Impulsive Behavior of Check Dam under Debris Flow

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Abstract

This paper presents a computational approach on the impulsive behavior of concrete check dam under debris flow. Currently the design of concrete check dam under debris flow is performed by applying two different loads. One is the fluid force in which the dynamic pressure due to jet stream is replaced with the static load, and the other is the impact load by collision of rock to the concrete dam. In this paper, the static behavior of concrete check dam under static fluid force was first found by a FEM analysis. Second, the impulsive behavior of check dam was investigated by considering dynamic fluid force with the rise time to the maximum load as a parameter. Third, the impact behavior of concrete check dam under collision of rock is examined by an impact elastic-plastic FEM analysis.

Keywords: check dam, fluid force, collision of rock, impulsive behavior, rise time

1. Introduction

More than one thousand sediment-related disasters per year have been occurred in the past five years in Japan. These disasters may be due to torrential rainfalls by unusual weather based on the mild temperature of the earth. The sediment-related disasters consist of debris flow, landslide and slope failure. In order to prevent the disasters due to debris flow, many concrete and steel check dams have been constructed in the mountainous area in Japan.

The debris flow is divided into three types〔1〕; i.e., the gravel cobble flow including large rocks, mudflow or turbulent flow including volcanic debris and immature debris flow without gravel. Currently the design of concrete check dams under debris flow is performed by two different loads〔2〕,〔3〕. One is the fluid force in which the dynamic pressure due to jet stream is replaced with the static load, and the other is the impact load by collision of rock to the concrete dam. Many studies have been performed for the investigation of impact load due to debris flow and wave breaking〔4〕,〔5〕,〔6〕,〔7〕,〔8〕,〔9〕. However, the impulsive behavior of concrete check dam has not been investigated by considering the fluid force as an impulsive load. To this end, a FEM analysis is used in order to examine the cause of disasters of concrete check dam wing collapsed by large-scaled debris flow from the impulsive point of view.

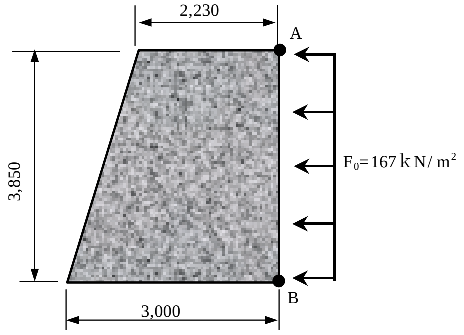


Fig.1 Concrete check dam wing under fluid force

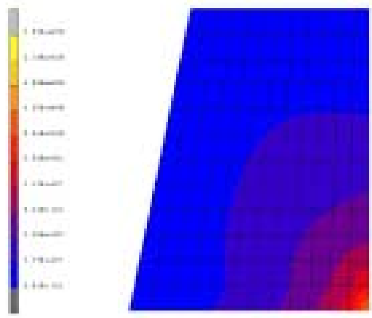


Fig.2 Max. principal stress by static analysis

First, a static FEM analysis is performed in order to confirm the validity of the method and to find the maximum static stress and deformation. Second, a dynamic FEM analysis is executed to investigate the effect of the rise time ratio to the maximum load on the dynamic behavior of check dam wing under only fluid force. Third, an impact FEM analysis is carried out to examine the effect of collision of rock on the dynamic behavior of concrete check dam wing.

2. Impulsive Behavior under Fluid Force

Many concrete check dams have been damaged by disasters due to debris flow. On July 1997, a concrete check dam [10] was collapsed by debris flow based on torrential rainfalls in Kagoshima, Japan and 21 people were killed and 13 people were injured. In order to investigate the cause of this disaster, static and dynamic FEM analyses were herein carried out for the concrete check dam wing by giving the estimated fluid force and collision of a rock.

2.1 Static analysis

The concrete check dam wing collapsed by large-scaled debris flow is first analyzed by being subjected to the static fluid force with equivalent distributed load (167 kN/m^2) which corresponds to flow velocity of 10m/sec as shown in Fig. 1. Herein, a two dimensional FEM analysis with plane rectangular elements is used and the bottom line of dam wing is fixed. Herein, the material properties of concrete are used as compressive strength $f_c' = 20$N/mm^2 and elastic modulus E=2x10^{4}N/mm^2.

As the computational results by static analysis, it is found that the horizontal displacement of point A was only 0.2mm and the maximum principle stress distribution was found as shown in Fig.2 in which the maximum tensile stress was about 1.4N/mm^2 at the bottom of wing (point B in Fig.1). If the limit tensile stress is assumed as about 2.0 N/mm^2, the maximum stress is estimated as 0.7 times of the limit stress. This fact means that the dam wing is not damaged by a static analysis using fluid force with velocity of 10m/sec. In other words, the dam wing may be damaged by the flow velocity of 14-15m/sec from the static point of view.

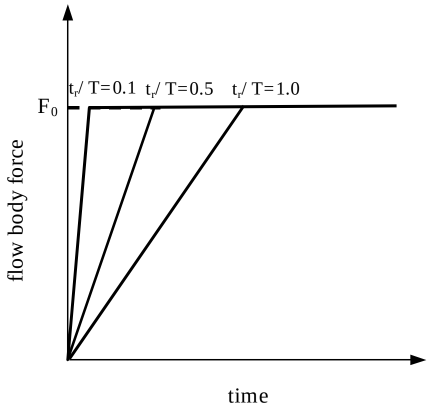


Fig.3 Fluid force – time relation

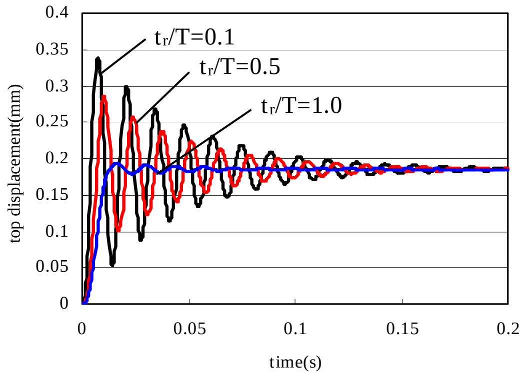


Fig.4 Top displacement—time relation

2.2 Dynamic analysis

First, the natural period or the natural frequency is required in order to examine the dynamic behavior of structures. The modal analysis is performed for the dam wing in Fig.1 and the 1st natural period is found as T=0.013sec (1st natural frequency is f=74.3Hz). Second, the debris fluid force is assumed as shown in Fig.3 by considering the rise time ratio t_r/T =0.1, 0.5, 1.0 （t_r ：rise time) as a parameter. Although the dynamic fluid force has three different rise time ratios, the magnitude has the same as the static load. The damping constant is assumed as 5% by using Rayleigh damping.

2.2.1 Displacement-time relation

Figure 4 shows the horizontal displacement of point A-time relation at the top of dam wing. It is found that the maximum displacement of t_r/T=0.1 is larger than those of t_r/T=0.5 and 1.0. This means that the maximum displacement(0.34mm) becomes about 1.7 times larger than the static one (0.2mm), if the fluid force is applied as an impulsive load(t_r/T=0.1). On the contrary, if the fluid force acts on the dam as a slow load (t_r/T=1.0), the maximum displacement becomes to the static one (0.2mm). It is also noted that the displacements in any cases are approaching to the static one due to the damping effects.

2.2.2 Principal stress-time relation

Figure 5 illustrates the principle stress of point B –time relation at the bottom of dam wing in Fig.1. It is confirmed that the principal stress becomes also large if the rise time ratio is small. It is found that the maximum stress of t_r/T=0.1 is 2.3 N/mm^2 which exceeds the tensile strength of concrete (2.0 N/mm^2). Therefore, it is recognized that the dam wing may be damaged by exceeding the limit tensile stress from the impulsive point of view. On the contrary, it is noted that the stress of t_r/T=1.0 is approaching to the static stress(1.4N/mm^2).

Therefore, it is confirmed that the dynamic behavior becomes an impulsive one if the rise time ratio is very small (quick), and it becomes a static behavior if the rise time ratio is large (slow).

In other words, if the fluid force acts on dam impulsively, the response of dam will become about 1.7 times larger than the static one.

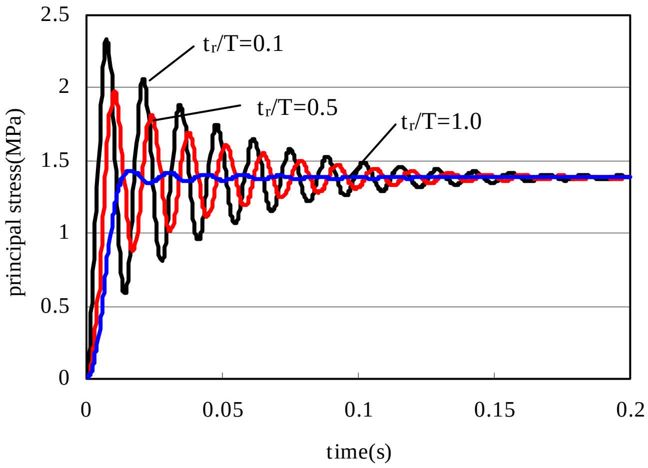
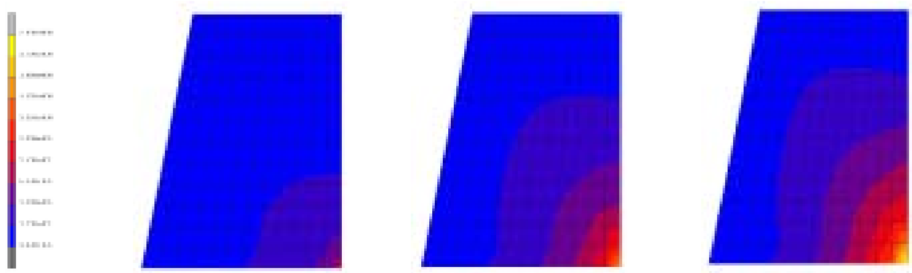


Fig.5 Principal stress of point B－time relation



(a) t=5msec (b) t=7.5msec (c) t=10msec

Fig.6 Time history of principal stress (t_r/T=0.5)

2.2.3 Dynamic behavior of principle stress

Figure 6 represents a time history of principle stress distribution of dam wing in case of t_r/T=0.5. It should be noted that the stress expands to the radial direction from the point B to the core of dam and the maximum stress is reached to the 2.3 N/mm^2.

2.2.4 Principle stress ratio–rise time ratio relation

Figure 7 shows the dynamic/static principle stress ratio- rise time ratio t_r/T relation. It is turned out that the stress ratio of short rise time becomes about 1.7 times larger than the static one. In other words, this means that if the fluid force acts on the dam as impulsive load, the dam wing may be damaged by exceeding the tensile strength of concrete(2.3N/ mm^2 >2.0 N/ mm^2).

3. Impact behavior under collision of a rock

Many studies on impact behavior of concrete structures have been performed so far, for instance, 〔11〕, 〔12〕, 〔13〕, 〔14〕, 〔15〕, 〔16〕.

In order to examine the effect of collision of a rock, an impact FEM analysis is performed for the same dam wing by hitting a rock with diameter of 1m and velocity of 10m/sec as shown in Fig.8.

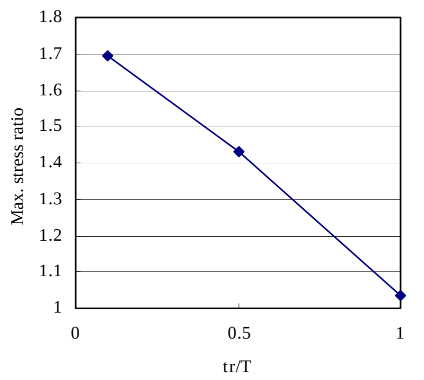


Fig.7 Max. stress ratio—rise time ratio relation

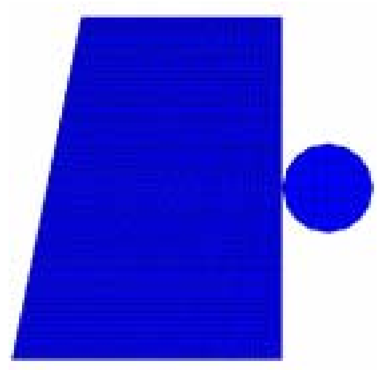


Fig.8 Concrete check dam wing under collision of rock (rock velocity V=10m/s, rock diameter D=1m)

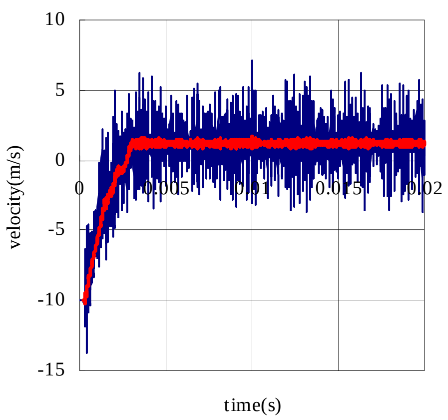


Fig.9:Velocity-time relation

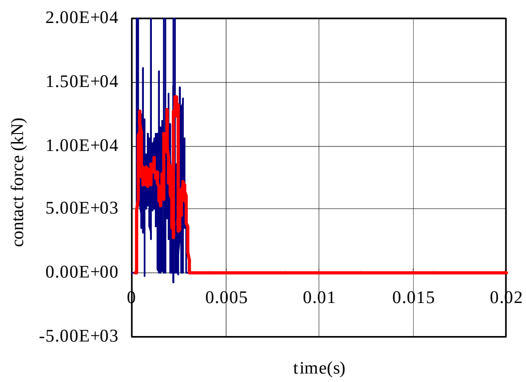


Fig.10 Contact force – time relation

3.1 Rock velocity

Since a rock collided with concrete dam, the velocity of rock is changed after impact as shown in Fig.9. It should be noted that the rock rebounds from the dam and its velocity changes from 10m/sec of left-direction to 2m/sec of right-direction after impact. This means that the kinetic energy of a rock is about 96% absorbed by the elastic-plastic deformation energy of dam wing.

3.2 Contact force—time relation

Figure 10 represents the contact force-time relation under collision of a rock on the dam wing. It is found that the contact force i.e., impact force is remarkably large at the moment of impact and collision between dam and rock occurs at many times (4—5 times) during very short time.

3.3 Displacement-time relation

Figure 11 shows the relation between displacement and time at the impact point. It is confirmed that the maximum local deformation (about 9mm) at impact point is much larger than the one (about 0.5cm) of rear face. It is also recognized that the deformation due to collision of a rock is much larger than the one due to dynamic fluid force, even if the impulsive fluid force with the same velocity of 10m/sec acts on the dam.

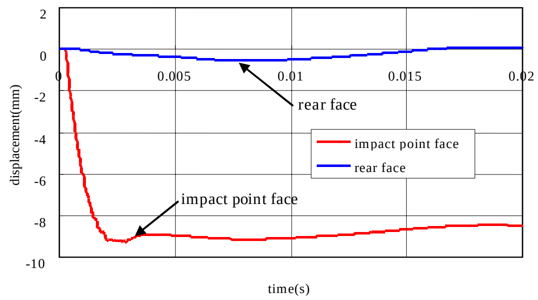


Fig.11 Displacement of impact point – time relation

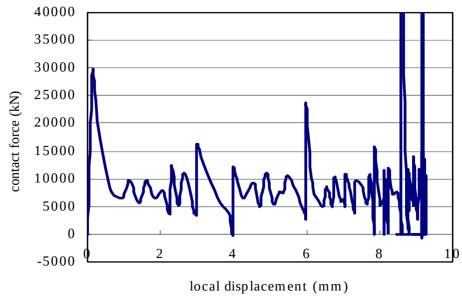
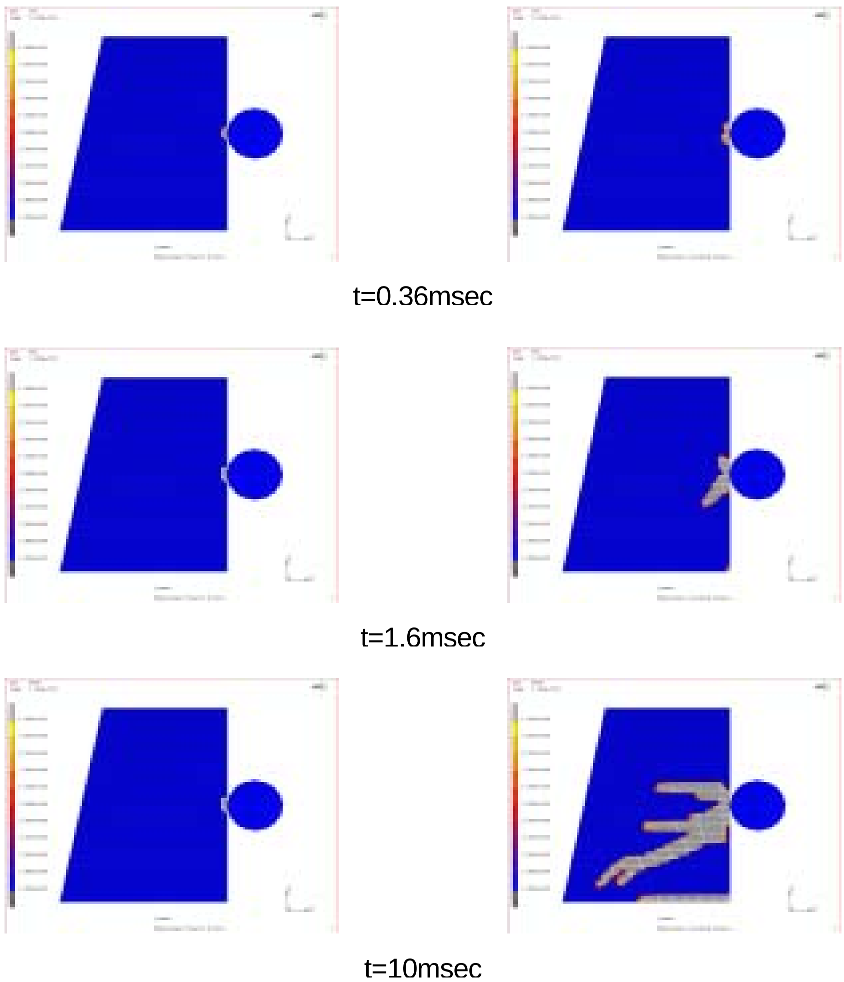


Fig.12 Contact force – local deformation relation



(a) Equivalent plastic strain (b) Equivalent cracking strain

Fig.13 Dynamic strain behavior of check dam wing

3.4 Impact load- local deformation relation

Figure 12 illustrates the impact load-local deformation relation under collision of a rock on the dam wing. It is quite interested to note that a rock hit many times (about 4-5 times) on the dam wing and as such, the impact load becomes quite large at final deformation, because of retaining the contact pressure between rock and concrete dam.

3.5 Impact strain behavior of dam wing

Figure 13(a) and (b) illustrates the equivalent plastic and cracking strains of dam wing under collision of a rock. Herein, the equivalent plastic and cracking strains correspond to the compressive and tensile strains, respectively. It is found from Fig. 13(a) and (b) that the collision phenomenon due to a rock is only limited at the impacted face which is almost damaged by the impact energy of rock at the time t=10msec. It is also recognized that the equivalent cracking strains are larger than equivalent plastic strains.

Conclusions

The following conclusions are drawn from this study.

(1) If the fluid force acts on the dam suddenly, the dam will behave impulsively and the dynamic response will be about 1.7 times larger than the static one.

(2) If the fluid force with the flow velocity of 10m/sec is impulsively applied to the concrete check dam wing, the dam wing may be damaged by exceeding the tensile concrete strength.

(3) It is confirmed from impact behavior of a rock that the local deformation at the impacted face is remarkably large rather than the global deformation of whole dam.

(4) It is interested to note that the collision between rock and dam occurs at many times(about 4—5 times), during very short time (less than 5msec) and, as such, the impact load increases at the maximum deformation level, because a rock continues to push on the dam until it rebounds.

(5) It is noted that the damage due to the fluid force is occurred in the whole dam, but the damage due to collision of rock is limited only at the impacted local area. Therefore, the concrete dam will be collapsed in case of applying the impulsive fluid force and collision of rocks simultaneously.

Acknowledgements

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