

EARTHQUAKE ENGINEERING IN FRANCE

by C. E. PLICHON^I

SEISMICITY

Because nuclear power plants must be safe against earthquakes, seismic design must be employed in France. For many centuries France has accumulated fairly extensive archives on seismic activity. These data are not so useful as accelerograms for earthquake engineering but the lack of records is less dangerous than the lack of historical observations, as is emphasized by the unexpected Charleston event in U. S. A.

A seismic map has been established by Rothe⁽¹⁾ taking into account maximum intensities observed and geological considerations. The first map is of maximum intensities which have been observed in the past. The length of the observation period is enough to reasonably prepare a second map that is of maximum intensities which might be expected in the future.

SAFEGUARD RULES

Two earthquake intensities are used:

- 1^o) The operating basis earthquake is the event after which the Plant is able to restart with a few repairs and verifications. The primary system and other facilities containing fission products are undamaged as well as containment vessel.
- 2^o) The hypothetical earthquake, generally two times greater than the previous one, is that after which, even if it has triggered the nuclear accident, the containment vessel is able to contain reasonably any fission products, and there can be a safe shutdown. This earthquake is never less than intensity VII (0.1 g).

DYNAMIC ANALYSIS

We perform a transient analysis for all structures containing or supporting a nuclear system. The steam power supply, as it is manufactured by others, is not analysed by us, but as it is a standard unit it seems there is no special difficulty. The purveyor verifies that the acceleration level and the bandwidth of the spectrum we give to him can be safely resisted. The analysis we do is not the most elaborate but it seems well adapted to our problem. Structures are assumed to be short beams with complex flexural and shear stiffness and rotary inertia (Fig. 2). The computer program is simple, it calculates the transient behavior of rigid bodies, moving in a vertical plane, each with two degrees of freedom: an horizontal translation and a rotation about an horizontal axis. It is possible to take into account the flexure of the slab subjected to opposite torques from vessel, internal concrete and soil:

$$\ddot{Y} = \sum_n \left\{ \frac{K}{M} Y_n + \frac{C}{M} \dot{Y}_n \right\}$$

^I Electricite de France, SEPTEN

For a cylindrical vessel the parameters are (Fig. 3):

$$K_S = \frac{\rho}{2} \frac{GS}{\rho} \quad K_R = \frac{ETg}{\rho}$$

The soil is assumed to be a semi-infinite elastic medium with a modulus, chosen generally high (20,000 kg/cm²), to get an upper bound of stresses in structure, or low (2,000) to get an upper bound of relative displacements. Only damping due to infinite radiation is assumed. The complex soil parameters are: ⁽²⁾

SHEAR

$$\frac{\mu R_0 F_R}{F_H F_R - F_D^2}$$

ROTATION

$$\frac{\mu R_0^3 F_H}{F_H F_R - F_D^2}$$

CROSSED

$$\frac{\mu R_0^2 F_0}{F_H F_R - F_D^2}$$

F_r , F_R and F_D being transfer functions between forces and displacement of a circle foundation on an semi-infinite elastic medium. This program given directly the maximum stresses and displacements in each spring and the maximum absolute acceleration of each center of gravity (Fig. 4 et 5).

ACCELEROGRAMS

The accelerograms we use are El Centro, May 18, 1940, San Francisco March 22, 1957, Taft, July 21, 1952, Vernon, March 10, 1933 and Parkfield June 27, 1966. All received a translational base line correction to give zero velocity at the end of the earthquake; then they have been filtered through two seismographs with 70% damping and natural undamped frequencies of 0.2 and 25 cps to eliminate high frequencies and effects of digitizing errors. All are normalized to 1 m/s² as a maximum acceleration. The mean spectrum is very smooth. We used also an algebraic expression for acceleration⁽³⁾ which gives results, for less than 1 second of quake duration, close to the mean of our natural earthquakes (Fig. 1).

RESULTS

The results of the calculations in terms of maximum stresses and displacements are used to design the walls. The base slab is designed with a static bidimensional finite-element method using asymmetric forces. The dome is separately calculated to withstand a vertical component of motion with a shell program including the skirt.

The first vertical frequency is about 15 cps when the wall is fixed at the base. The equivalent mass is low (27%) compared with that of the horizontal first mode and, of course, to achieve the total mass it is necessary to take into account the participation of higher modes even if they are out of the seismic band with. As the higher modes are numerous there is a better way to get their participation. Recalling that the static

deflection is the sum of the whole eigenvectors in phase with a pseudo velocity of g , and that the participation of the higher eigenvectors is the difference between static deflection and first eigenvectors with an adequate acceleration. Then it is easy to combine dynamically the first eigenvectors and the "residus" of the others.

We have compared the frequencies, seismic coefficients and equivalent masses of the structure alone both by the short beam and the thin shell theories; differences are less than 10% and hence, they are acceptable compared with the differences between two natural earthquakes of equal maximum acceleration.

TABLE I

Second mode	Freq.	Seismic coef.	Equiv. mass
BEAM	18.67	.505	.177
SHELL	17.6	.561	.162

The cost of constructing for earthquakes loading for 7-8 intensities is estimated at 2% of the structure cost. For non-pressurized containment structures the amount of concrete is enough due to biological protection; only the reinforcement is increased generally by 25%.

PROPOSALS FOR FUTURE

It was found that rigid structures increase the absolute acceleration. There is only one way to avoid this phenomenon which is to filter the soil acceleration so as to tune the system at low frequency, with a large equivalent mass and, if possible, a more favorable mode shape. This effect can be obtained with a small amount of hooped elastomer (5 to 10 cms). Then it is possible to control the first mode frequency and, to push up the old rigid one, to decrease its equivalent mass and also its bad effects. However this technique has been already used for gas-cooled St-Laurent des Eaux and Bugey nuclear plants but not yet for a light water plant. This would be interesting but needs some engineering studies to adapt the containment vessel's bottom to an edge-type foundation, piping systems to relative displacements of about 2 to 5 centimeters, etc...

- (1) IIIth WCEE - 1969 - J.P. Rothe - Seismicity Maps of France
- (2) Annales ITBTP - 1967 June - G. Delauze - Réponse à un mouvement sismique d'un édifice posé sur un sol élastique.
- (3) Ith Conference Structural Mechanics in Reactor Technology September 1971. Problemes de Seismes D. Costes.

