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A seismic isolation measure for dams

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ABSTRACT: For mitigating the earthquake hazard of dams, the right way is to reduce the dynamic water pressure acting on the dam. In this paper, an analysis of air bags used as seismic isolators placed between the dam and water is discussed. It may be applied to existing dams as well as new constructing dams.

1 INTRODUCTION

Reservoir dams are very large structures and very important structures. The collapse of a reservoir dam is a very terrible event which may kill many people and destroy much property. Even if only a small crack in a dam is produced by an earthquake, the leakage of high-pressure water through the crack can cause it to be enlarged and eventurally lead to the collapse of the whole dam. This is in marked in contrast to the fact that most dwellings will remain standing if small cracks appear in them. Therefore cracks in reservoir dams are more critical than cracks in dwellings. Untill now, the safety design of dams is not solved. Some computer programs enable the calculation of water pressure acting on dams under some suppositions, but these programs cannot reduce the water pressure. Especially, for older reservoir dams designed and built several decades ago, analysis of dam stress, earthquake intensity and the map of seismic regionizations, the induced earthquakes caused by the water reservoir, etc. were probably not accurately completed. There were many ignorances in dam designing.

Can such older reservoir dams be strengthened against to earthquakes ? No. For example, the structure of the Xinfengjiang dam in China was stiffened by changing an arch dam to a gravity dam. Then the natural frequency of this dam raised. As a further result, the dam withstood the dynamic water pressure and the inertia forces of the dam itself due to an earthquake were all greater than before. On the other hand, strengthening a reservoir dam is very expensive.

By the way, it is un-imaginable by using active control actuators to pull-push a large dam which something like a small hill.

During an earthquake, a dam vibrates against the water causing dynamic water pressure acting on the dam.

Sometimes the dynamic water pressure is greater than the static water pressure. Depending on the earthquake intensity, the dynamic water pressure can be large enough to cause damage to a dam. When the dynamic water pressure is reduced, the safety of the dam is increased.

2 AIR-BAG ISOLATOR

During an earthquake, the dam vibrates and pushes the water causing the dynamic water pressure acting on the dam. Sometimes the dynamic water pressures are greater than the static water pressures.

How to reduce the dynamic water pressure ?
Using Air-Bag Isolators. (Fig. 1)

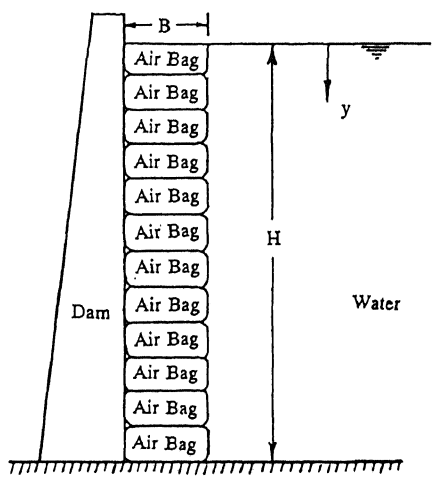

Fig. 1 Sketch of dam and air-bag isolators.

Water is an incompressible fluid. When a dam vibrates, it will push the water into motion and produce a dynamic water pressure. If some air-bags are placed between the dam and the water (Fig.1), the vibration of the dam will not push the water directly, but push the air-bags first, and then transmit the pushing force from the air-bags to the water. Owing to the compressibility of the air, only a little portion of the vibration of the dam will be transmitted to the water, i.e. it reduces the dynamic water pressure acting on the dam. Much of the vibration is absorbed by air bags. The larger the air-bag, the smaller the vibration transmitted to the water.

Let :

D(y,t)-----Displacement of Dam,

B(y,t)-----Width of air-bag,

P_s(y)------Static water pressure, $[P_s(y)=\rho \cdot y]$

P_d(y,t)----Dynamic water pressure,

S(y,t)------Horizontal Shortening of air bags,

V_x(y,t)-----Velocity of water at the interface of an air bag and water,

Φ(x,y,t)----Potential function of water,

y --------- depth under the water surface,

ρ --------- Density of water.

In vibration, the width of the air bag is $\{B(y,t)-S(y,t)\}$. Since the air-bags are confined by each other, the air bags can not change their cross sections.

By Boyle's law :

$$[B(y,t)-S(y,t)]\cdot[P_s+P_d(y,t)]=B(y,t)\cdot P_s$$

$$S(y,t)=B(y,t)\cdot\left\{\frac{P_d(y,t)}{P_d(y,t)+P_s}\right\} \tag{1}$$

So that the vibrational displacement of water (at the interface of an air bag and water) is:

$$[D(y,t)-S(y,t)]$$

The vibrational velocity of water (at the interface of an air bag and water) is :

$$V_x=\frac{\partial}{\partial t}\left[D(y,t)-S(y,t)\right]$$

The velocity related to the potential of water is

$$V_x(Y,t)=\frac{\partial\Phi(x,y,t)}{\partial x}=\frac{\partial}{\partial t}\left[D(y,t)-S(y,t)\right] \tag{2}$$

and the dynamic water pressure is :

$$P_d(y,t)=-\frac{\rho}{g}\cdot\left[\frac{\partial\Phi(x,y,t)}{\partial t}\right] \tag{3}$$

The dynamic water pressure $P_d(y,t)$ will act on the dam by the transmission from air bags. Then the horizontal displacement of the dam may be calculated as :

$$D(y,t)=[K]\cdot[P_d(y,t)] \tag{4}$$

$[K]$ --------Stiffness matrix for the dam.

There are four equations, to solve for the four unknowns : D(y,t) , S(y,t) , P_d(y,t) and Φ(x,y,t) , combined with the wave equation for the water potential function :

$$\nabla^2\Phi(x,y,t)=\frac{1}{C^2}\left\{\frac{\partial^2\Phi(x,y,t)}{\partial t}\right\} \tag{5}$$

and the boundary conditions at the water free surface with :

$$\frac{\partial\Phi(x,y,t)}{\partial t}\Big|_{y=0}=0$$

and at the bottom of the reservoir with :

$$\frac{\partial\Phi(x,y,t)}{\partial y}\Big|_{y=H}=0$$

Finally, all of the unknowns can be calculated.

3 EXAMPLE

Let's consider a plane vertical rigid dam of 100 feet in height. Its length is rather long that the analysis may be treated as a two-dimensional problem. Between the dam and the water, there are many air bags with width B (there are three cases : B=1 foot, B=2 feet and B=3 feet). The ground is taken to vibrate in simple harmonic motion with an amplitude of four inches, and at frequency from 2 c/s to 10 c/s. The dynamic water pressure acted on the dam can then be calculated.

Comparing the results for these three cases, the dynamic water pressures acted on the dam are shown in Fig. 2 and Fig. 3.

In summary, it is seen that the reduction of dynamic water pressures vary with respect to two parameters :

(1) **the width of the air-bag.** The wider the air bag, the larger the reduction factor that is obtained;

(2) **the frequency of the ground motion.** The higher the frequency of ground motion, the larger the reduction factor that is obtained.

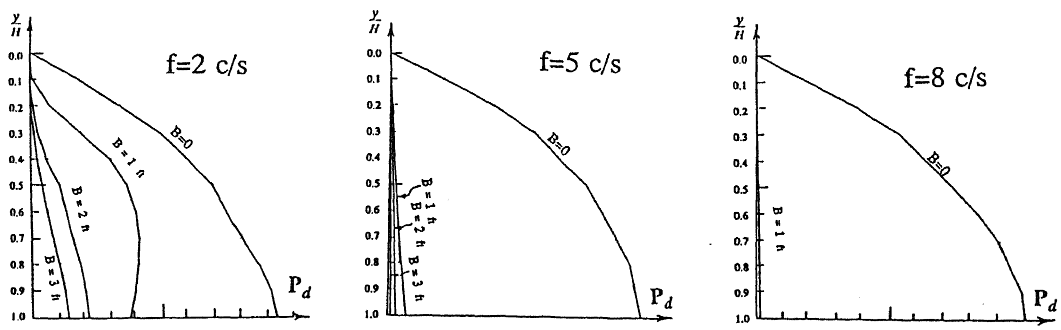

Fig. 2 Dynamic Water Pressure vs. Depth (B ---- Width of Air Bag Isolator)

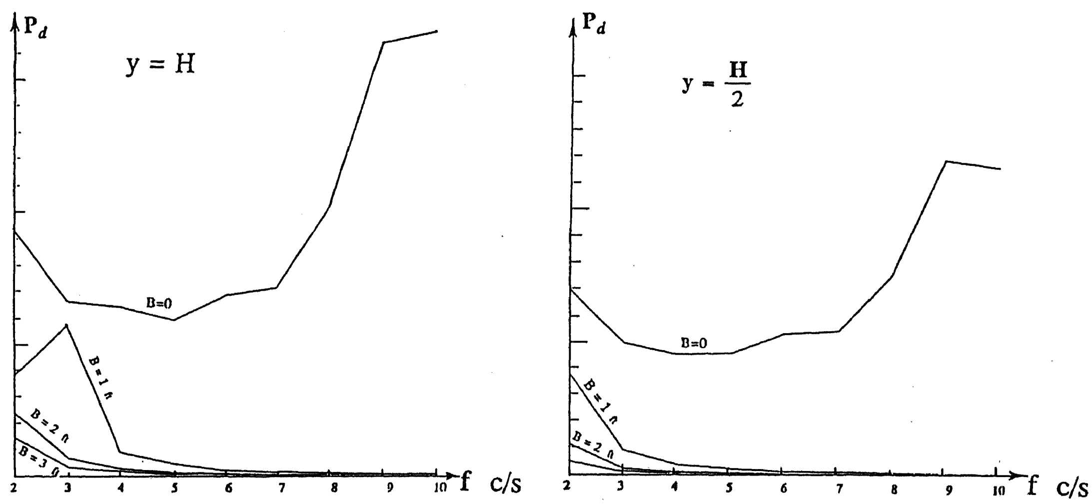

Fig. 3 Dynamic Water Pressure vs. Frequency of Ground Motion.

4 CONCLUSION

In this paper, an example of the simplest type of dam is treated. If the dam is not a rigid structure, and does not have a vertical plane shape, the analysis may be very complicated, especially in three-dimensional calculations of the dam and the water reservoir. But the results will also be good when the air bags are inserted between the dam and the water.

This measure can be applied to existing dams as well as applied to dams under construction. Air bags are inexpensive and easy to fabricate.

During battle, reservoir dams are highly defended. If a bomb explodes in the water near the dam, the water pushes a tremendous impulse force to the dam. It is terrible, but air bags placed between the dam and the water can release this impulse force.(Fig. 4)

To verify the results from this analysis, model experiements should be done. I need financial support and co-laborators. Even through, it would be expensive, but it would be much cheaper than restoring the hazard of a dam.

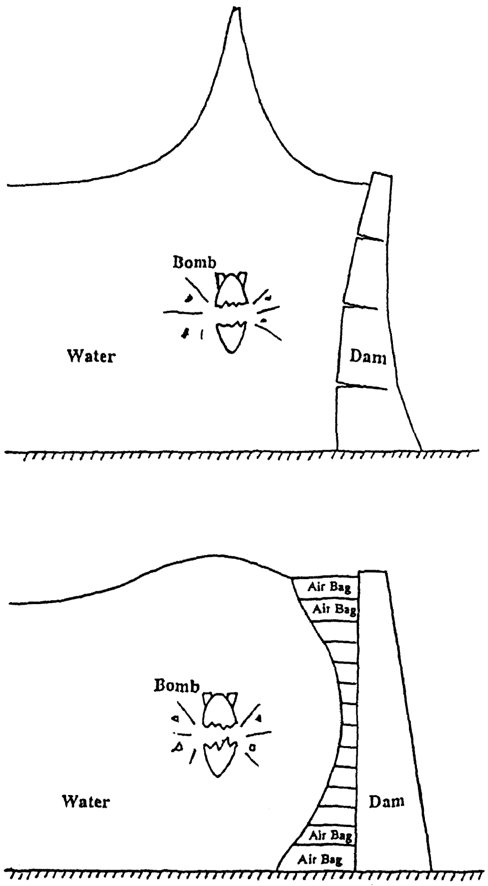

Fig. 4 Anti-explosion measure for dams

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