Zeitschrift: IABSE reports of the working commissions = Rapports des commissions de travail AIPC = IVBH Berichte der Arbeitskommissionen

Band: 30 (1978)

Artikel: Seismic design for central nuclear en Embalse - Cordoba

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DOI: https://doi.org/10.5169/seals-24168

SEISMIC DESIGN FOR CENTRAL NUCLEAR EN EMBALSE - CORDOBA

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S U M M A R Y

Structures of Reactor Building and Service Building of the Central Nuclear en Embalse - Córdoba, were designed for seismic action performing static analysis and dynamic modal analysis, using finite element models. The main features of these models, and salient results of the analysis are reported in this communication.

1. INTRODUCTION

Argentine second Nuclear Power Plant, of 600 MWe, is at present in an advanced stage of construction near Embalse, Province of Córdoba.

It has a CANDU reactor, using natural uranium as fuel and heavy water as moderator and coolant. The reactor and the complete Nuclear Island of the Plant is supplied by AECL (Atomic Energy of Canada Limited).

The Plant is located in a moderately seismic zone, qualified as zone 1 in Argentine Earthquake Resistant Regulations (CONCAR 70). Due to building function, in design of structure were applied, in addition to above mentioned Regulations, requirements of AECB (Atomic Energy Control Board of Canada), which are indicated in relevant design specifications.

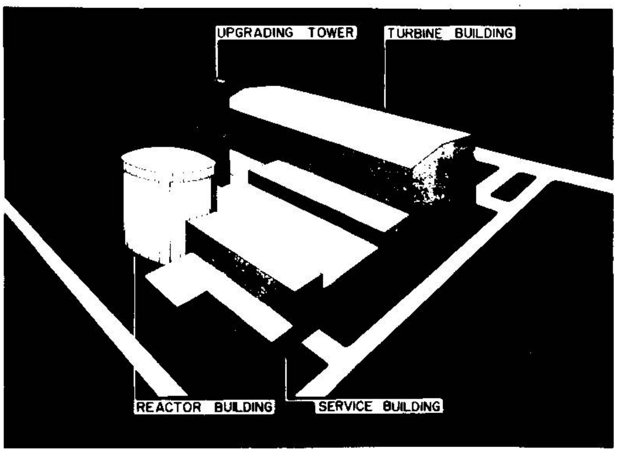

Fig. 1 - Aerial view of future Embalse Nuclear Power Plant

2. DESCRIPTION OF THE PLANT

Main buildings of the Plant include three adyacent buildings, of different type:

- Reactor building
- Service building
- Turbogenerator building

This communication refers only to the first two buildings, also called Nuclear Island, since same requirements are not applicable for Balance of Plant.

Reactor building includes an internal structure, in reinforced concrete, of several floors, which gives support and housing to Reactor and other equipment of primary system. Containment structure is a prestressed concrete cylinder with a dome of spherical sector shape, and has a protective function in case of a nuclear accident.

Service building includes spent fuel storage bays, heavy water upgrading tower, and a multistory building housing different systems for service of reactor. Its structure is in reinforced concrete.

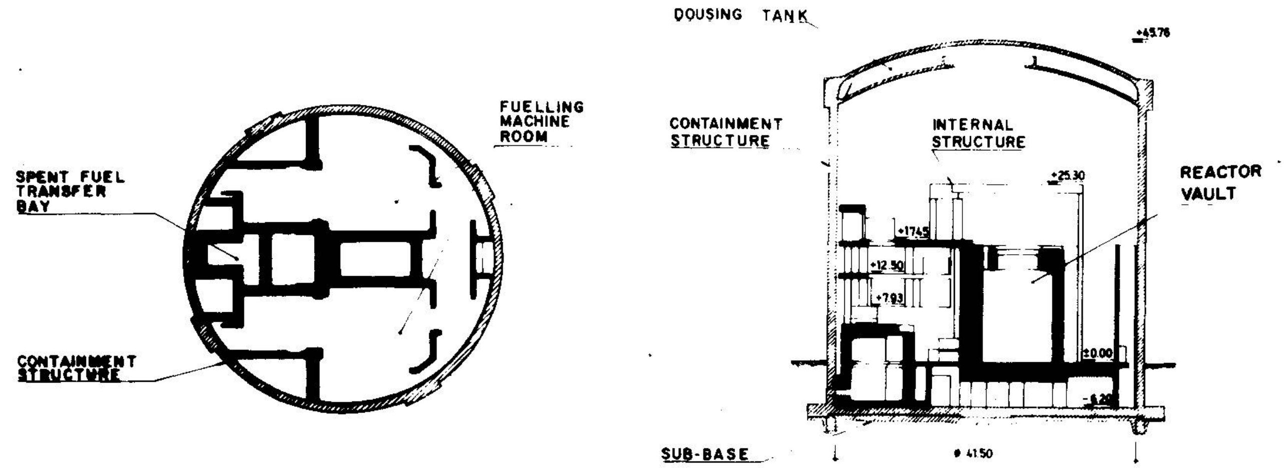

Fig. 2 - Reactor Building Plan and Elevation

3. DESIGN REQUIREMENTS

Basic design specifications, by AECL, define the "Design Basis Earthquake" (DBE) as the earthquake which has a probability of occurrence of one event per 1.000 years. Horizontal response spectrum for this earthquake is indicated in Fig. 3; to be used together with a vertical response spectrum, which is one half of horizontal response. Moreover, the "Site Design Earthquake" (SDE) is defined as the earthquake which has a probability of occurrence of 1 event per 100 years. Its spectrum is obtained from DBE spectrum, reducing its ordinates to one half.

AECL's design requirements, in general terms are:

Loading hypothesis to be considered:

I. Normal operation, with or without wind.
II. Normal operation with SDE earthquake.
III. Accident in primary sistem.
IV. DBE earthquake, with Plant shutdown.

For the first two hypothesis it is required that maximum stresses be below maximum normally allowable values. For the other two hypothesis (exceptional loading) increased values for maximum stresses are allowed.

For containment structure a fifth loading case, proof pressure, is specified; moreover, structure shall be leak proof, and this requires absence of cracks in every case, and absence of tensile stresses in the inner face, for normal loading hypothesis.

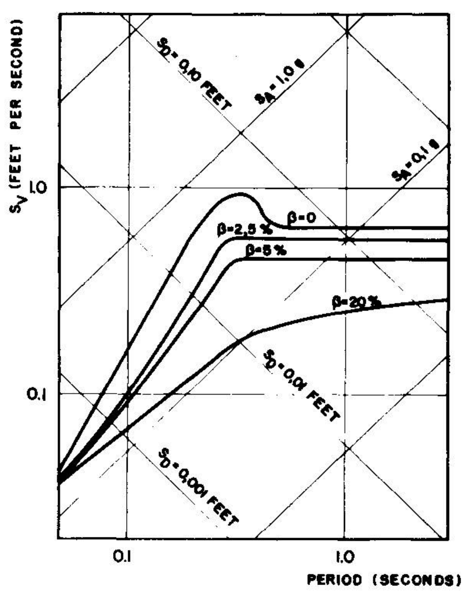

Fig.3 - Design Basis Earthquake Spectrum

To compute stresses, elastic behaviour of material is assumed.

4. EARTHQUAKE RESISTANT DESIGN OF STRUCTURES

Taking into account different features of structures, in each case different procedures were used.

4.1 - Reactor Building Internal Structure

This structure was analyzed using a finite elements model and the earthquake effect was considered in a first approach by means of horizontal static forces.

These forces were obtained using accelerations previously computed by a dynamic analysis on a very simplified lumped mass stick model.

Later, a new dynamic analysis was performed, using another finite element model, somewhat simpler than the one used for static analysis.

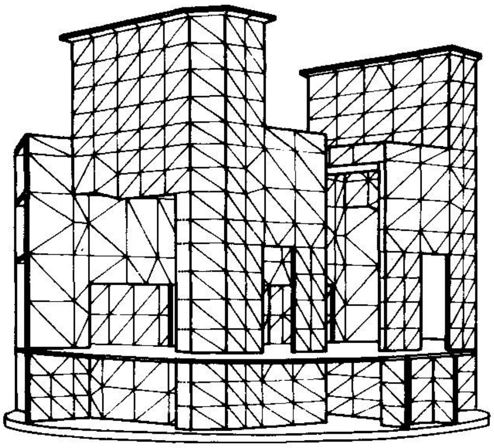

Fig.4 - Reactor Building Internal Structure - Finite Element Model for Static Analysis

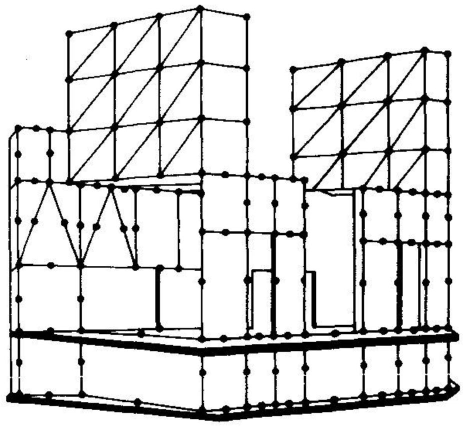

Fig.5 - Reactor Building Internal Structure - Finite Element Model for Dynamic Analysis

The figure does not show foundation soil, which is represented in the actual model by means of a cylinder of 20 m depth, and with a radius 20 m larger than base slab radius. Also containment structure mass is considered, in an approximate way, as a concentrated mass in the vertix of a piramidal membranal surface fixed to base slab contour.

This model has 173 degrees of freedom, and masses are concentrated in 36 joints.

Natural period of first mode is of 0.32 sec.

Design earthquake response was evaluated using a mean damping ratio of 4 % for the whole soil-structure system. By this value is intended to have a weighted mean value between a damping ratio of 2 % for concrete structure and 10 % for soil.

In dynamic response the first 12 modes are considered; modal composition was performed by square root of sum of squares.

Maximum acceleration of highest points of structure reaches 0.58 g.

<u>4.2 - Reactor Building Containment Structure</u>

For this structure earthquake effect is less important than other loading cases, like proof pressure or accident. Hence earthquake was not considered in static analysis, which on other hand was performed by means of an axisymetric model, since main loadings have this type of symetry.

Then dynamic analysis was performed using a finite element model which includes base slab, on elastic supports, perimeter wall, both domes, steel structures for dousing system, and water mass in dousing tank and piping.

This model has 116 degrees of freedom. First natural mode period is 0.42 sec. For design earthquake response damping ratio of 2 % was used for structure and 5 % for interaction with soil.

First 40 vibration modes were considered, performing modal composition by square root of sum of squares.

Overstresses in concrete due to earthquake are about 15 kg/cm2.

For elements of dousing system structure maximum horizontal accelerations of about 0.29 g were obtained.

4.3 - Service Building Structures

Due to extension and irregular shape of this building, its structure was divided into five sectors by means of expansion joints. Structures in general are formed by cast in place reinforced concrete columns, beams and slabs. Earthquake resistant elements are in general space frames, but there are also, for functional requirements, some concrete walls, which give to the structure more stiffness and strength. In some cases concrete walls were added to minimize mass excentricity with respect to stiffness center.

Some building sectors house only systems and equipment not directly related to Plant operation, e.g. maintenance shop, laboratories, etc. For these sectors it was considered sufficient a static analysis, i.e. compute natural period of the structure from deformation under horizontal static forces; determine seismic coefficient C for that period according DBE spectrum, compute total lateral force using this coefficient, and distribute it over the height, in accordance with CONCAR 70 Regulations. In this way were analyzed Sector II, whose natural period is 1.6 sec. in one direction and 1.1 sec. in the normal one, and C = 0.10 was assumed; and Sector III, whose natural periods range between 0.36 sec. and 0.75 sec., assuming C = 0.15.

For other sectors, housing equipments and systems of major importance, same procedure was used, but in addition a dynamic analysis was performed to compare its results with those of static analysis. These sectors are:

- Sector I, which houses spent fuel bays and main airlock for access to reactor building. For static analysis was used C = 0.10. Dynamic analysis showed a natural period of 1.2 sec, and accelerations of highest points of
- Sector IV, housing Control Room, Radwaste and D_2O tanks. Most of columns of this sector are fixed in basement slab, which rest directly on soil. Plan is almost square and structure is regular. Static analysis used C = 0.15. Dynamic analysis was performed with different hypothesis about stiffness of soil-structure system, including or not influence of masonry walls, which are not considered as earthquake resistant elements. Results comparison demonstrated that neither foundation soil flexibility nor walls modify substancially structure behaviour. Moreover, displacements and accelerations of each floor are sufficiently near to those of static analysis. Consequently these results were assumed valid, without any correction. Natural first mode periods range between 0.47 and 0.49 sec, and accelerations of highest points range between 0.296 g and 0.326 g in one direction, and 0.355 g and 0.368 g in the normal one.
- Sector V, which houses systems directly related with the reactor, like heavy water systems, and other important systems and equipments. From structural point of view, peculiarity of this sector are a very irregular plan layout, and a 70 m high very slender tower, with reinforced concrete walls, housing the heavy water upgrading tower. Static analysis used C = 0.15 for the base building and C = 0.10 for the tower. According to results previously obtained for Sector IV masonry walls and foundation flexibility were not accounted for, because walls distribution and foundation features are similar for both sectors. Instead of this, damping ratio influence was investigated, reanalyzing for β = 7%; 4% and 2%.

Comparison of results indicated that, even in the very conservative hypothesis of damping ratio of 2%, displacements and accelerations are much below those of static analysis. Specially for stresses verification in the tower it is necessary to reduce forces obtained by static analysis, even if, following recommendations of most Regulations, reduction was limited to 75 % of those values, while forces resulting from dynamic analysis are only 71 % of same values.

Natural first mode period is 1.63 sec. Accelerations of highest points of base building range between 0.285 g and 0.448 g in one direction and between 0.204 g and 0.347 g in the other, depending on assumed damping ratio. In the tower accelerations for highest points range similarly between 0.489 g and 0.968 g and variation of accelerations along the tower shows a minimum about the upper third of its free height, typical of this kind of building.