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SEISMIC ANALYSIS OF A PWR 900 REACTOR : STUDY OF REACTOR BUILDING WITH SOIL-STRUCTURE INTERACTION AND EVALUATION OF FLOOR SPECTRA

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Summary

The seismic analysis of a nuclear reactor can be divided in 2 steps :

- study of building (equipments are integrated as mass only) ; computation of natural modes and frequencies, seismic response, floor spectra at various levels
- study of equipments : computation of natural modes and frequencies, seismic response using floor spectra computed in the previous step.

The present study deals with the first step. The reactor-building includes the concret containment building and the internal building (internals).

The concrete containment building is axi-symmetric, internals are roughly axi-symmetri except buckles, steam generators casemates and some holes in floors.

The calculation has been performed on a 3-D thin shell model of internals with equipments as masses. The results show that the first two modes have the same frequencies (5.87 Hz), and each of them represents 90 % of the total mass of internals. A seismic analysis with this model shows that only the first two modes play some role (this model is sufficiently simple to include some equipments as thin shells and beams).

Then an equivalent axi-symmetric model has been built.

We get with this model the same mode and the same frequency as in 3D model.

On this model a parametric study of the soil-structure interaction effect has been performed using "Bechtel" springs :

- evaluation of the modes and frequencies versus the soil stiffness.
- evaluation of seismic response of the reactor building for 2 different spectra (EDF and DSN) and different soils.
- evaluation of floor spectra at different levels of the reactor building in order to study seismic responses of equipments and eventually internals.

In conclusion this paper shows how a complex structure can be simply modelised in order to perform a parametric study of the seismic response and to come back to a more refined description of some parts of building or equipments.

1. Introduction

The purpose of this paper is the evaluation of seismic response and floor spectra of a typical PWR 900 reactor building with respect to soil-structure interaction (for soil stiffness).

The typical PWR 900 reactor building consists of a concrete cylindrical external building and roof dome, a concrete internal structure (internals) on a common foundation mat as illustrated in figure 1.

The seismic response is obtained by SRSS method and floor spectra directly from ground spectrum and modal properties of the structure.

Seismic responses and floor spectra computation is performed in the case of two different ground spectra :

- EDF spectrum (mean of oscillator spectra obtained from 8 californian records) normalized to 0.2 g (illustrated in figure 2)
- DSN spectrum (typical of shallow seism) normalized to 0.3 g (illustrated in figure 2).

The first section is devoted to internals' modelisation, the second one to the axisymmetric model of the reactor, the third one to the seismic response, the fourth one to floor spectra.

2. Internals (3D model)

Internals are a complex 3-D structure composed of concentric cylindrical walls, connecting radial walls, floor slabs and S.G. casemates.

A 3-D shell model of internals sufficiently simple but giving a right geometric representation except for some small buckles, slabs and holes has been defined and is illustrate in figure 3 (the mesh was performed with the code COCO [1]).

Equipments are, for our purpose, included as masses but it could be possible to includ some of them as beams and shells regarding the small size of our 3-D model (1752 d.o.f).

Small tests on different parts of the structure have been performed to verify that the hypothesis taken for modelisation are acceptable.

A comparison with a previous more refined 3-D shell model shows that the two models ha same lowest modes and frequencies (under 20 Hz). Our model can be viewed, in some ways, as a "minimal 3-D model". The mode calculation was performed by the finite element code TRICO [2] .

This PWR model has two fundamental frequencies of 5.87 Hz and the corresponding modes are orthogonal. Each of these modes represent 90 % of the total mass of internals and equipments. The mode shape is illustrated in figure 4.

3. Reactor building : axisymmetric model and natural modes

a) Model

The results obtained for internals lead to a definition of an axisymmetric model for the reactor building : equivalent axisymmetric model for internals, other parts of reactor building being axisymmetric.

The equivalent axisymmetric model of internals was build up as follows :

. axisymmetric parts of internals (external cylindrical wall, internal cylindrical wall or tank wall, 4 floor slabs) are described by axisymmetric finite elements [3] .

. radial walls are modelised as added mass and their stiffness was taken into accoun with the 3D previous model

. S.G. casemates are taken into account as added masses

. equipments are modelised as added mass , but some of them could be [illegible] axisymmetric shells (fuel tank for example).

The equivalent model gave the same mode frequency and mode shape as the 3-D model.

The evaluation of horizontal seismic response of the 3-D model, clamped at the lowest floor slab, with EDF spectrum input shows that the first two orthogonal modes give almost the overall response, so our equivalent axisymmetric model is sufficient to represent internals in seismic response.

The model of reactor building is obtained by adding to internals axisymmetric model, the external cylindrical wall, roof dome and foundation mat.

This model is illustrated in figure 5.

The soil-structure interaction was represented by springs, as defined in [4] , applied on the external radius of foundation mat.

b) Modes

We present in Table 1 the natural frequencies and modal masses for 3 soil stiffnesses (E = 1000, 5000, 10000 bars).

The first mode is a rotation of the structure, its frequency is almost proportional to $\sqrt{E}$ (rigid body movement), the second one is a translation with a small rotation, the third is a translation rotation.

The sum of modal masses of these three modes is almost the total mass of the structur

The second mode is illustrated in figure 6. All computation for this model have been done with AQUAMODE code [5] .

4. Seismic response

A seismic response has been computed by SRSS method with the two spectra illustrated in figure 2 as input for 3 soil conditions.

a) EDF spectrum (mean of 8 U.S. spectra)

The maximum values obtained for displacement, acceleration, and stress are given in Table 2.

The most important part of the overall response is given by the first mode for displacement, it remains important for acceleration, the two following modes give the major contribution to the overall response for stresses.

One can notice an important decreasing of displacement and an important increasing of acceleration and stress in increasing the soil stiffness.

b) DSN spectrum

The maximum values obtained for displacement, acceleration and stress are given in table 3.

All remarks done for EDF spectrum remain valid for DSN spectrum as input.

5. Floor spectra

In order to study equipments, direct computation of floor spectra was made using ground spectrum and modal properties of the structure [6,7,8] .

The displacement of an oscillator (ν,β) on a floor is given by : (see [6])

$$\left[\omega\, x\,(t)\right]^2_{max} = \frac{e^{-\beta\omega t}\int_0^t e^{2\beta\omega t'}\, E_p^2\,(t')\, dt'}{(1-\beta^2)\int_0^{T_m} Ep^2(t)\, dt} \cdot C\,(\nu,\beta,t) + \frac{\nu^2}{\omega^2}\,\frac{\int_0^{\nu} F^2(\nu_1)\, \nu_1^2\, d\nu_1}{\int_0^{\infty} F^2\,(\nu)\,\nu\, d\nu}\ ,$$

with $$C\,(\nu,\beta,t) = \int_{-\infty}^{+\infty} \left|\gamma_p\,(\nu_1)\right|^2 \frac{2\,\beta'\omega}{(\omega-\omega_1)^2 + \beta'^2\omega^2}\, d\nu_1$$

$$\beta'^2 = \beta^2 + (0.131)^2/t^2\nu^2 \quad , \quad \omega = 2\pi\nu \quad .$$

V is the difference between exact and computed asymptote,

E_p is the envelope of floor movement obtained by square sum of the envelopes of each mode,

γ_p is the Fourier spectrum of floor movement computed from modal properties of the structure

F is the modulus of ground Fourier spectrum,

C is a smooth function of time (convolution).

The floor spectra were computed by the code TIROIR [9] for EDF and DSN spectra as inpu normalized to 1 m/s^2.

In figure 7 is illustrated the floor spectrum with EDF spectrum as input versus the soil-stiffness, in figure 8 the floor spectrum with DSN spectrum as input.

We notice that the difference between the spectra is decreasing with an increasing of soil stiffness.

6. Conclusion

This paper gives a parametric study of a typical PWR 900 reactor building versus the soil stiffness. We get stresses in the building, floor spectra at several levels of the building.

With this results it is possible to study the seismic response of equipments.

This paper shows, also, how a complex structure can be simply modelised in order to perform a parametric study of the seismic response.

One can also use the efforts obtained as input for a static computation of the stresse in some part of the structure or equipment.

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Table I - Frequencies (Hz) and modal masses (tons)

E_{soil} (bars)	1000		5000		10000	
Mode	ν	m	ν	m	ν	m
1	0.7	31920	1.5	31440	2.0	30840
2	1.8	19150	3.7	17270	4.4	12350
3	5.6	60	6.1	2930	7.2	7780
4	12.0	0	12.0	0	12.0	20
5	14.3	0	14.5	20	14.6	20
6	17.7	20	17.8	30	18.0	120

Table II - Maximum values for displacement (δ in mm), acceleration (γ in m/s^2), stress (σ in bars): EDF spectrum.

E_{soil} (bars)	δ	location	γ	location	σ	location
1000	131.	Top of	2.60	Top of	23.0	Down of
5000	58.	roof	5.60	roof	63.0	internals'
10000	43.	dome	7.20	dome	83.4	cylinder

Table III - Maximum values for displacement (δ in mm), acceleration (γ in m/s^2), stress (σ in bars) : DSN spectrum

E_{soil} (bars)	δ	location	γ	location	σ	location
1000	67.	Top of	1.60	Top of	17.3	Down of
5000	42.	roof	4.50	roof	65.1	internals'
10000	31.	dome	6.00	dome	92.8	cylinder

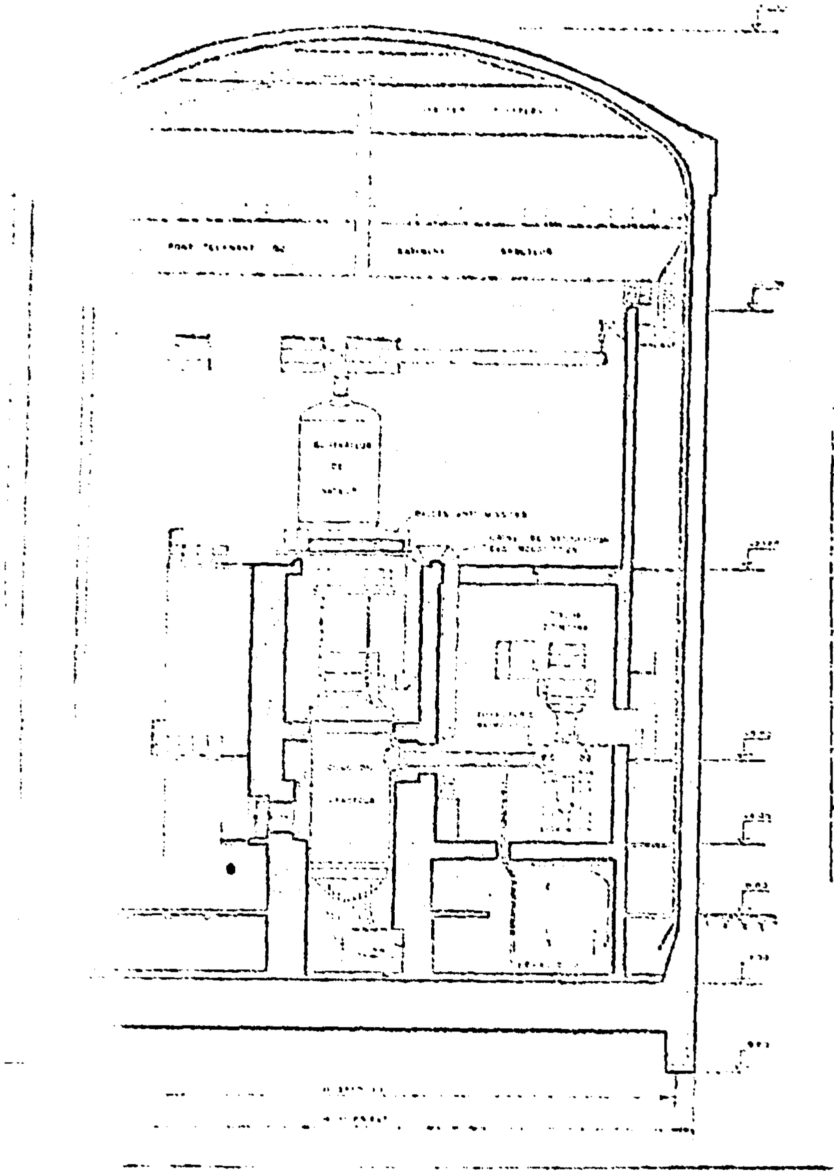


FIGURE 1 : TYPICAL PWR 900 REACTOR BUILDING

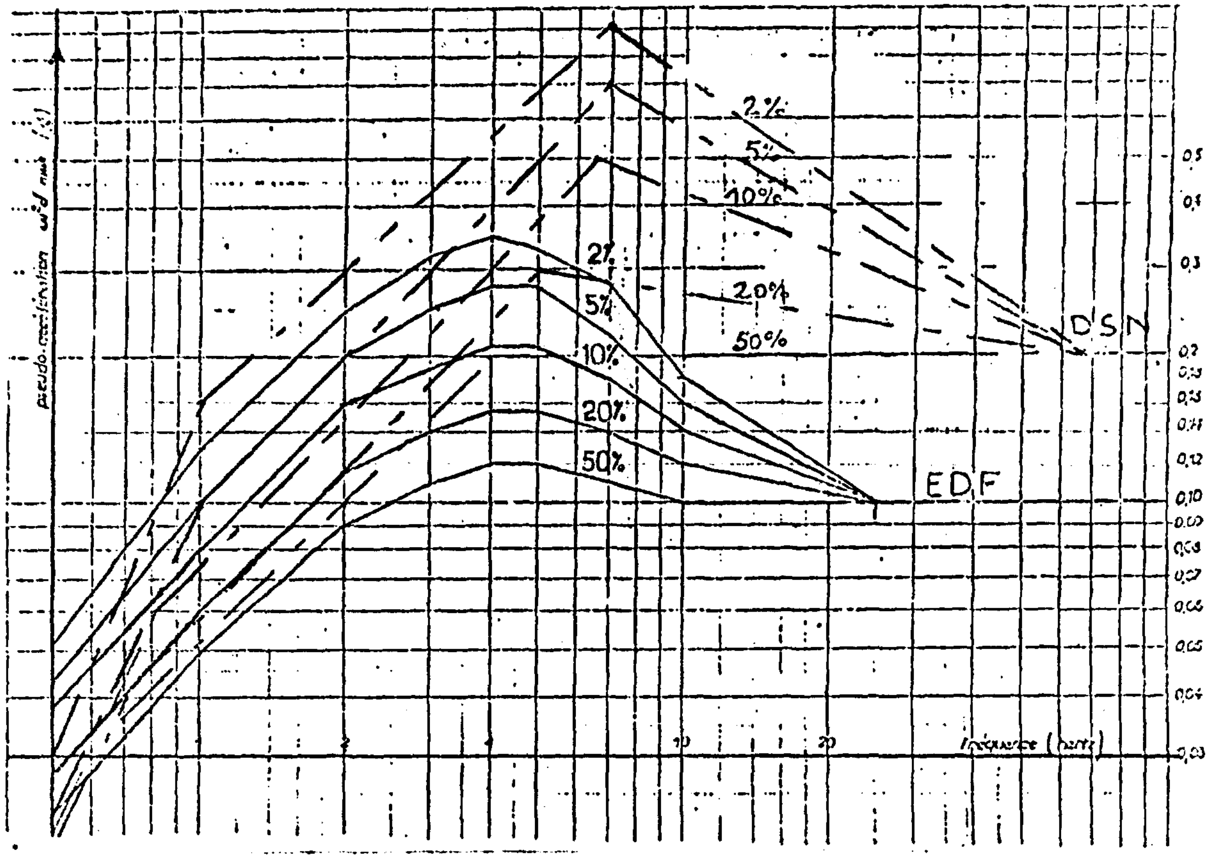


FIGURE 2 : EDF ET DSN SPECTRA

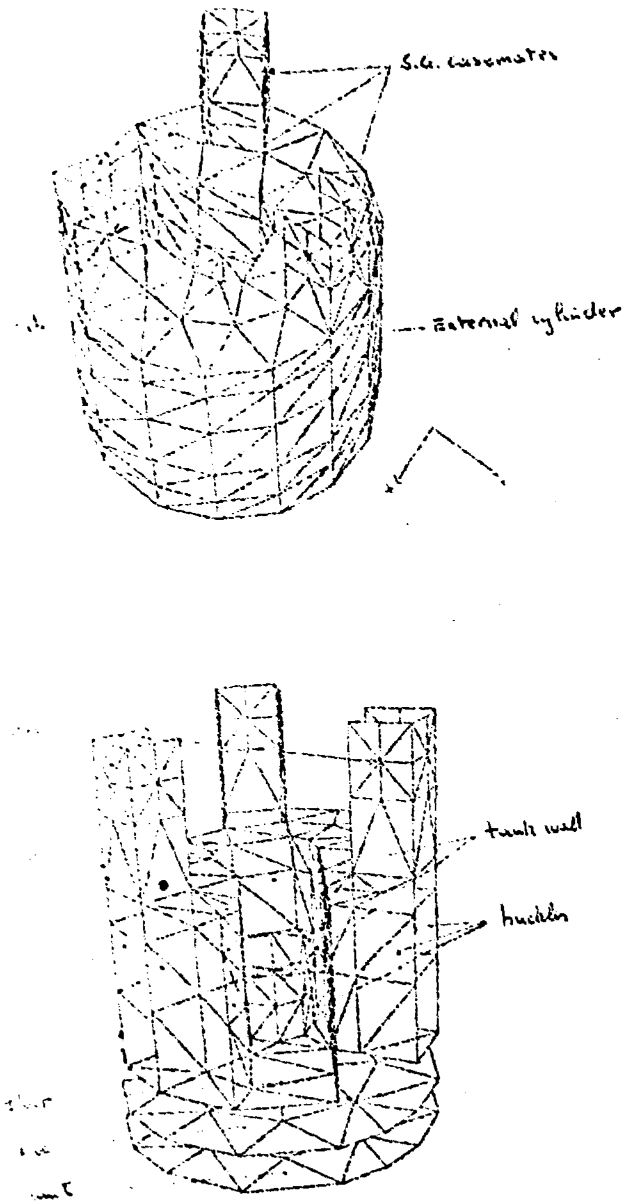


FIGURE 3 : 3-D MODEL OF INTERNALS

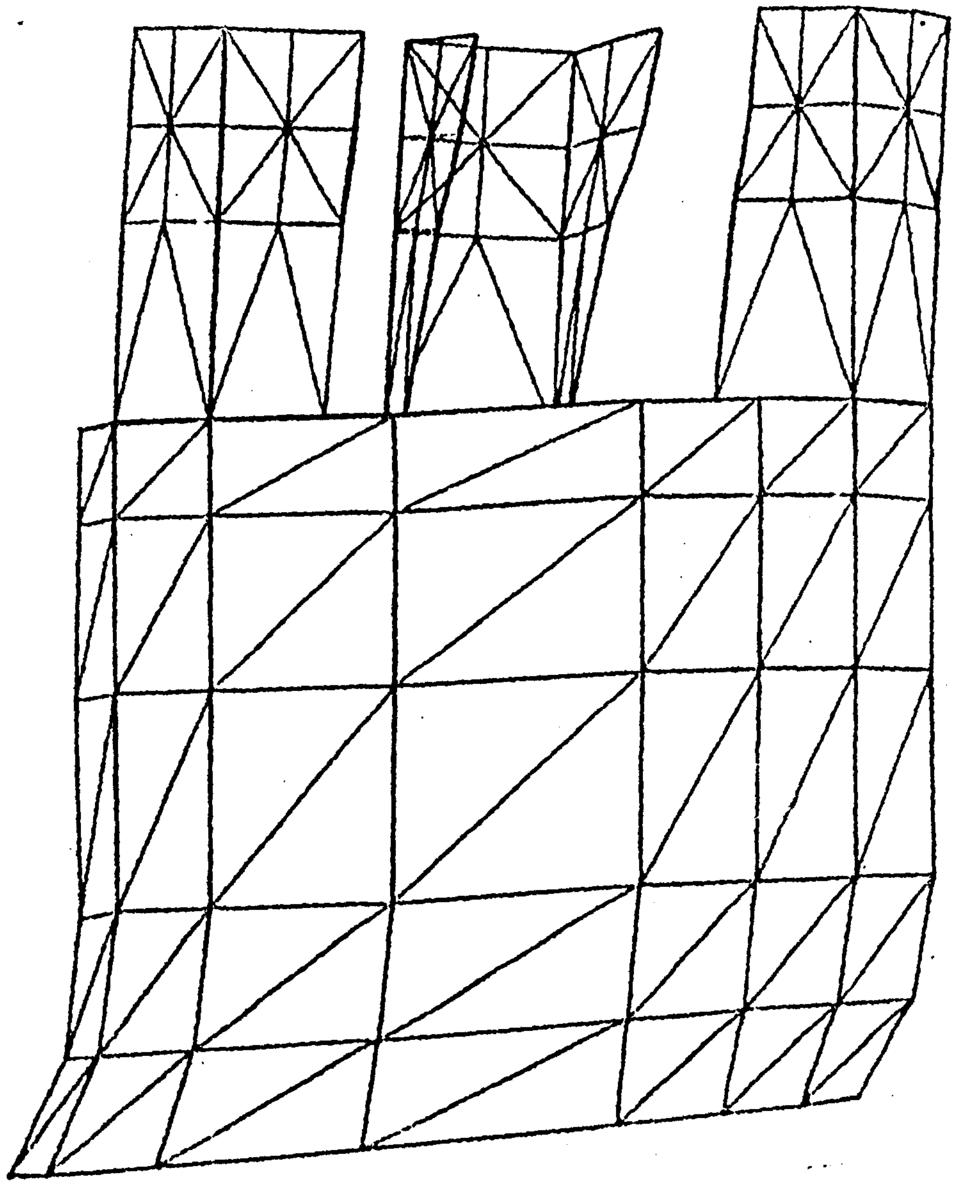


FIGURE 4 : FIRST MODE SHAPE OF 3-D MODEL

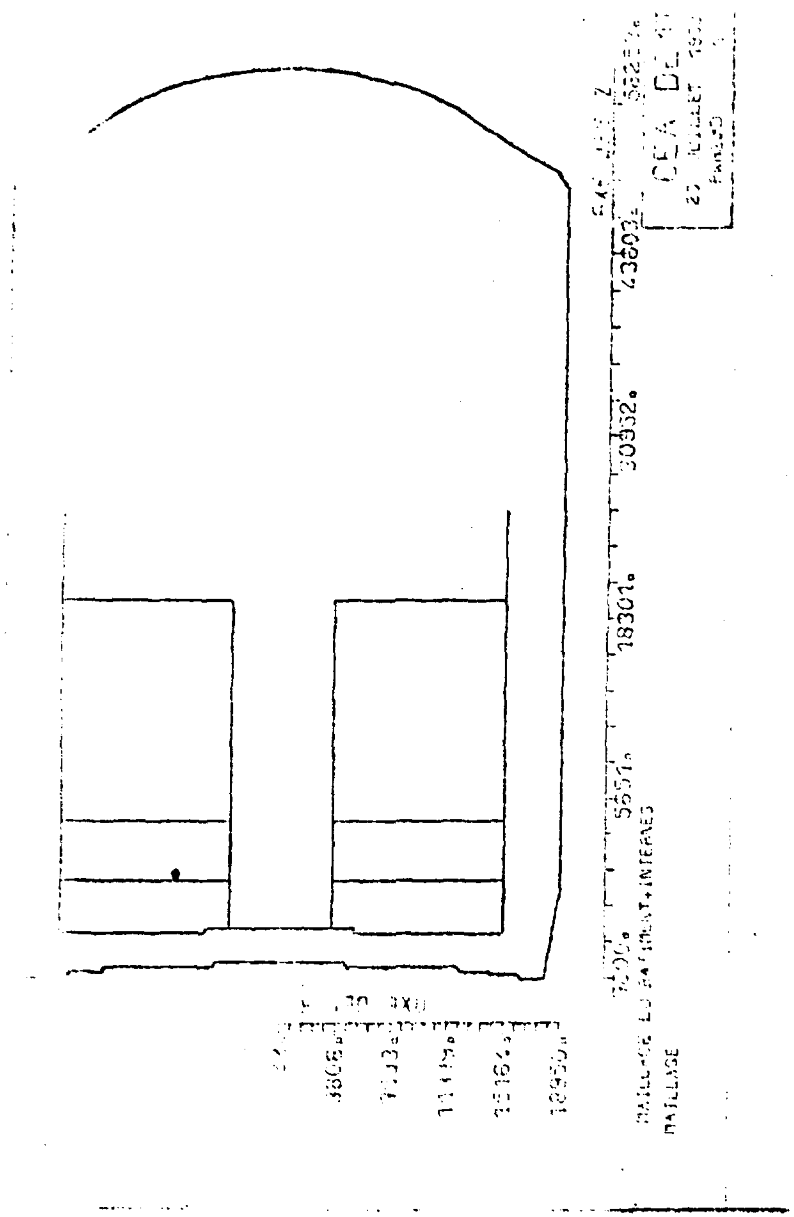
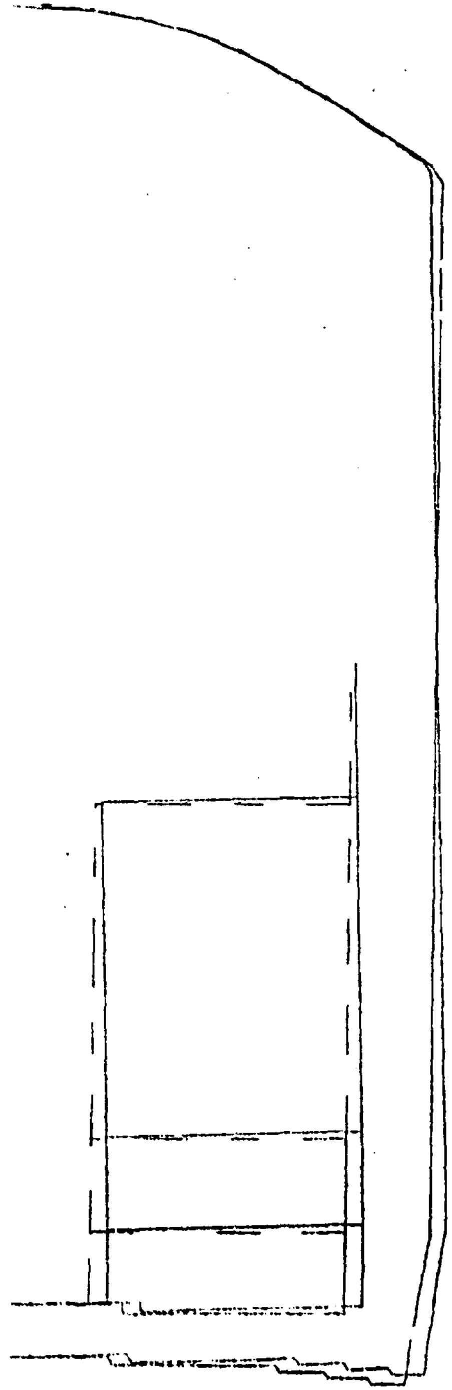


FIG... : AXISYMMETRIC MODEL OF REACTOR BUILDING



...URE 4 : SECOND MODE SHAPE

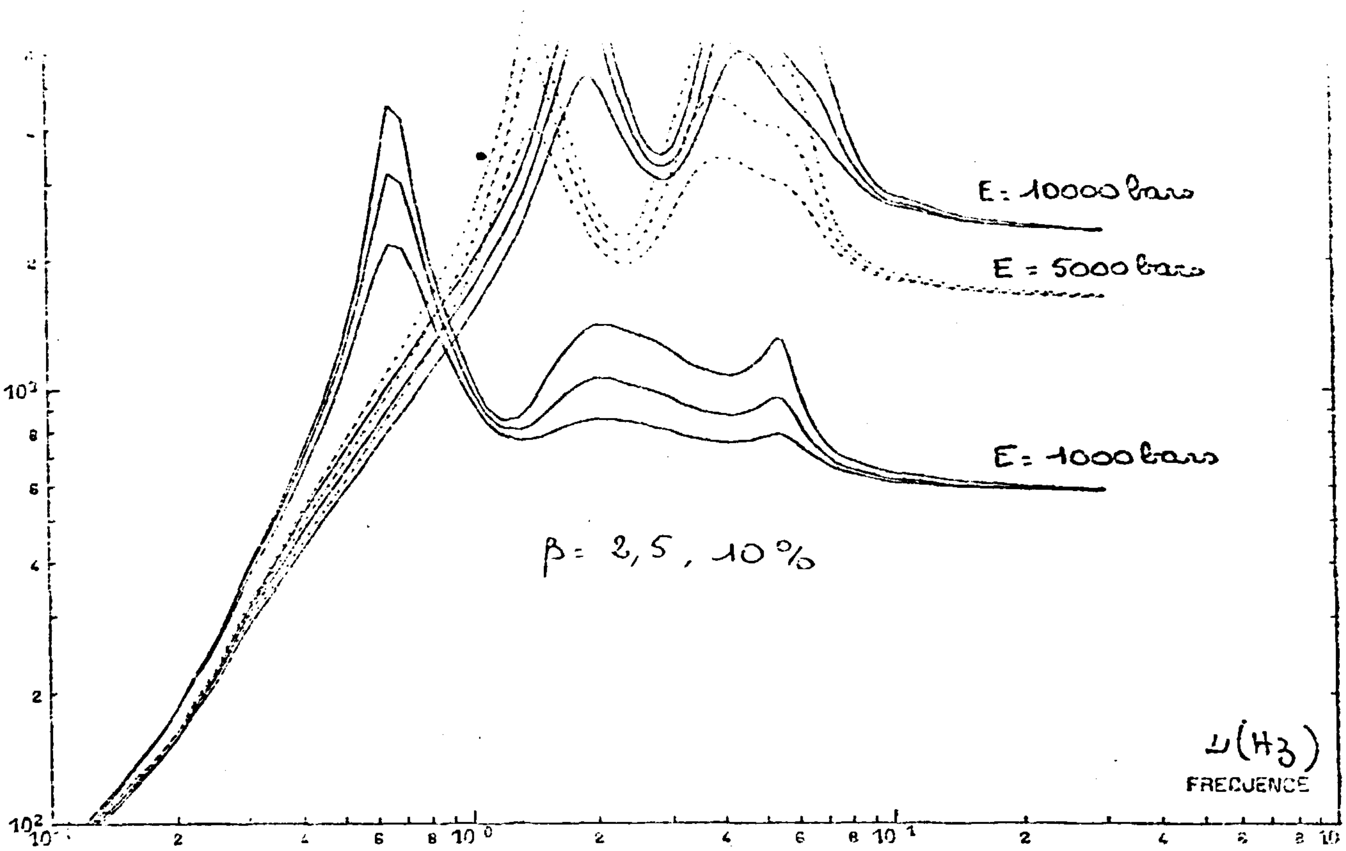


FIGURE 7 : FLOOR RESPONSE SPECTRA (EDF INPUT)

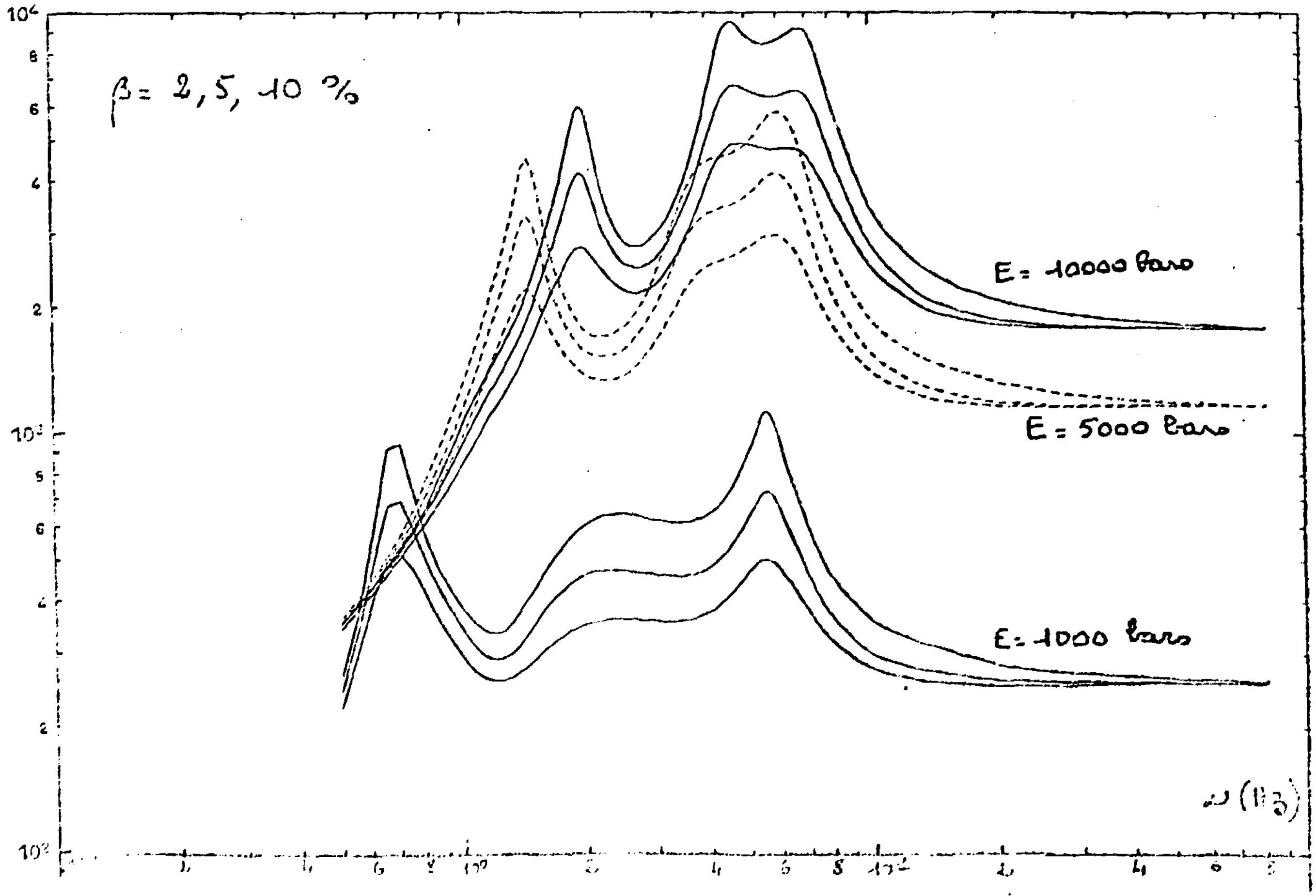


FIGURE 8 : FLOOR RESPONSE SPECTRA (DSN INPUT)