# STUDIES ON EARTHQUAKE BEHAVIOUR OF LARGE DAMS

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## SUMMARY

A multiannual program of research on the dynamic structural behaviour of large concrete dams is illustrated. Aspects covered range from the development of new types of mechanical exciters and new types of vibration detectors for in-situ tests, to model studies and numerical (F.E.) computations. The body of knowledge acquired, including artificial and natural excitation of several large dams, allowed to conclude favorably toward the possibility of assessing earthquake consequences on such large structures.

## INTRODUCTION

The seismic safety of dams was object of examination by the "Direzione Studi e Ricerche" (D.S.R.) of ENEL way earlier than the latest seismic events. In fact, since about fifteen years, D.S.R. is carrying out an important research (theoretical as well as experimental) extended in various directions with the purpose of setting up reliable methods for the forecasting of the behaviour of dams in case of earthquake of known characteristics.
C.I.S.E. (Centre for Information, Studies and Experiences) was commissioned to develop a new generation of F.E. mathematical models in order to study the dynamic behaviour of massive structures, while in situ tests on a considerable number of large dams were carried out with the cooperation of I.S.M.E.S. (Experimental Institute for Models and Structures). In a similar way other technicians of C.I.S.E. performed in situ tests in order to study non-contacting laser interferometric vibration sensors.

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## 1. STATE OF THE ART OF THE RESEARCH

Nowadays it is possible to draw up a provisional balance and to show some results. The research will go on to clarify the several aspects not yet sufficiently ascertained.

### 1.1 Testing criteria and aims

Mechanical exciters were employed to carry out in situ tests on a numerous sample of great structures with different construction typology, in particular on concrete dams.
According to the assumptions that the system under study is described through a series of linear differential equations with constant coefficients, the processing of the data furnishes informations on the eigenvalues (natural frequencies and associated dampings) and on the corresponding eigenfunctions. These parameters are necessary as a check of the mathematical model, e.g. a F.E. one, to be used for seismic safety analysis. In case of good agreement between the experimental and theoretical parameters we can be sure on the forecasting of seismic behaviour of the structure given by the numerical code (at least as far as the structure can be presumed to remain largely in the elastic-linear field). Dynamic parameters, obtained from theoretical and experimental studies, constitute a rather concise map of the structure and of its state of preservation.
After some years (or after some important events) a novel in situ test can be carried out and a comparison with the previous one will be able to give diagnostic pieces of knowledge about its safety.
In same cases experimental and numerical tests were carried out separately, unbeknown to each other, yelding a good agreement.

### 1.2

Vibrodynes both with eccentric steel masses and with mercury masses excited directly the structure.
Level and frequency of excitation could be set at will, within certain ranges (e.g. up to 60 metric tons amplitude and 0.5 to 20.0 Hz frequency).

### 1.3

More recently small "rotating vector" vibrodynes have been developped to be applied at the same time, in different points, in order to carry out a so-called multiexcitation. This system should lead to an easier separation of the natural modes of the structure.

1.4

Exciters able to develop a very high force, designed in order to excite directly the foundations of the structures, are on well advanced planning.

1.5

The response of the dam is usually recorded at many points (from 50 to 150) by seismometers.
Recently optical laser interferometric sensors have been developped and employed in situ by C.I.S.E. The results are rather good and encourage their employ even under extreme conditions. In fact this type of instruments doesn't need any installation work because they operate remotely, as far as 250 meters. The vibratory pattern of the structure is simply obtained shining the laser light beam to the various points of interest. Nowadays, it seems possible, given the high sensitivity attained, to carry out the tests also with natural excitation( i.e. breeze wind or pressure waves in the reservoir).

1.6

F.E. mathematical models developped in these years allow to compute vibrational characteristics and seismic response of the body of the dam with both full and empty reservoir (in the former case taking into account fluid-structure interaction).
As concerns the structure, these models are based on classical hypotesis of small strain, small displacements and on linear elastic behaviour of the material. The interaction with the reservoir is described assuming the fluid as compressible and its field of motion as characterized by small surface displacements and small velocities.
Computation of seismic response yields the internal stresses due to earthquakes of well known characteristics.

## 2. CRITICAL ANALYSIS AND PROPOSAL FOR THE FUTURE

2.1

Nowadays it seems to be necessary to pay more attention to the seismic input (in opposition to what effected in the past).
We intend to show further on some aspects of particular interest for us.

2.2

A subdivision of the Italian territory into zones in order to define the local statistical seismic risk is essential.
This work is being carried out jointly by E.N.E.A. and E.N.E.L., with the cooperation of other national scientific bodies (e.g. C.N.R.).

2.3.

The carrying on of the seismological studies and in particular of the mechanisms of seismic sources, are necessary.
The influence of the local topography on the trasmission of seismic waves must be investigated.

2.4

Probability of collapse and estimated level of damage, not available at the moment, will have to be computed.

2.5

Non-linear behaviour of materials subjected to high rate of stresses, non-linearity concentrated along the construction joints, mechanism of collision between the elements and the non-linear behaviour of rock foundations will have to be better investigated and taken into account.

2.6

Doubts about values assigned to some parameters (as damping factor) translate into doubts on the appraisal of numerical results.

2.7

Improvement of knowledge and a satisfactory answer to all the problems pointed out above will have to lead to the definition, necessary for design purpose, of typical response spectra.
To take into account all these parameters, also statistical ones, will lead eventually to well represent the seismic risk for each class of structural typology.

## 3. COMPARISON BETWEEN RESULTS OBTAINED FROM IN SITU TESTS AND NUMERICAL ONES

Experience carried out on real structures and on laboratory models were performed. Numerical analysis of these type of structures taking into account the fluid-structure interaction were carried out by the F.E. code INDIA (Ref. 1).

This analysis showed, at particular frequencies, rather similar modal shape of the structure associated with very different distribution of the pressure in the fluid. After these numerical results a new set of studies utilizing in situ tests were performed and a better definition of the application of the solution given by WESTERGAARD for the problem was tried. Influence of reservoir on seismic response and on the position of the maximal stresses was noted if referred to the solution with incompressible fluid. Experimental results obtained employing different types (natural and artificial) of excitation make us sure on their goodness.

Measured displacements on the crest of an Italian dam during earthquake aftershocks occurred in May 1976 were compared with previsional ones, as computed by a F.E. numerical model; the seismic input was taken as the recorded motion near the foundations during the same event.

The results gave a good agreement (Ref. 2,3,4). Recordings obtained through the seismic Italian network were very useful to know.

## 4. CONCLUSIONS

Experience carried out with artificial small amplitude forces and seismic excitation confirm a good agreement with previsionals models, whose reliability is thus proven. In a general way it is impossible to anticipate what happens when the level of the stresses is getting close to ultimate strenght of material and there are strong phenomena of non-linearity. Numerical codes able to discretize material behaviour outside the range of linearity could solve this problem.

Much attention must be paid to fracture mechanism under ciclic loads and variations of modal parameters. Nowadays we are examining the possibility of realizing a small prototype to carry out a limit condition test.

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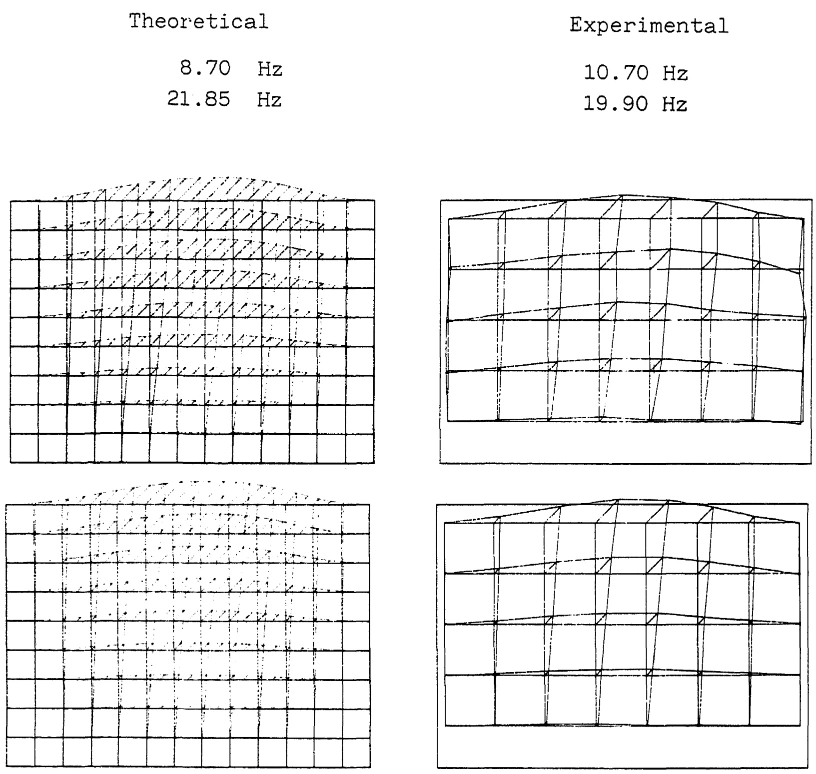


Fig. 1 Comparison between the first theoretical modal shapes (left) and the experimental ones (right) of a thin steel plate embedded in a very stiff concrete tank in the case of full (up) and empty (down) reservoir.

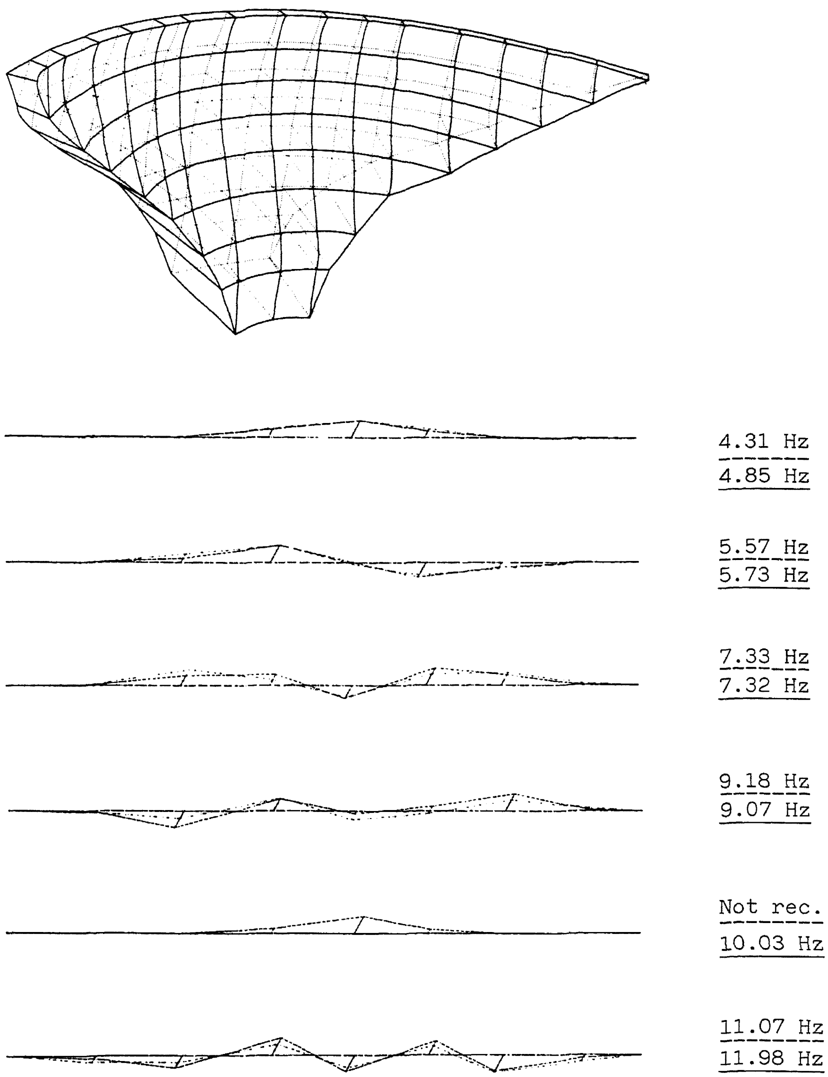


Fig. 2 Arch gravity dam (arch crest) - Comparison between six theoretical modal shapes and experimental ones (by mechanical exciters).
—— computed - - - - measured

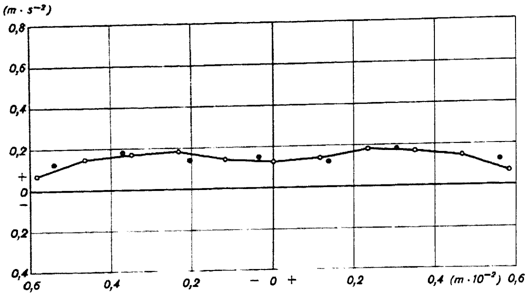


Fig. 3 Ambiesta dam (arch crest) - comparison between computed and measured accelerations during the after shocks of the Friuli's earthquake.

o—o computed • measured

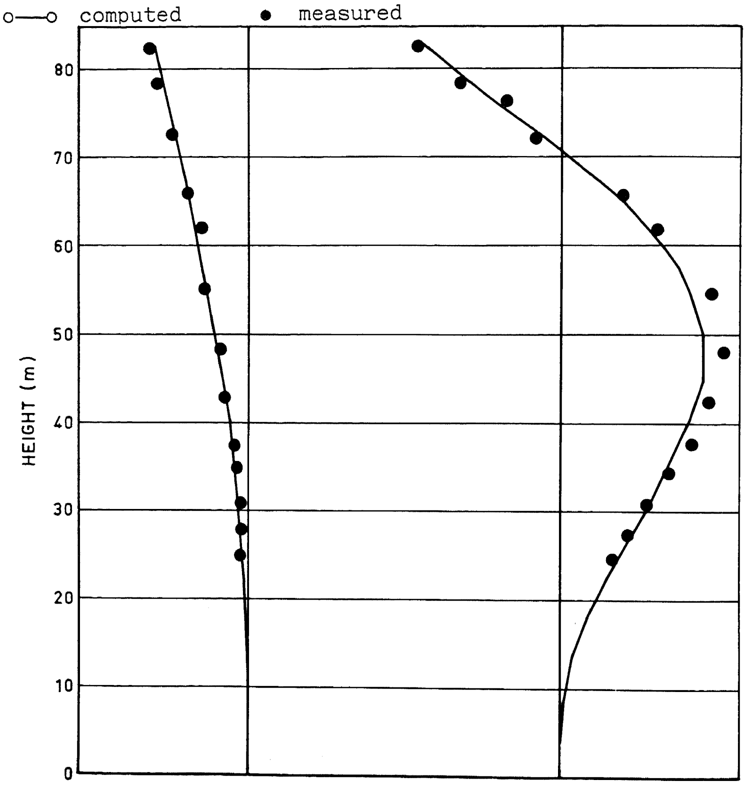


Fig. 4 Chimney - Comparison between computed modal shape and experimental ones gained during wind excitation (the 1st mode on the left, 2nd on the right). —— computed • measured