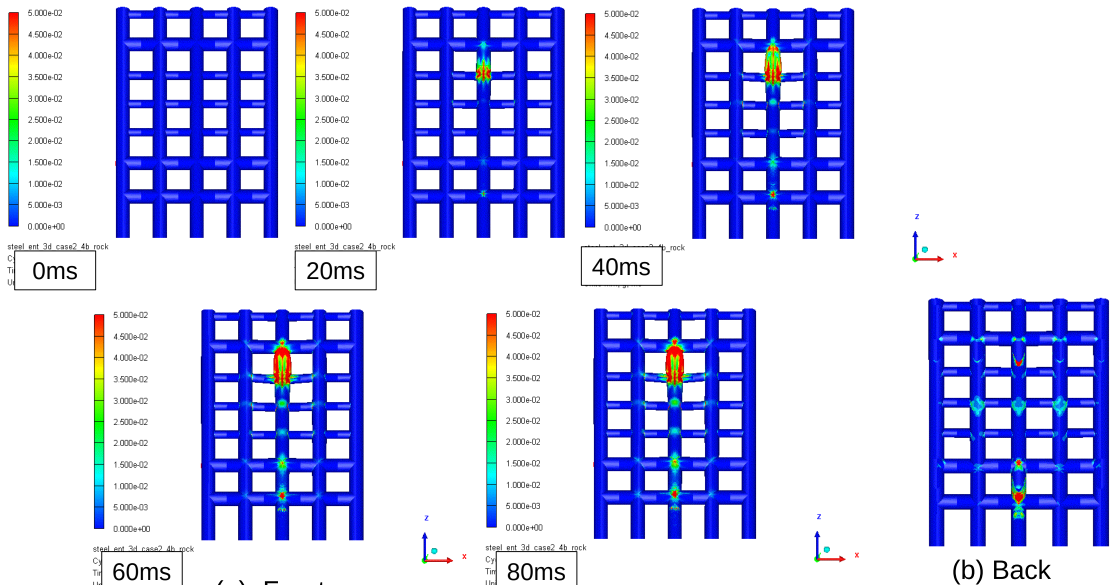


Figure13: Local deformation of front struck by rock impact of Case1



(a) Front (b) Back

Figure 14: Damage process (front and back) of steel open dam against Case 1

Figure 15 illustrates the damage process of the side of the steel open dam against Case 1. It was recognized that the damage was only limited at the impact point at the time t=30-50ms, but it propagated to the joint D between the diagonal member B and cross beam E at the time 70-100ms. The maximum plastic strain (0.05 (5%)) has occurred at the impact point and the joint D at the time 70-100ms.

Figure 16 shows the relationship between reaction of pipe and time by a rock impact of Case 1. It is interested to note that the reaction of pipe A (1000kN) was smaller the one of fluid load (3000kN), because the impacting rock energy was only absorbed by the local deformation of the pipe at the impact point, and, as such, the impacting force did not so much transmit to the pipe A near the footing of the structure.

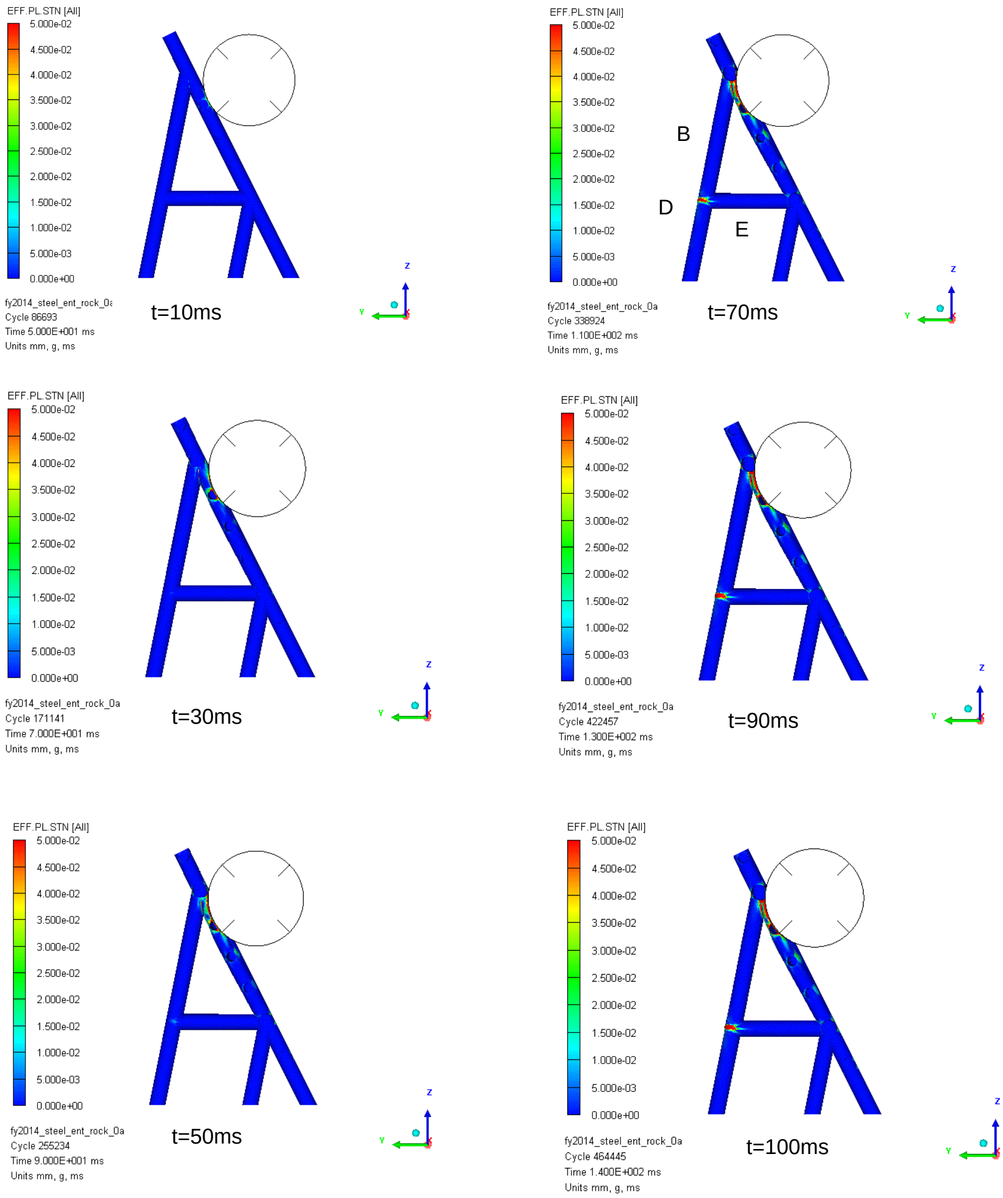


Figure 15: Damage process (side) of steel open dam against Case 1

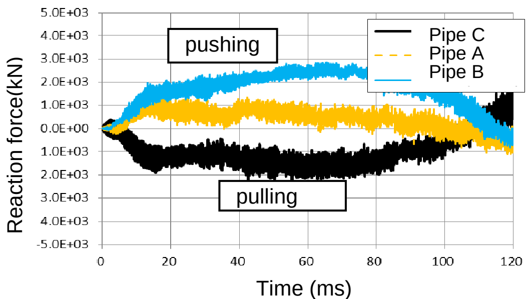


Figure 16: Reaction force-time relation of Case 1

3.3 Case 2: Rock with diameter of 6.7m and velocity of 9.7m/s

The FEM impact analysis was also conducted for a steel open dam against Case 2 : a large rock with diameter of 6.7m and velocity of 9.7m/s, which were measured by the site field survey. Figure 17 shows the deformation process (side) of the steel open dam against Case 2. The structure was not completely collapsed against Case 2, although the large deformations occurred at the time 120-180ms.

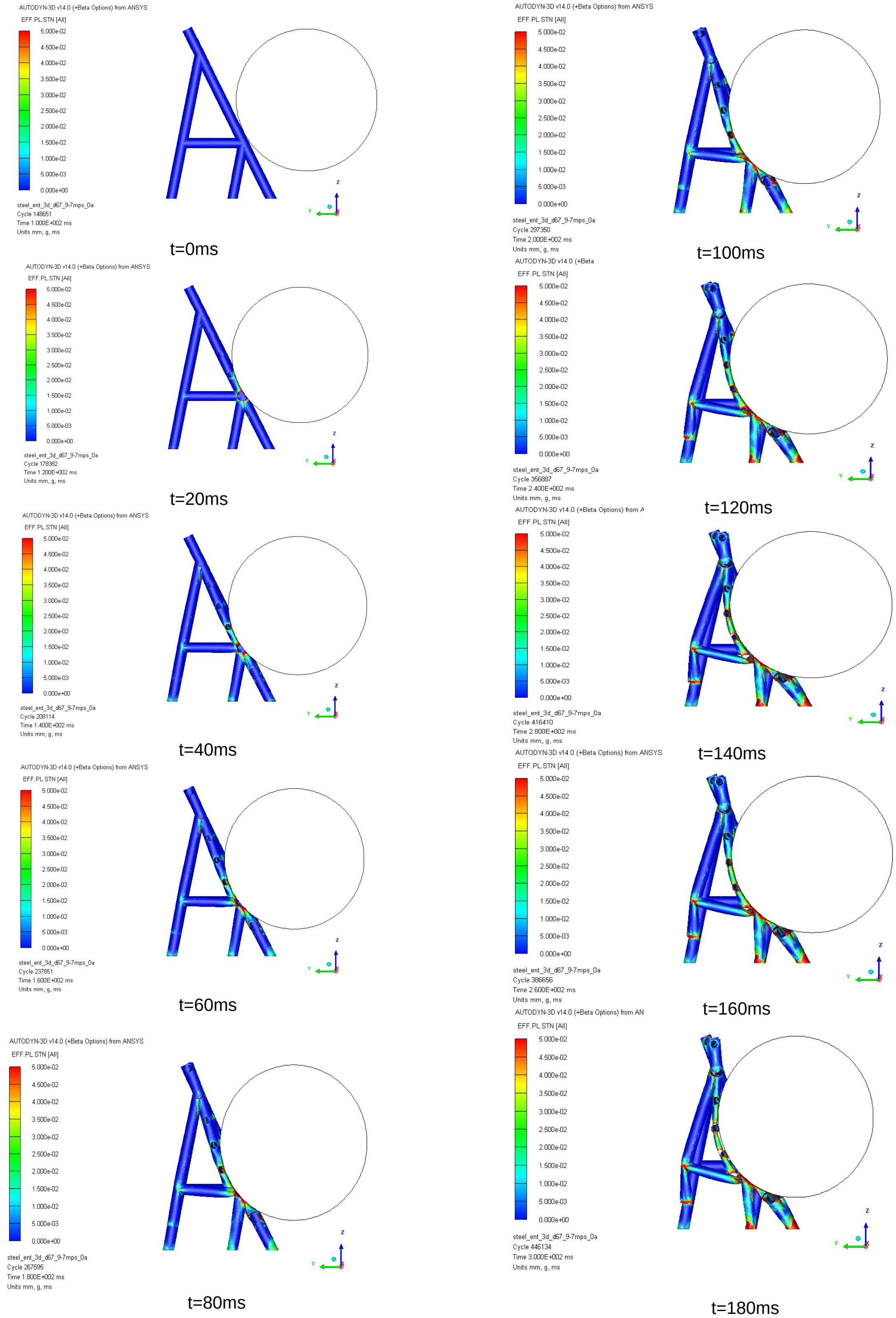


Figure 17: Deformation process (side) of steel open dam against Case 2

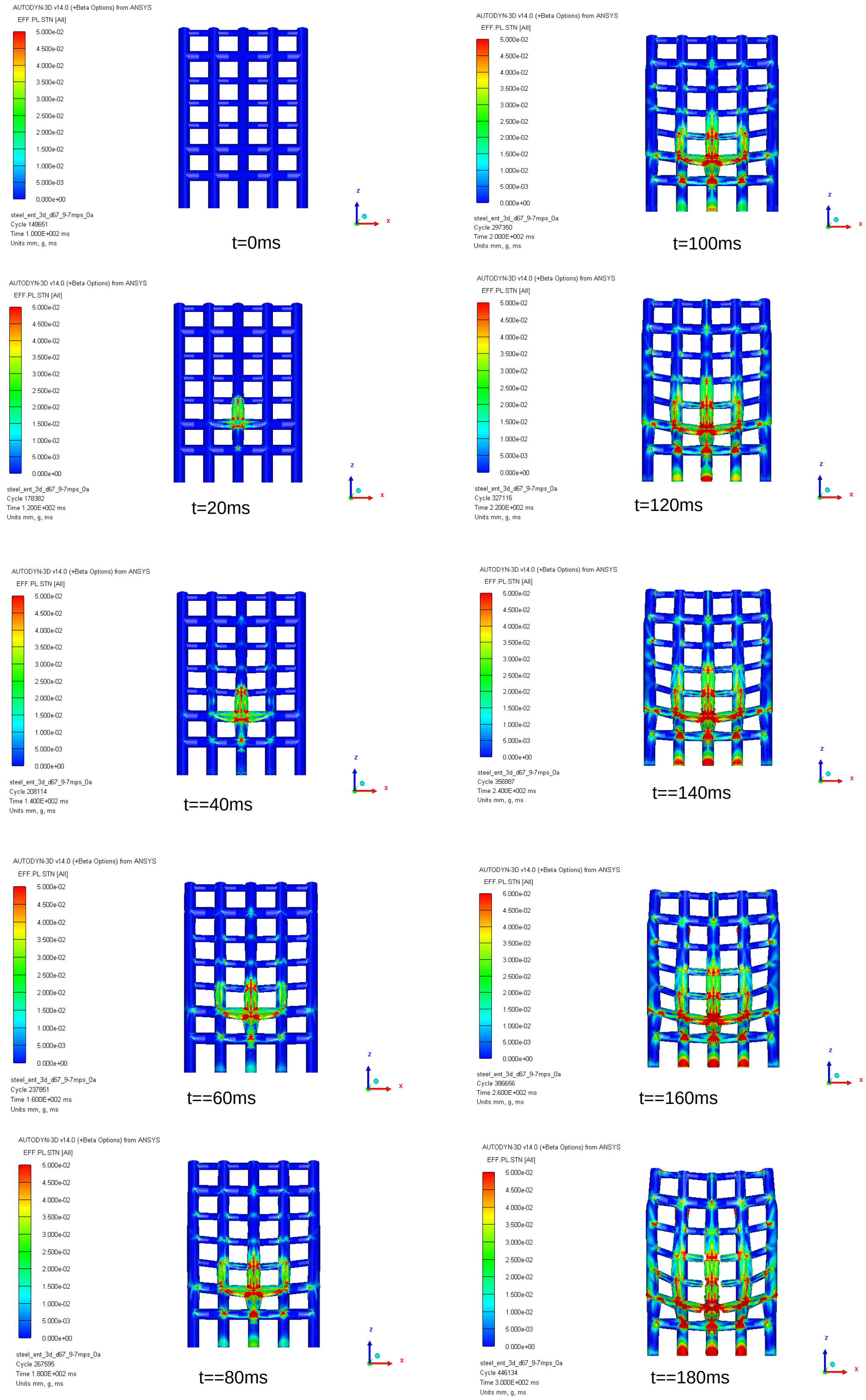
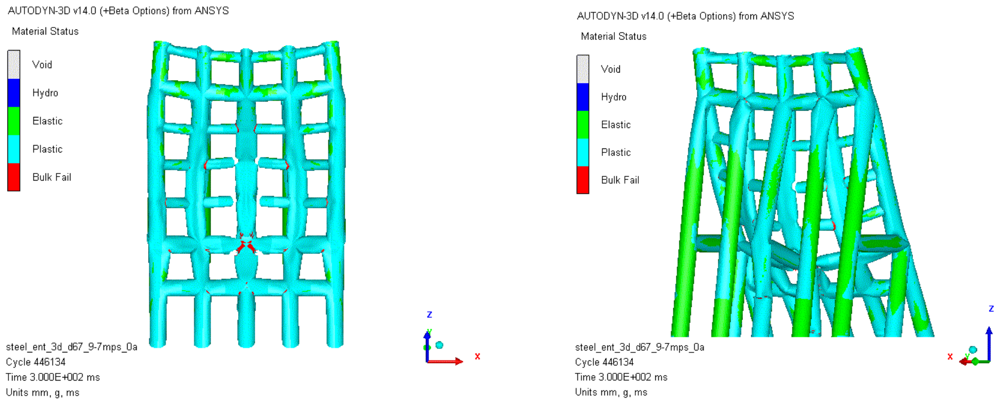


Figure 18: Damage process (front) of steel open dam against Case 2

Figure 18 shows the damage process (front) of steel open dam against a rock impact of Case 2. It was found that the first plastic strain occurred at the joint between front column and diagonal members at the time t=20-40ms, and it propagates to the rear diagonal member through the cross beam at the time t=60-80ms. It was also recognized that the impacting rock energy was absorbed by the global deformation of the dam as well as the local deformation of a pipe at the time t=120ms-200ms, as shown in Figure 18 (d)-(f).

Figure 19 (a) and (b) represent the final deformation profiles at the front view from upstream and the diagonal view from downstream against Case 2, respectively. It was judged that the joint between the center column and the diagonal member was severely damaged, as shown in Figure 19 (a) and the global buckling occurred at the diagonal member of the center, as shown in Figure 19 (b).



(a) Front view from upstream (b) Diagonal view from downstream

Figure 19: Final deformation profile by rock impact of Case 2

3.4 Comparison with the concrete dam against rock impact of Case1

The concrete dam as shown in Figure 20 was analyzed [9] against the same rock impact condition of Case 1 to compare with the steel open dam. Figure 21 shows the computational result of concrete dam against rock impact of Case 1 [9]. It was found that the shearing failure and the tensile failure occurred at the whole body and at the bottom, respectively, as shown in Figure 21. Therefore, the concrete dam was completely collapsed and overturned, while the steel open dam was only damaged at the impact points, as shown in Figures 14 and 15.

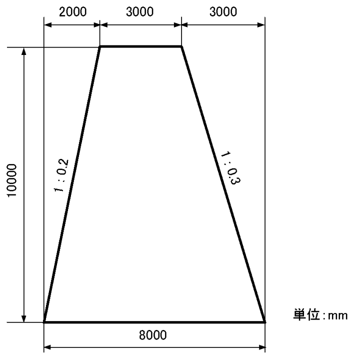


Figure 20: Concrete dam model

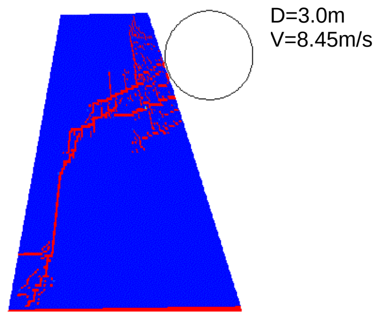


Figure 21: Collapse mode of concrete dam against Case 1

4. CONCLUSIONS

The following conclusions were obtained from this study.

(1) After the results of site field survey, most of rocks were less than the average diameter of 3.0m and the velocity of 8.45m (Case 1), but the largest rock was found with average diameter of 6.7m and the velocity of 9.7m/s (Case 2).

(2) From the results of computation against the limit fluid load, the steel open dam was not so damaged, although the pulling force of pipe A and the pushing force of pipes B and C were large (3000kN/m), respectively.
(3) From the computational results against rock impact of Case 1, the damage of the steel open dam was only limited at the impact points and the structure was not collapsed.
(4) As for the Case 2, the structure was not collapsed with damage of the buckling of diagonal column at the center and large plastic strains at center members, nevertheless the kinetic energy was 15 times larger than the Case 1 as shown in Table 1,
(5) On the contrary, the concrete dam was completely collapsed as the same rock impact as Case 2.

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