THE DYNAMIC BEHAVIOUR OF DIAMOND-HEADED HOLLOW GRAVITY BUTTRESS DAMS

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SUMMARY

Due to the high seismic risk present in a few Italian districts a study of the dynamic behaviour of diamond-headed hollow gravity dams was carried out in view of the special socio-economic importance of the type of structures. A numerical investigation about the linear elastic behaviour of a typical buttress by 3D finite elements computer program with boundary conditions of either full or empty reservoir and for different hypotheses on the behaviour of lateral contraction joints was performed.

INTRODUCTION

The high seismic risk of Italian districts was pointed out by the recent very strong earthquakes in 1976 in northern Italy and in 1980 in southern Italy and suggested a new set of studies on buttress dams that had, till 20 years ago, a great development (12 hollow gravity dams were built in Italy). More recently Italian gravity dams designers dropped, in practice, this typology because of the increasing costs of labor in opposition to the lower growth of costs of materials employed. In fact the saving due to the lower quantity of material employed for hollow gravity dams in opposition to gravity ones decreased in the last years because of the increasing costs of the forms necessary for the construction of the inner hollow.
Nowadays, after many years from the construction, a new set of studies was justified by the ageing process of materials and the increasing awareness of the seismic risk.

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MODAL ANALYSIS - NUMERICAL AND EXPERIMENTAL INVESTIGATION

In order to investigate the applicability, in the 3D space, of the solution provided by Westergaard for the problem of fluid-structure interaction the CISE (Centre for Information, Studies and Experience) was comissioned by "Direzione Studi e Ricerche" DSR of ENEL a new generation of F.E. mathematical models. In this way the study of the dynamic behaviour of concrete structures taking into account the interaction between the body of a dam and the water in the reservoir excited by an earthquake of known characteristics was performed. The numerical code "INDIA" was the result. On the other hand ISMES (Experimental Insitute for Models and Structures) carried out several in situ dynamic artificial-excitaton tests. For some arch and gravity dams a good agreement between numerical and experimental parameters was obtained so that, nowadays, we have a better comprehension of the phenomena and besides a good forecasting of their seismic behaviour given by the code is possible.
In order to obtain an experimental confirmation of the code INDIA, for butress dams, a set of in situ tests was carried out in the case of natural excitation (wind pressure and micro-tremors) but the results obtained were not fully satisfying. On the other hand the studies carried out on a similar English dam, having about the same dimension of the one under study, by University of Bristol (G.B.) (Ref. 2) were very useful to check our numerical results showing, in the case of full reservoir, good agreement and allowed to see how the contraction joints modify the global dynamical behaviour. Another numerical analysis on the dynamical behaviour of the body of the dam, by commercial F.E. codes ASKA and BERDYNE, was carried out and the good agreement with the code INDIA confirmed again the validity of the new code.

Boundary Conditions

The actual behaviour of the construction joints is generally unknown. A rapid ageing of the bituminous material, fulling the joints, normally after a few years from the construction, is noted. Probably the inner electric resistances are not able to keep the bitumen in the quasi-fluid state. The testing methods, developped in the last years, in order to check the state of the joints gave no success.
All that illustrated above shows the difficulty of computing the kinematic resistance to the single buttress motion. In order to investigate the dynamic behaviour of the single element two limit kinematic conditions were specified.

1) In the first limit condition the single buttress was completely free and influence due the nearby buttress is not taken into account. The minimum distance (a few millimeters) between the vertical surfaces

of the two buttress was considered enough to permit the free vibration of the element. In this way a left/right (side of the valley) motion is allowed.

2) In the second limit condition the bituminous material of the contraction joints in completely crystallized so that no longitudinal motion is allowed.

Effects of the reservoir on the dynamic structural behaviour

Modal analysis of the structure and of the system (structure and fluid), taking into account the fluid-structure interaction, were carried out. In the case of full reservoir the analysis showed, at the eigenfrequencies, a rather similar modal shape of the structure associated with very different distribution of the pressure in the fluid.
The results are shown in fig. (3).

Seismic response

The seismic response of the typical buttress was obtained with the method of the response spectra. The spectra employed in the analysis were computed from the strong motion recording of May 1976 (Friuli) in the northern Italy assuming a structural damping coefficient of 5% of the critical one. The response spectra method was employed in order to reduce the high computational time involved in these type of analysis if carried out by a direct integration method. However, in spite of different support schematization, it looks clear that the hollow gravity dams, while they have a good stiffness and resistance for upstream-downstream motion, do not possess comparable reserves (for very strong intensity motion) in the direction of the crest. From a practical point of view this fact can be considered not worrying because a coincidence of direction and frequency that provide the excitation of the critical modes in very unlikely to happen. However we wanted to examine how to increase the resistance of the buttress against these particular seismic events. In our numerical model we have realized a set of connections (concrete beams) between all the nearby buttresses in order to force every structural element to move together.
This solution gave good results and they are shown in fig. (3) and in table (1).

Thermal load

From the data recorded by thermometers (inside and outside the body of the structure) it has been possible to carry out a numerical study of

the thermal behaviour of the buttress.
The distribution of the temperature and of the stresses involved, during all a year (the base annual cycle), was the result and an example is shown in fig. (4) for an horizontal section near the top of the dam.

CONCLUSION

These studies about the dynamic and the thermal behaviour allow to better undersand the structure, to point out the weakness and the way to avoid them.

Case	Max.Displ. (cm)	Max.Vel. (cm/sec)	Max.Acc. (cm/sec)	Max. Stress Kg/sq.cm.
Contraction joint: closed Reservoir : empty	0,2	9	500	±12
Contraction joint: closed Reservoir : full	0,5	22	900	± 8
Contraction joint: open Buttress: bounded by lateral beams	0,9	30	1300	±22
Contraction joint: open Buttress : free	3,2	75	1760	±80

Table 1 – Response of the buttress to the Friuli's earthquake (Damping factor 0,05).

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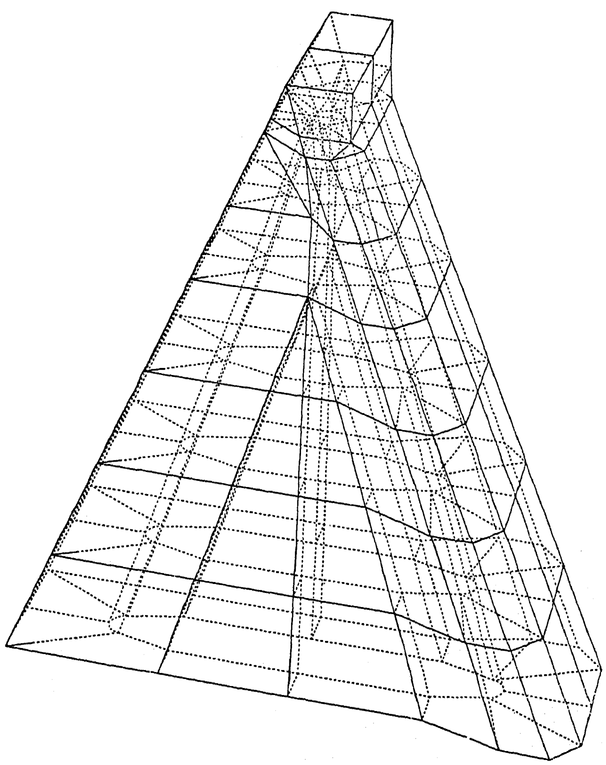


Fig. 1 Finite Element Mesh employed as numerical model:
803 nodes
92 isoparametric elements
2169 degrees of freedom

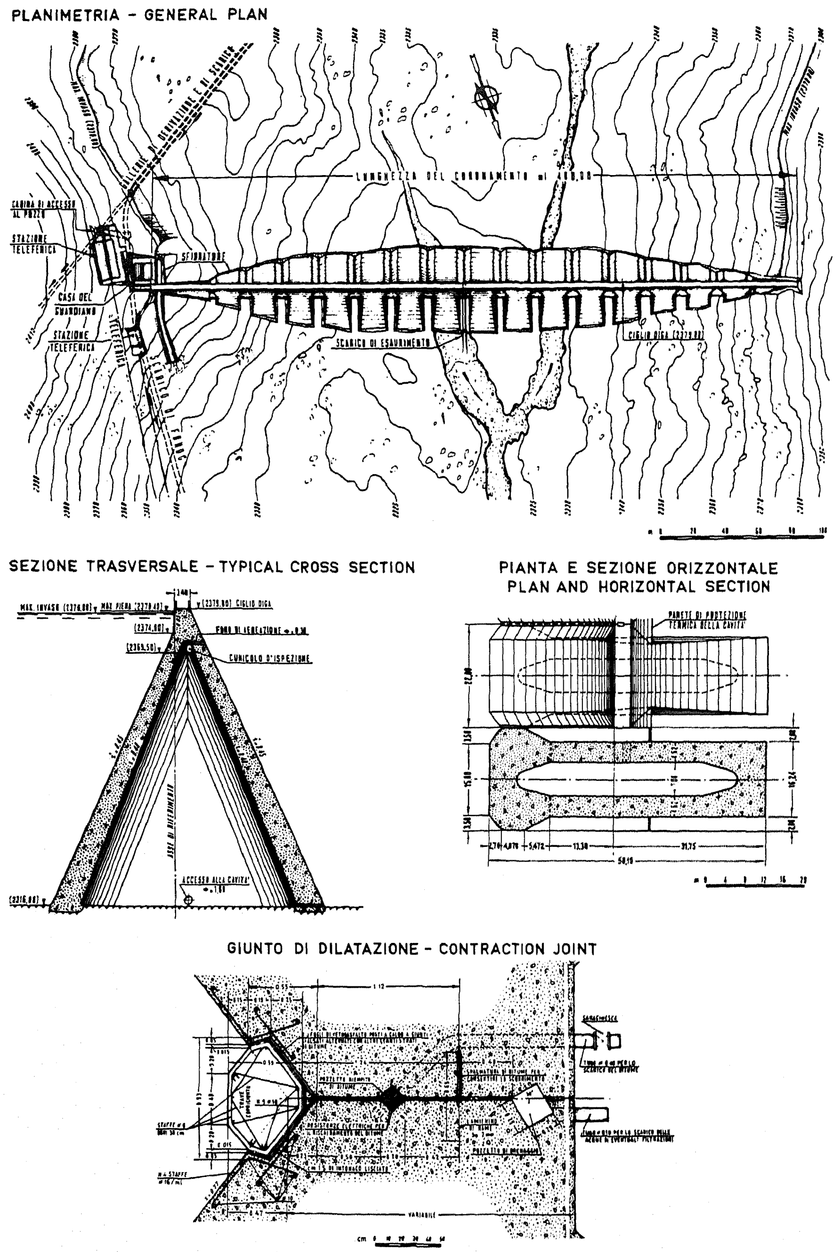


Fig. 2 Pianta generale e caratteristiche geometriche principali di una una diga italiana a speroni cavi.
General layout and main geometric data of a buttress Italian dam.

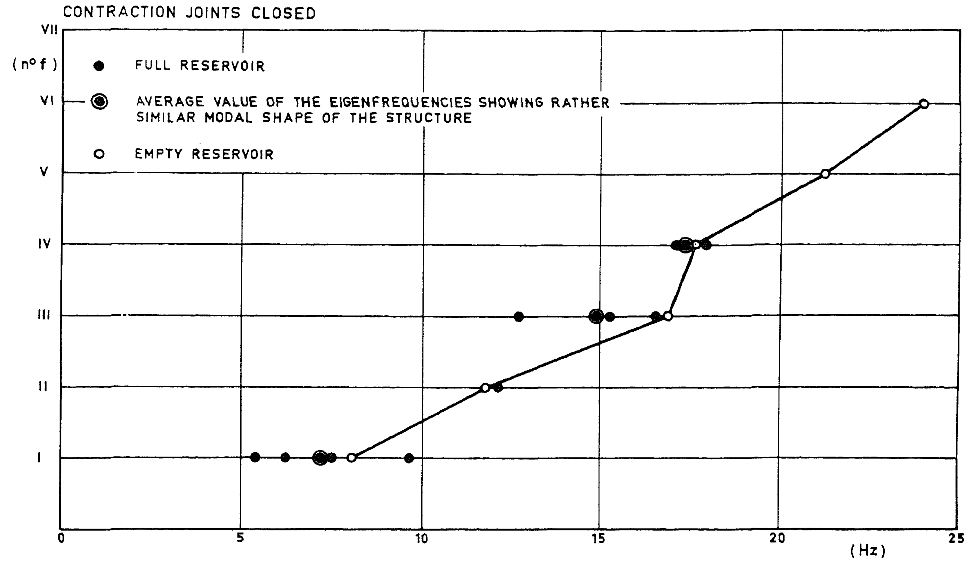
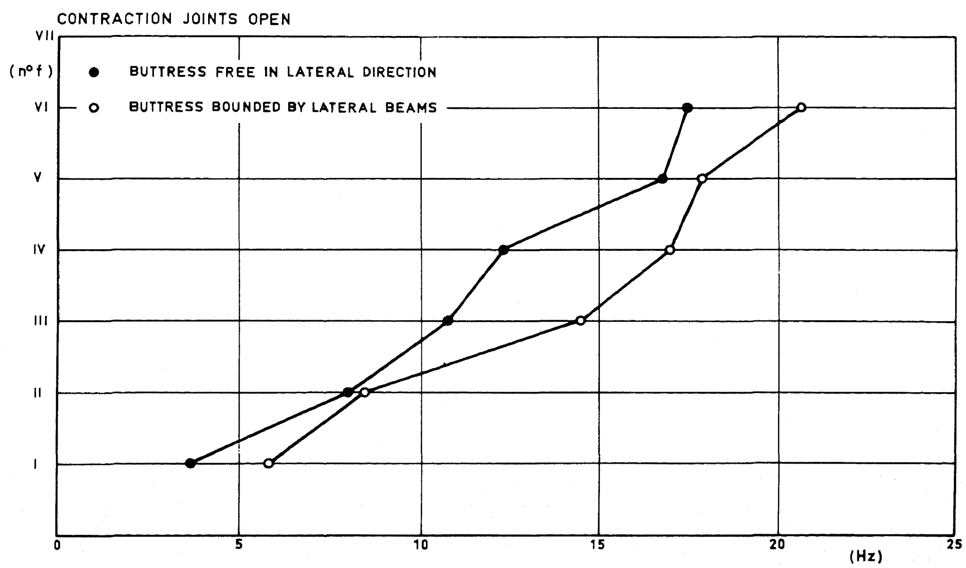


Fig. 3 Dynamic map of the structure in the limit conditions assumed showing the influence of the parameters on the eigenvalues.



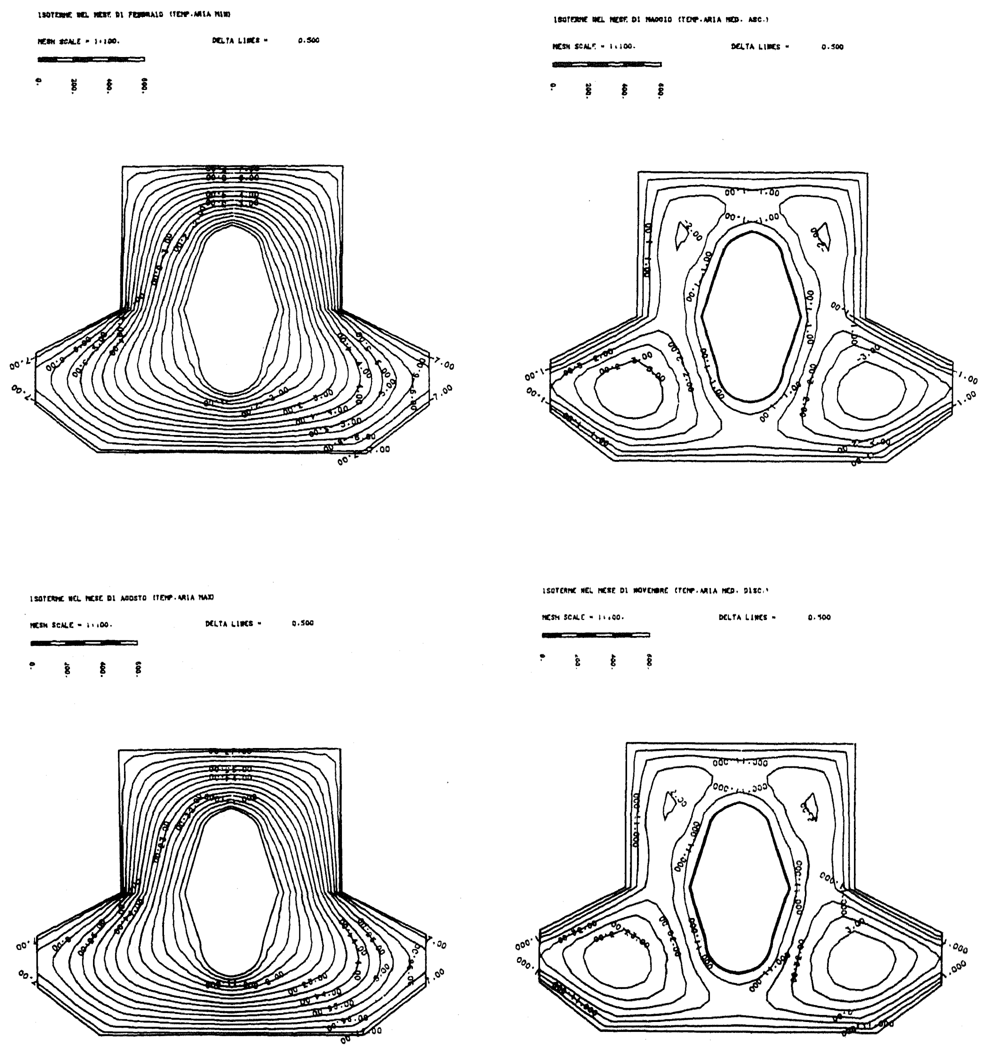


fig. 4 - Horizontal section near the buttress' top.
Map of isothermal lines at February, May, August, and November.