4th Session SEISMIC EFFICIENCY OF LARGE STRUCTURES (RECOMMEN DATIONS, CHECKING AND SURVEILLANCE)

DISCUSSION

Address to participants by R. G. T. LANE - ENGLAND

"Probelms in Assessing the Effects of Earthquake on Dams"

CLOUGH

Only five accepted examples of reservoir induced seismic events with magnitude M = 5 have been reported. This is a very small number compared with the number of large dams in the world. Also, the accepted hypoth esis is that reservoir induced seismicity (events) involve only the "triggering" of the existing strain fields - no significant increase of seismic energy is pro duced by the reservoir. In view of these facts, do you believe reservoir induced seismicity should have any influence on design criteria for dams?

LANE

On the question of statistics, the figures I have relate to very large dams defined as those higher than 100 m or with reservoir capacity exceeding one thousand million cubic meters.

Out of all such dams built in the world, 1 to 14 has shown induced seismicity. Now there are due to be built during the next few years another 140 dams of that size. That means that on the basis of statistics we can expect ten more cases of appreciable induced seismicity within the near future. That is the statistical position.

CLOUGH

I would like to comment on that, because the number you quoted is accepted as reservoir induced seismicity, but most of those are essentially micro-earthquakes or very small earthquake activities, and the only ones that might induce appreciable damage are those of magnitude 5 or greater. So the number of these is very much smaller.

LANE

The prefix "micro" is usually used for very small events. There have been two or three cases of induced seismicity of magnitude 6 (Richter). But the point I raised is that these events are very close to structures and they are very shallow. Therefore, it is thought that the effect of even a small one could be appreciable, and this requires geological study also. I would recommend that for every large dam the question of induced seismicity should be seriously taken into account.

Your second question was related to factors causing induced seismicity. Various causes are suggested. Some people have referred to the weight of water but this is small compared with the weight of rock which once filled the valley. I do not think weight of water is in itself any problem. My own theory is that the water penetrates into the faults. Now these faults extend well beyond the reservoir area and they are also very deep. We are talking now of kilometres, of tens of kilometres or even more. Water is already in that fault and when you add to it a hundred metres of head, there is an elastic compression of water. This elastic compression of water takes time, but gradually the water down to great depths will be affected by this elastic compression; letting more water in and at the same time increasing compression. This accounts, in my opinion, for two things: it explains the long delay between the impounding and the effect; in the case of Kariba it was 5 weeks before it happened. But during that time, an area of perhaps tens of even hundreds of square kilometres has had its pressure increased by one hundred metres, and that is a lot of pressure. In my opinion that is the probable reason for induced seismicity.

CAPOZZA

I think it should be emphasized the particular role played by the actual state of stress on the arising of an induced seismicity. As a matter of fact, should the actual stresses be very near to the strength in a point of the rock mass, just a little increasing in the pore pressure could be required to allow the starting of a slip generating seismicity.

Whether this seismicity could attain high levels or not, it depends, among other things, on the amount of elastic energy stored in the rock mass, and so on conditions related again to the pre-existing state of stress.

Paper 4/1 R. PRISCU, A. POPOVICI, C. STERE - ROMANIA

"The Consequences of Partially Grouted Joints Upon the Arch Dam Seismic Behaviour"

CLOUGH

If I understand the paper correctly, the analysis of the dam response considers the ungrouted joints to be represented by reduced stiffness, but does not account for the non-linear effect of the joint opening and closing during the dynamic response. In your opinion does the true non-linear response differ significantly from the assured linear partially grouted dam response?

PRISCU

When modelling the dam ungrouted joints with beam elements of reduced stiffness, some phenomena have been disregarded as: the shear effect in the dam joints, the non-elastic behaviour of the whole system, the damping variation with the intensity of the dynamic response.

The presented analysis has been carried out in the linear-elastic domain with the SAP IV computer program, elaborated by the University of Berkeley; that computer program has been adequately fitted out to the Romanian in use computers and it includes some routines written by us.

We know some computer programs performing some of the foremen-tioned neglected phenomena (NONSAP, ADINA) do exist, but there is the unhappy situation that we do not still take advantage of it.

We are aware the proper consideration of some above disregarded phenomena could really yield some quantitative change of the dam static and dynamic response. In the paper, a qualitative comparison related to the dam monolithic structure has been sought for, that last variant being also analysed in the linear-elastic domain.

LANE

I believe that the ordinates of fig. 4 are all ten times too large and a decimal point should be added; also in fig. 7 I find it difficult to understand the large horizontal stresses in the area where the joints are ungrouted.

PRISCU

The values of the velocity potential function ψ presented in figure 3 are correctly represented. This fact could be properly noticed by making an analogy with the classical relationship of Westergaard. Let us consider for instance the network point (i) of the dam central cross-section, situated at the depth $4 \cdot \Delta z = 132$ m below the crest, whereat the potential function is $\psi_i = 99.6$ m.

The specific added mass normally directed to the dam upstream face comes out to be:

$$m_{hi} = \rho \cdot \psi_i = 0.102 \times 99.6 = 10.15 \quad tf.s^2/m^3 \qquad (1)$$

If, in the foreconsidered point (i), an acceleration of $0.1\,g \approx 1\ m/s^2$ normally directed to the dam surface (c_{ni}) is being taken into consideration the hydrodynamic pressure will be:

$$p_{hi} = m_{hi} \cdot c_{ni} = 10.15 \times 1 = 10.15 \ \ tf/m^2 \qquad (2)$$

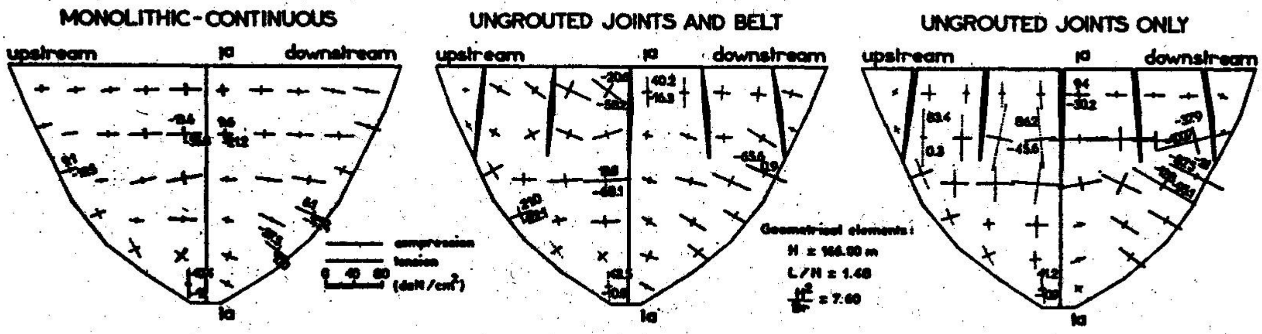
One comparatively gives the same hydrodynamic pressure by using instead the Westergaard relationship, with the same above data:

$$p_{hi} = a_{ni} \cdot C_p \cdot \sqrt{H \cdot z_i} = 0.1 \times 0.9 \cdot \sqrt{165 \times 132} = 13.20 \ \ tf/m^2 \qquad (3)$$

However, the values of the potential function take into consideration the dam and valley (reservoir) geometry and the earthquake wave direction.

The dam structure discretization has been carried out through Clough -Fellipa thin shell finite elements, according to the SAP IV program /6/. The computer program gives out stresses within the element centers. Therefore, in fig. 7, the horizontal and vertical stresses are represented for the medium cross-section of the dam central block (cross-section a-a).

As to have a more complete picture upon the stress distribution of the three considered schemes (monolithic, partial grouted joints with and without stiffening crest belt), in the hereby enclosed figure the principal stresses σ_1, σ_2 are presented, yielded by the hydrostatic pressure with the reservoir level up to the dam crest.



Principal stresses σ_1, σ_2 produced by hydrostatic pressure, according to the three analysed variants.

Paper 4/5 O. FISCHER - CZECHOSLOVAKIA

"Seismic Behaviour of Guyed Masts"

GROSSMAYER

I just wanted to ask if you can also make some considerations concerning dynamic excitation of the anchors of the guys, because if I understand you well, you consider only the excitation for the mast and static displacement for the guys.

FISCHER

In principle it would be possible to solve the effect of horizontal excitation of the guy-foundation similarly like that of the mast-foundation, described in the paper. The "influence-numbers" /7/

$$p_{(k)} = \frac{\int \mu v_o(x) \; v_{(k)}(x) \; dx}{\int \mu v^2_{(k)}(x) \; dx}$$

which depend on the product of the natural mode of the mast and the static deflection line caused by unitary displacement of the mast foundation, this static deflection line should be replaced by that corresponding to the unitary displacement of the guy-foundation. The rest of the solution remains the same.

LANE

I would like to ask if you have been able to check your theory on actual structures.

FISCHER

Till now we could check only the method for computation of natural frequencies and modes. Measuring the vibrations of a guyed mast in wind we have found the frequencies, which corresponded quite well to the calculated ones.

Paper 4/8 A. CASTOLDI - ITALY

"Contribution of the Surveillance to the Evaluation of the Efficiency of Dams. Example of the Ambiesta Dam"

CLOUGH

I would merely like to ask about the recent work using only two components of seismic input instead of three. Of course we all agree that even a three-component input is an over-simplification. But I was wondering why you did not include the vertical component in your representation.

CASTOLDI

The true reason for not having included the vertical component is that it has not been recorded. Since the number of seismometers was limited, and since it was therefore necessary to make a careful choice of the measuring points, it has been considered more important to determine the distribution along the dam foundation of the horizontal components (to which the seismic response of the dams is strictly related) than the vertical component.
In any case, from a conceptual point of view, there are no difficulties in taking into account all the three components.

CLOUGH

There is one additional comment in that direction. As you probably know from the literature, Prof. Chopra's studies on the hydrodynamic interaction mechanism have demonstrated that in gravity dams, at least, the vertical component is or may be as important as the horizontal component in generating seismic response.

CASTOLDI

Yes, that is true. However, it should be pointed out that the Ambiesta dam, on which these recordings have been taken, is an arch dam, not a gravity dam.

CLOUGH

But I think the same might be true in the case of the arch as well.

CASTOLDI

This is a matter which should be checked. However, in my opinion, the contribution of the horizontal components of the seism to the horizontal components of the response of an arch dam is by far more important than that of the vertical component. This statement is justified if one considers that the modal shapes of the arch dam usually show vertical components less than 10 ÷ ÷ 20% of the horizontal ones. It follows that the participation coefficients of the first vibration modes are smaller for a vertical seism with respect to a horizontal one.

GROSSMAYER

I would like to ask if you can draw any conclusion about the distribution of the excitation along the base and abutment of the Ambiesta dam.

CASTOLDI

Yes, 10 of the 30 instruments used were placed along the abutments of the dam at different levels and enabled to know the distribution of the excitation along the foundation.

Some data concerning the amplification factors are shown in the paper: they range between two and four, with a large dispersion around these mean values depending on the direction and frequency content of the motion. It has not been possible however to find a correlation among the records at different levels.

LANE

I do not know the Ambiesta dam, but I am wondering whether there is an other structure near the dam to enable a simple understanding of the site behaviour for comparison with the more complex behaviour of the dam. This would help to separate various effects.

CASTOLDI

I do not think that there is such a structure near the dam. We have monitored the dam and its foundation quite extensively, so that we have a good picture of the situation; yet we could not find correlation among the records. In my opinion, it may not be a matter of better knowing the site geology or the earthquake features, but how the energy spreads from it source and reaches the abutement and the dam.

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