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CALCULATIONS OF CONCRETE CONTAINMENT TIGHT LOSS : STUDIES OF A REINFORCED CONCRETE SLAB WITH NON UNIFORM THICKNESS

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ABSTRACT

A study was carried out in order to investigate the validity of a concrete model including tensile fracture and strain-softening under compressive loading. Triaxial tests were performed on micro-concrete specimens, and the post-peak behaviour of the material was characterized. The parameters required by the model were therefore obtained.

The case of a circular slab loaded up to failure was then considered, in order to compare the numerical results obtained by a finite elements analysis including the concrete model, to the experimental data.

1. Introduction

Safety analysis of nuclear power plants involves situations where reinforced or prestressed concrete is severely damaged under accidental loading. One of these situations is the case of internal pressurization of the containment building. Preliminary elastic analysis has shown that under these circumstances, tight-loss might happen in the vicinity of the gusset between the shaft and the floor of the structure.

A specific study was carried out, in order to estimate the corresponding risk. The investigation consisted of four stages :

- test on a micro-concrete circular slab where the geometrical singularity of the real structure was simulated
- formulation of a simple model, in order to account for tensile fracture and strain-softening of concrete in compression
- tensile tests and triaxial tests on micro-concrete, where the post-peak behaviour of the material could be investigated
- determination of the model parameters, finite elements calculation of the slab, and comparison between the numerical results and the experimental data.

2. Description of the test on the slab [3]

The slab was circular, its diameter was 1500 mm. Its thickness varied between 90 and 160 mm in order to create a geometrical singularity of the same type as the one existing between the shaft and the floor of a PWR concrete containment (see figure 1). It was made of micro-concrete . The slab was simply supported on its periphery and loaded at its center by a circular ring of 400 mm diameter and 25 mm width. The load was increased up to failure (at about 20 tons). The reinforcements are shown on figure .

Force and deflections, measured at various points, were recorded during the test (see figure 2).

3. Description of the material model [4][5][6]

3.1. Concrete model

A simple model has been formulated, to account for non linear behaviour of concrete when analyzing the behaviour of a structure loaded up to failure.

Two main damage modes are considered : tensile fracture and shear damage under compressive loading.

For tensile damage, it is assumed that fracture occurs when the maximal principal stress reaches the tensile strength σ_t of the material :

$$\max_{i=1,3} (\sigma_i) \leq \sigma_t$$

This criterion is depicted in the principal stresses space by a pyramid with 3 orthogonal faces. If it occurs that during loading, one of the principal stresses oversteps the limit stress σ_t, this principal stress as well as the limit stress in traction in this direction are set equal to zero.

For an axisymetrical structure, the model accounts for two different cracking modes :

a) cracking in the circumferential direction

b) cracking in a diametrical plane.

The directions of the first cracks are stored in order to describe the subsequent orthotropic behaviour of the cracked concrete.

On the other hand, shear damage is accounted for by use of two Drücker-Prager criterions :

- the first criterion corresponds to initial damage of the material. After it has been reached, it undergoes strain-softening, while concrete is subjected to further deformation.
- the second criterion corresponds to the situation when shear damage has been completed. Therefore, it corresponds to a lower bound limiting strain softening. It is assumed that after this second criterion has been reached, concrete behaves as a perfectly plastic material.

In the principal stresses space, the corresponding surfaces are two right circular cones with different slopes. The first cone may move down towards the second one, which is fixed.

The parameters required for the model are determined by triaxial tests performed under constant confining pressures.

For the flow rule, the normality principle has been assumed, as a first approximation.

3.2. Reinforcement modeling

For the reinforcements, a classical Von Mises criterion is used, with isotropic strain hardening and plastic flow according to normality principle.

The finite elements corresponding to reinforcement share their nodes with the concrete elements. It is therefore assumed that no relative slip occurs between steel and concrete.

4. Determination of the concrete model parameters

4.1. Shear damage parameters

Several triaxial tests have been performed on micro-concrete cylinders Ø 11 cm, H 22 cm. The experimental device was a classical one (see figure 3). The tests were run under constant confining pressure. The use of a servo-hydraulic testing machine allowed to control the axial displacement rate, so that the behaviour of the material could be investigated, after the maximum load bearing capacity of the specimens had been reached (see figure 4).

On the basis of tests datas, stress-strain curves have been linearized, and the numerical values of the model parameters have been obtained. (Figure 5).

4.2. Tensile strength

Classical Brazilian tests were performed in order to measure the tensile strength of the micro-concrete.

5. Application to the Slab calculation

The model described previously has been implemented in the INCA program [1] of the CEA-SEMT system [2] . The first tests were consistency tests, which consisted in calculating the simple tests performed to identify the model parameters. For this purpose, a single element mesh was used, and various lateral pressure levels were applied together with the axial loading. The results were in good agreement with the input curves.

For the slab calculation we used a mesh composed of quadratic finite elements, with 146 eight nodes elements and 2 six nodes triangles, for the concrete. The reinforcements are discretised by 64 two nodes finite elements and 37 ring elements with one node only. The complete mesh is displayed on figure 6 . The calculation is being performed. Unfortunately the full results were not available at the time of the preparation of this paper.

6. Conclusion

From the first results of the plate calculations and the elementary tests on simple cylinders, the following observations can be made :

1) the modelization of traction, which has been presented, leads to some numerical difficulties, because of the sharp variations of stresses in the damage directions. Therefore displacements have been controlled in the calculation, with small step at the beginning of cracking.

2) strain softening does not present numerical difficulties.

However, the subsequent perfectly plastic behaviour yields to some difficulties in the convergence tests.

Some improvements are planned :

- better description of strains by use of a non-associated potential flow rule
- incorporation of friction between the crack-lips
- accounting for non linearity of experimental hardening curves.

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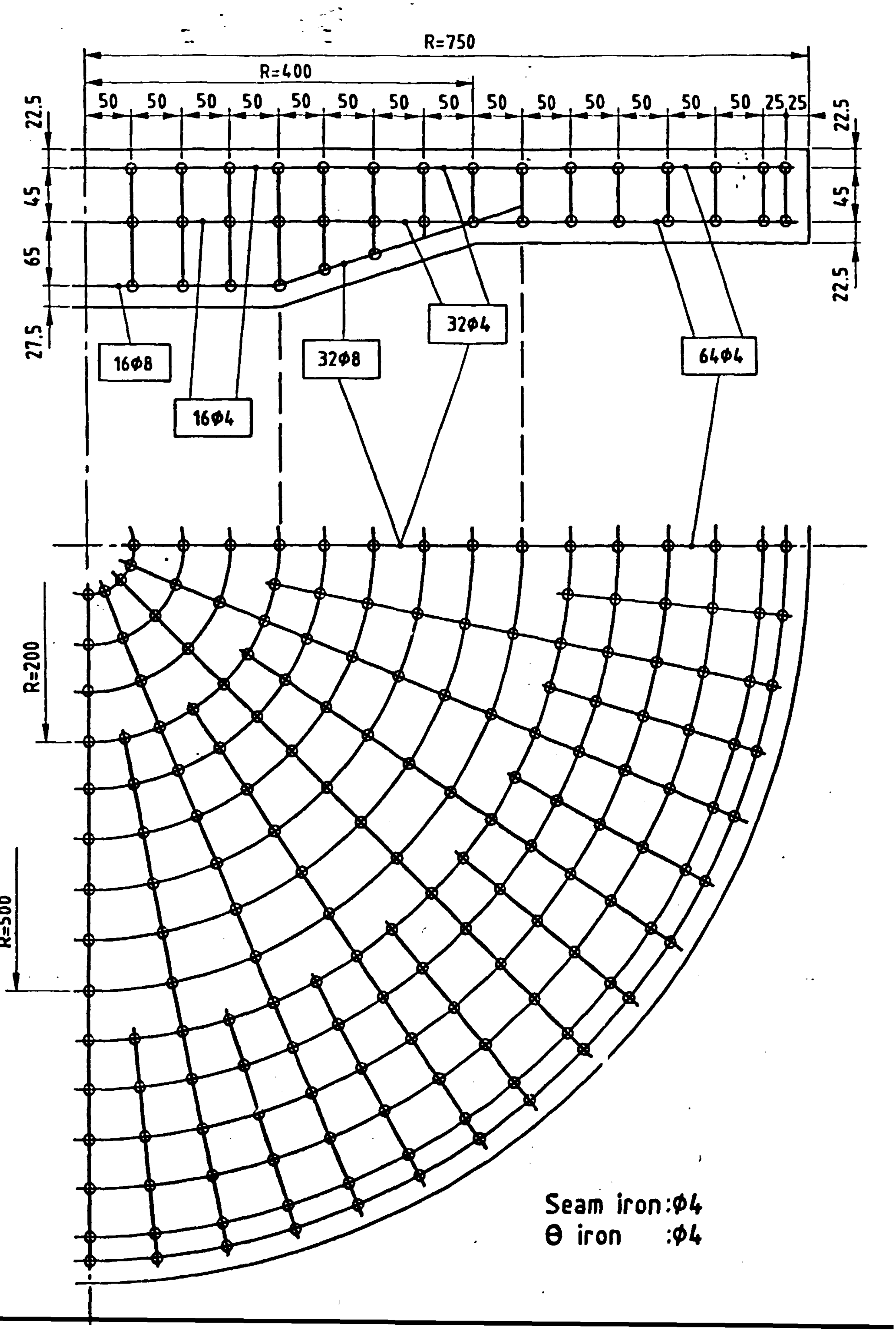
- LIST OF FIGURES -



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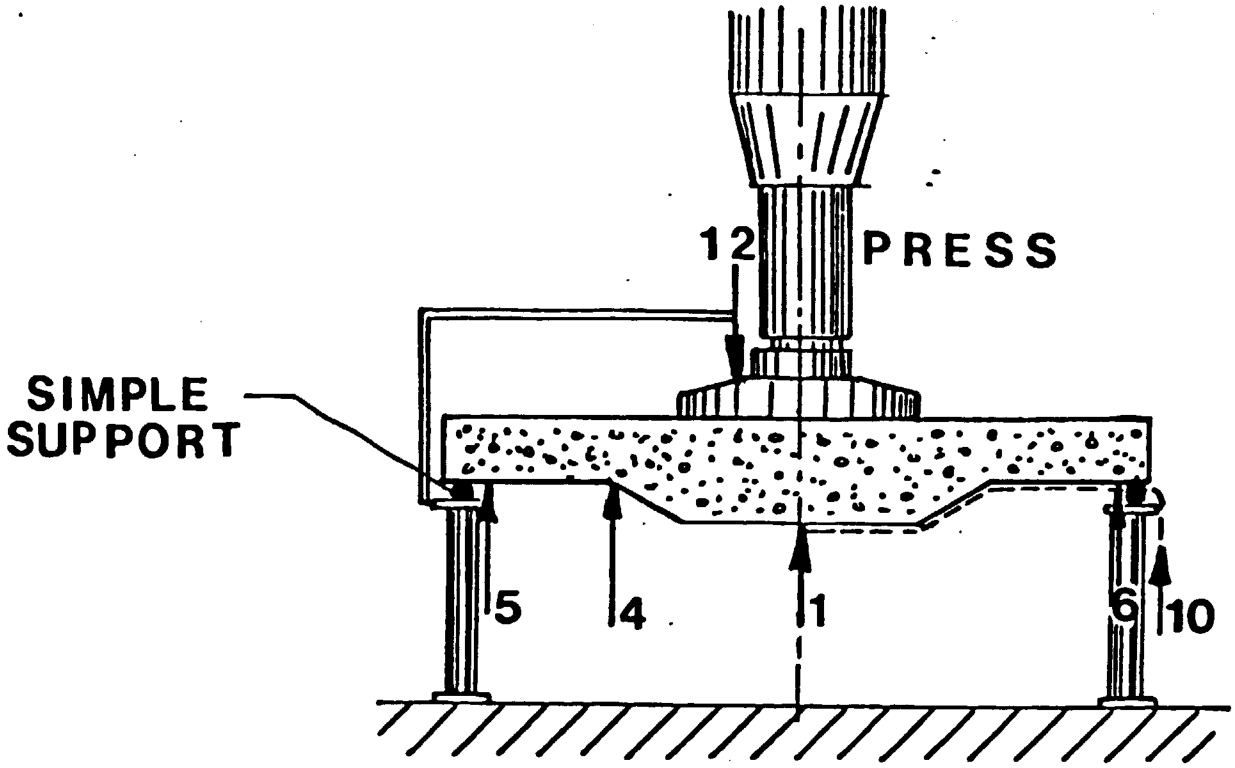
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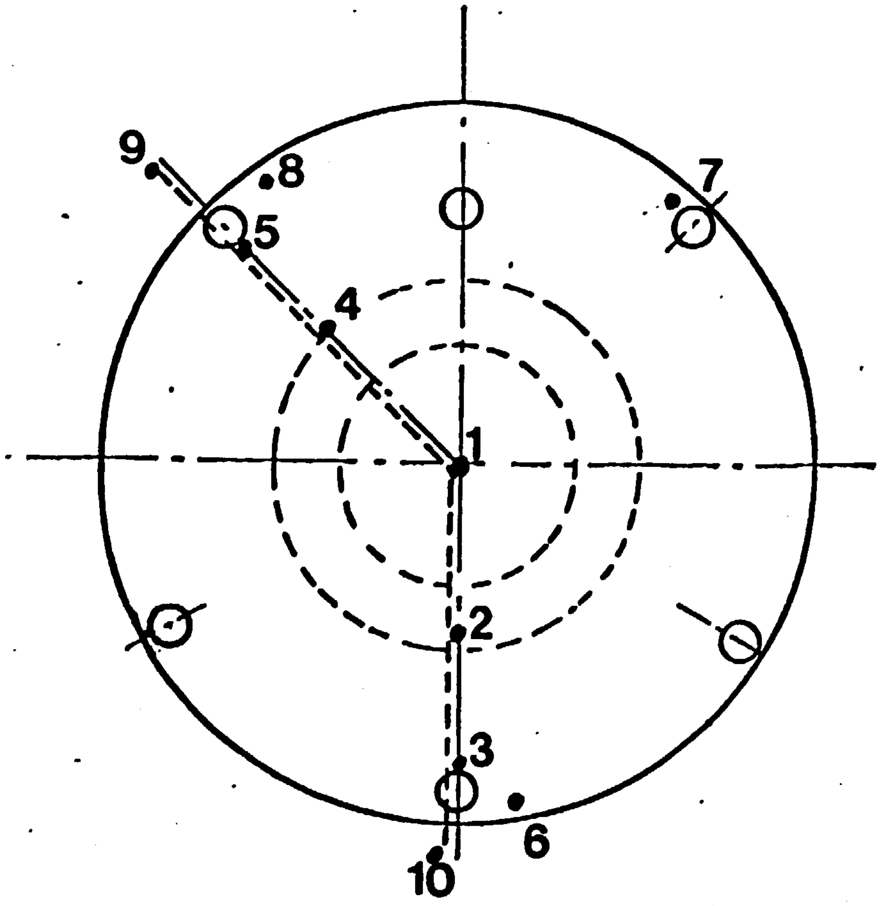
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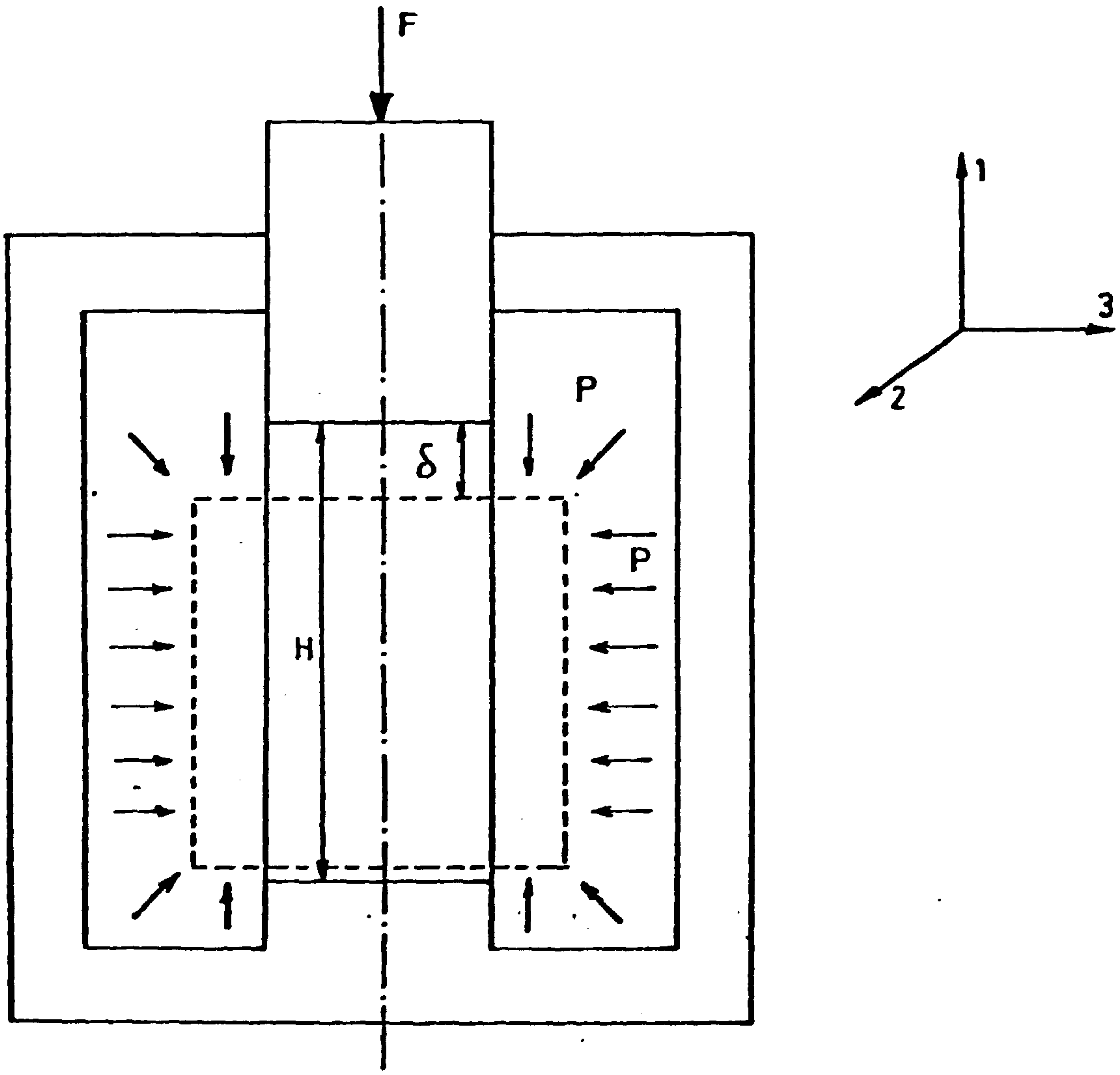
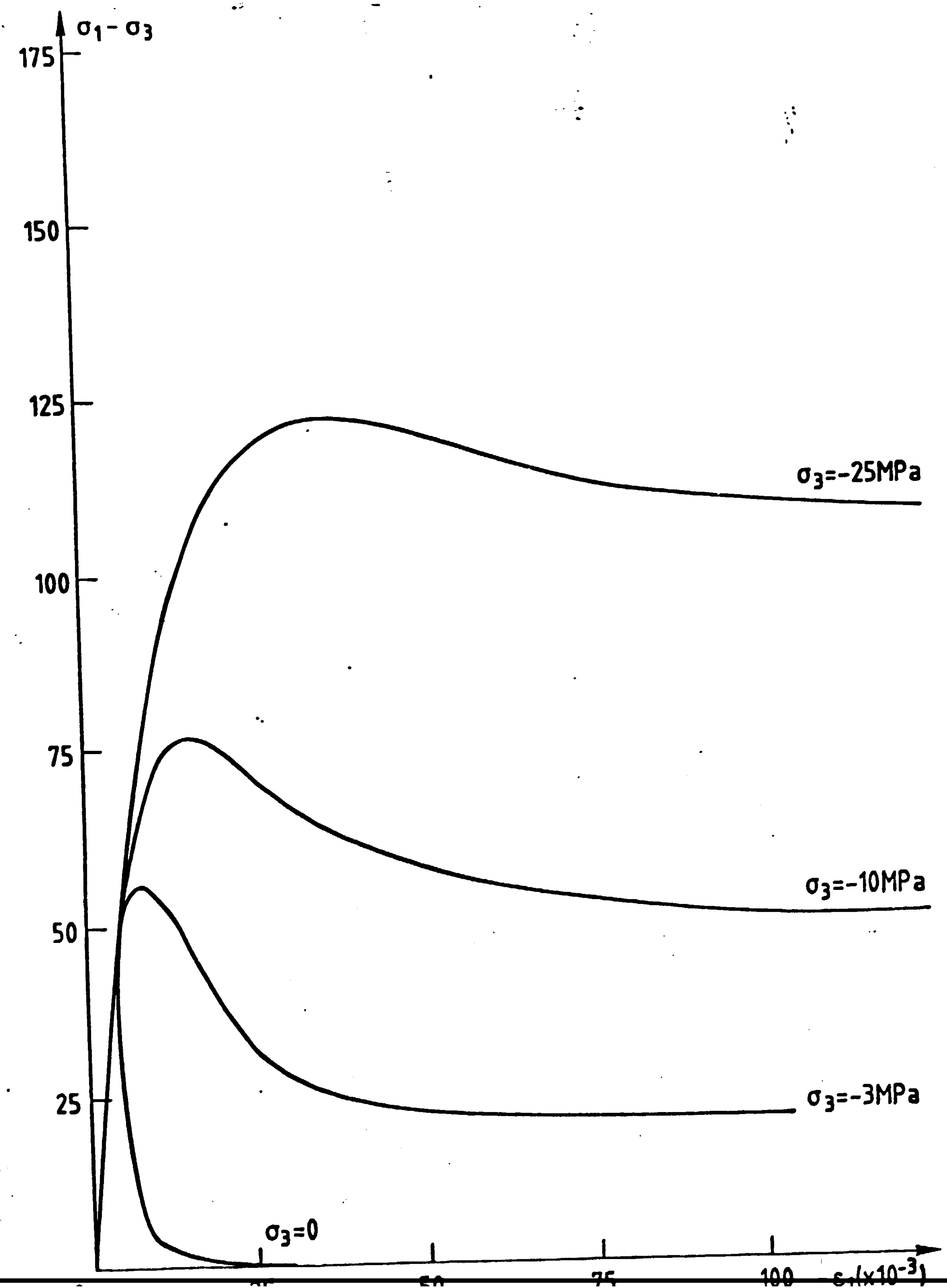


FIG. 3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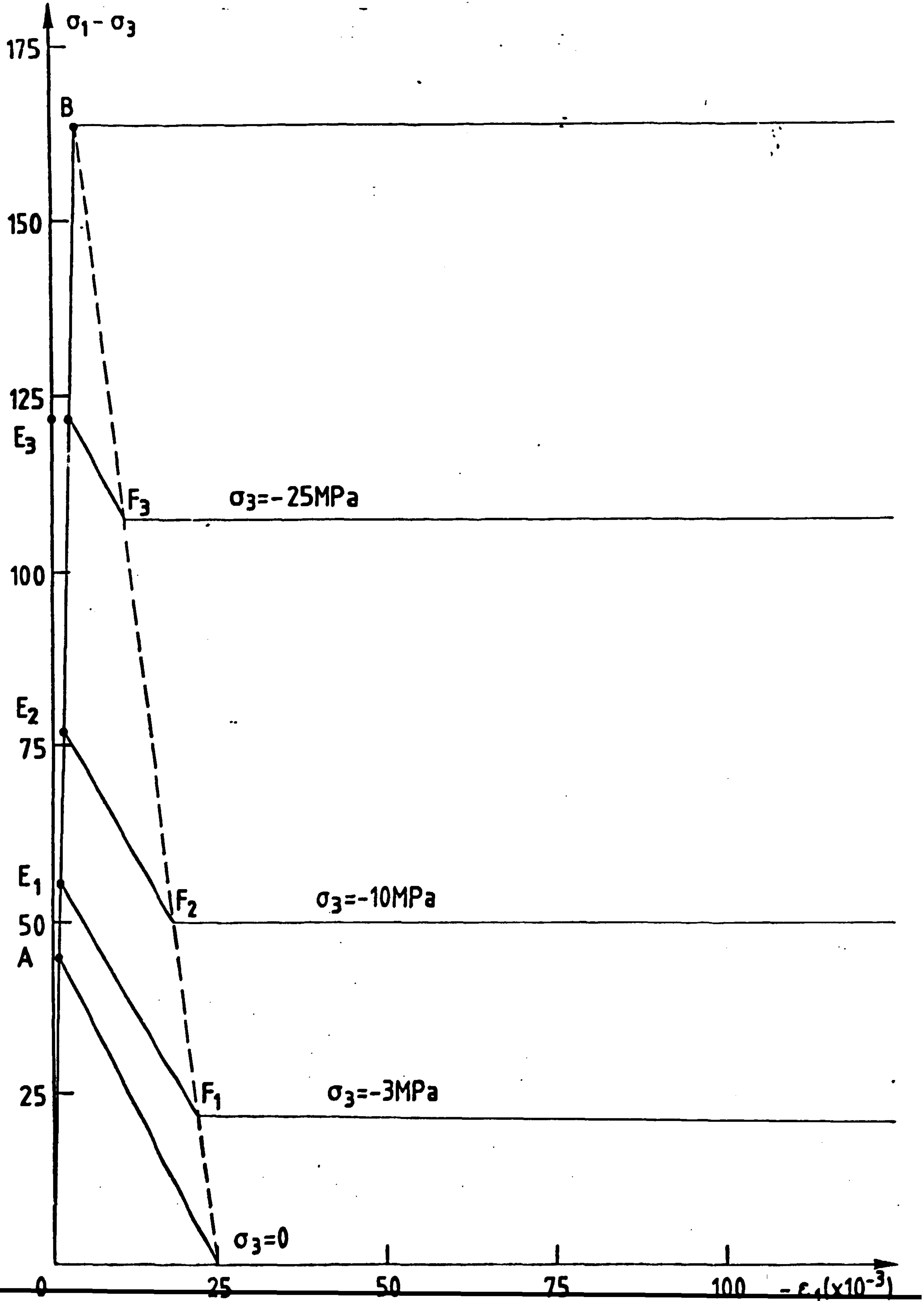
σ1 - σ3
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- ε1 (x10-3)
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A
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