

PERFORATION OF A CONCRETE SLAB BY A MISSILE : FINITE ELEMENT APPROACH

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A specific concrete model has been developed to investigate the problem of concrete walls perforation by a missile : Three types of damage are accounted for : Traction damage, shear damage, hydrostatic pressure damage. For the first one, a maximum principal stress criterion is chosen. When fractured the concrete behaves in an anisotropic first tensile fracture direction. For the shear damage, two domains are distinguished, which correspond to brittle and ductile behaviors. The brittle shear is represented by a plasticity law with strain softening while a strain hardening is assumed for ductile shear.

The yield surfaces are described by Drucker-Prager and Von Mises criteria, with strain hardening depending on the state of stresses. In both cases the plastic strains follow the Hill's principle for the hydrostatic pressure damage, the plasticity criterion involves only the first invariant of the stress tensor. Deformations are computed using classical plasticity equations. The damage modes are coupled on the basis of KOITER's rule.

In order to investigate the validity of this concrete model in simple compressive conditions, tests are performed in following configuration : microconcrete used in perforation tests is cast in a cylindrical mould 100 mm diameter, 50 mm wall thickness made of very strong steel. The concrete height is 400 mm. A silver layer is put on the inner face to decrease the friction coefficient. The load is transmitted to the concrete by means of a metal piston. A quasi static test is first performed using a hydraulic testing machine. A second one is then impacted by a 32 kg mass dropping from 19 meters. In both cases the displacement and the forces are recorded for comparison with calculations.

## 1. Introduction.

In the frame of safety studies, the impact of a plane on a nuclear reactor concrete containment must be investigated. Most of the time, this problem is divided into two parts : first, the crush of the soft part of the plane, which communicates a load to the whole building, and then the impact of the engines considered as stiff structures, which may possibly perforate the concrete wall.

The first problem consists in determining the force corresponding to the plane crush during time, and applying it to the building.

In the second problem, the wall is considered as a flat plate and empirical formulas are used.

The development of fast dynamics computer codes makes it possible to treat simultaneously both parts of the problem. However it requires a realistic modelization of the concrete behaviour up to the ruin. Such a model has been implemented in the PLEXUS program [1] of the CEASEM system [2]. In order to check it, it is necessary to compare it with test results. The simple case of a rigid missile perforating a concrete slab has been selected.

## 2. Description of the test [3]

The tested slab was a square plate, of 1.46 m side and 0.26 m thickness, without reinforcements. The plate was simply surrounded by an iron band used as a mould. It was supported at the four corners by load cells.

The missile was a 0.2 m diameter cylinder of 72 kg mass. The speed at impact was 78 m/s. The missile went through the plate and emerged with a 29 m/s residual speed.

## 3. Description of the concrete model [5] [6]

The concrete model used to calculate the test, accounts for three damage modes :

- damage by traction
- damage by shear stresses
- damage by hydrostatic pressure.

Concerning the damage by traction, the chosen criterion consists in limiting the maximum principal stress :

$$\begin{aligned} \text{Max } (\sigma_i) &\leq \sigma_t \\ i &= 1, 2, 3 \end{aligned}$$

where  $\sigma_t$  is the tensile strength of the material. In the principal stresses spaces, this corresponds to a pyramid with three orthogonal faces. During the loading, if one the principal stresses occurs to overstep the  $\sigma_t$  limit, this limit is set to zero as well as the corresponding principal stress.

In the axisymmetric case, the model accounts for two different cracking modes :

- radial cracks
- cracks in diametral plane.

This enables a description of the orthotropic behaviour of cracked concrete, by keeping the memory of the direction of the first cracks.

Concerning the damage by shear stresses, two domains are distinguished, according to the combining pressure :

- a brittle domain, corresponding to low confining pressures, which is limited by a Drucker-Prager criterion, characterized by strain-softening ; this criterion may move down

to another fixed Drucker-Prager criterion representative of a perfectly plastic behaviour.

This modelization enables a full unloading in the simple compression case where there is no confinement pressure.

- a ductile domain, corresponding to high combining pressures, which is limited by a Von Mises criterion and characterized by strain-hardening ; this criterion may move up to a fixed Drucker-Prager criterion representative of a perfectly plastic behaviour.

Concerning the damage by hydrostatic pressure, the relation between the volume variation and the hydrostatic pressure has been approximated by a bilinear diagram. The first part (elastic) corresponds to the deformation of the skeleton, the second (inelastic) corresponds to the pores crushing. In the principal stresses space, the yield surface is a plane perpendicular to the trisectrise ; it undergoes strain hardening as the material is deformed.

For all cases, the normality principle has been assumed for plastic flow. The various damage modes can be coupled, on the basis of Koiter's rule stating that the plastic flow vector lies in the cone defined by the external normals to the criteria. [7]

#### 4. Identification of parameters required by the model

For the tensile strength, Bresilian tests have been carried out. For the damage by shear stresses, tests have been performed on 11 x 22 cm cylinders made of micro-concrete. It handles of classical triaxial tests with constant confining pressure (see figure 1). For the damage by hydrostatic pressure, tests have been performed on 2.4 x 5 cm cylinders made of micro-concrete at Ecole Polytechnique. The pressure was raised up to 200 MPa (see figure 2). The experimental curves have been linearized as shown on figure 3.

#### 5. Application to the plate calculation

The model presented has been implemented in the code PLEXUS [1] of the CEASEM system [2] [4]

Since the perforation of the plate by the missile is a local problem, the tested square plate has been approached by an axisymmetrical plate in the calculation. The radius of this plate has been chosen in order to have the same mass as for the original plate.

A rigid belt has been assumed at the periphery of the equivalent plate, and the load cells were supposed to be uniformly distributed around it. The cross section of the plate has been meshed by 375 triangular elements and the cross-section of the missile by 64 triangular elements, 6 elements working as membranes have been placed at the periphery to model the belt (see figure 4)..

The calculation is being performed. Unfortunately, the results were not available at the moment of the preparation of this report.

#### 6. Conclusion

The model presented in this paper appears to be a simple and powerful tool for the calculation of reinforced concrete structure up to the ruin. Of course, it can be further improved, according to the specificity of each problem. Some developments will be incorporated in the near future :

- better description of the non linearity of the stress-strain curves
- introduction of a non-associated flow rule
- damage by traction including possible friction on cracks sides

- account for thermal effects on concrete properties
- account for the residual water influence on concrete properties.

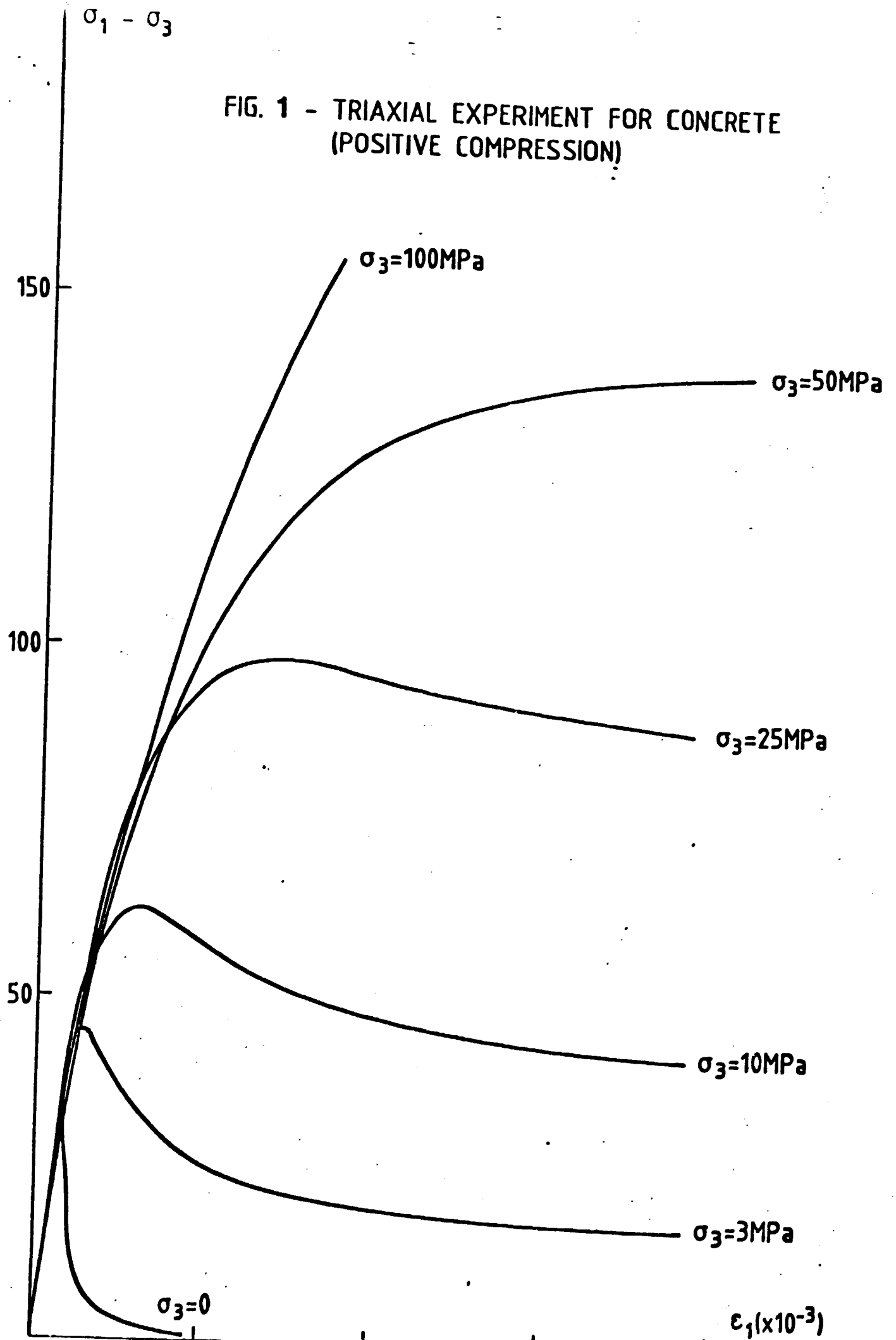
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- LIST OF FIGURES -

- FIGURE 1 : Triaxial experiment for concrete (positive compression)
- FIGURE 2 : Pressure versus longitudinal strain
- FIGURE 3 : Linearization of experimental curves (positive pressure)
- FIGURE 4 : Mesh

FIG. 1 - TRIAXIAL EXPERIMENT FOR CONCRETE  
(POSITIVE COMPRESSION)



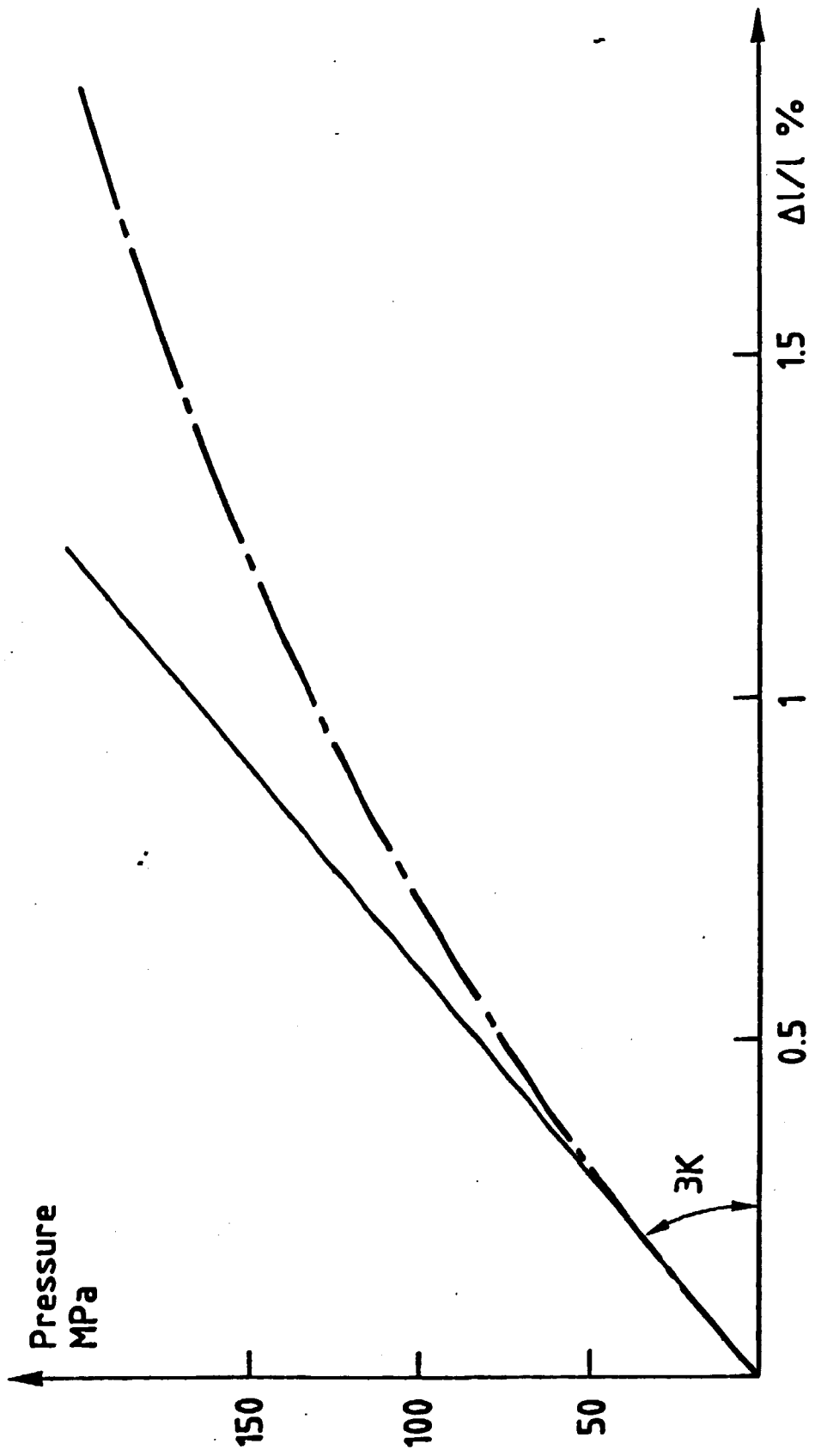


Fig. 2



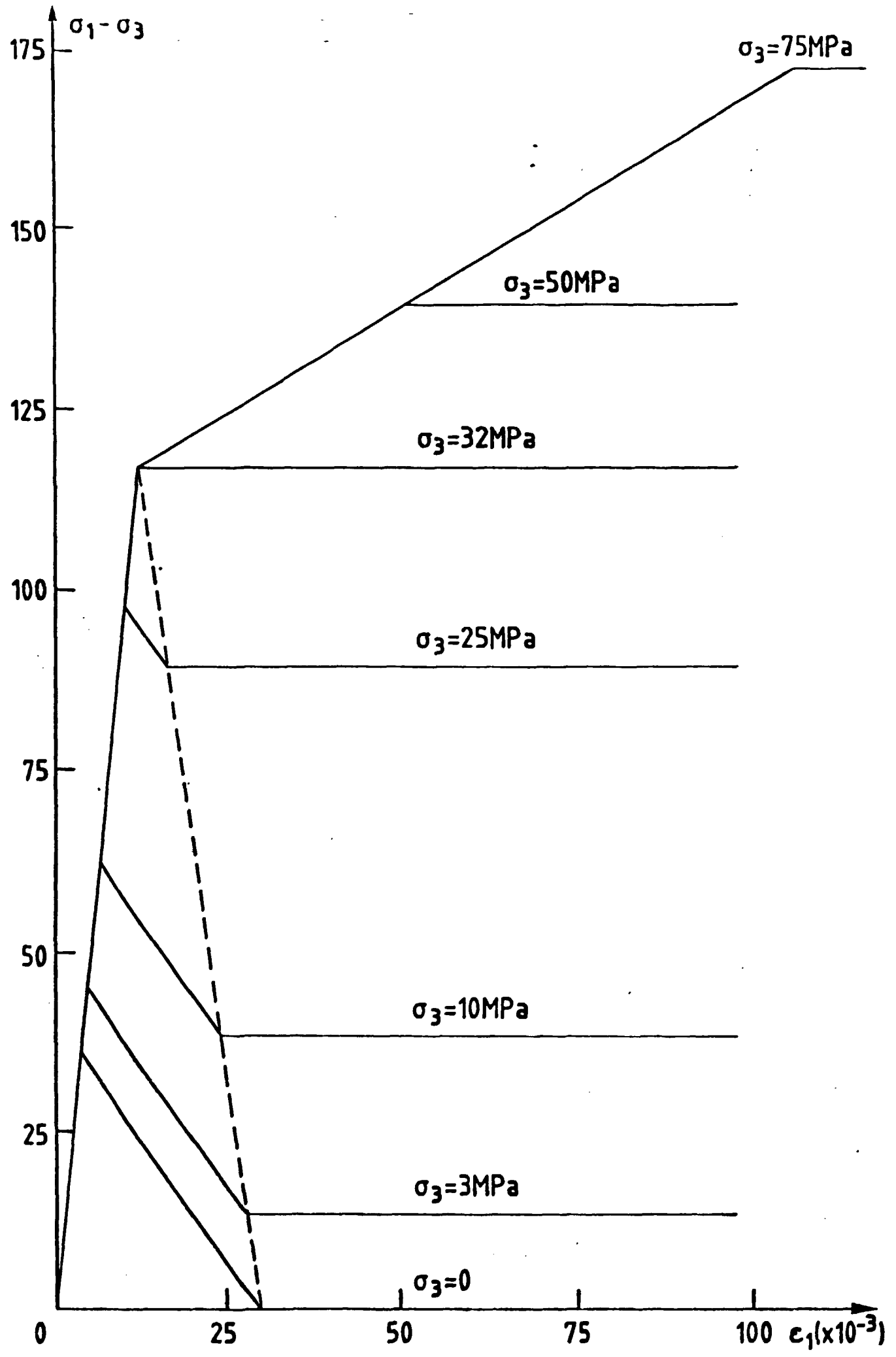
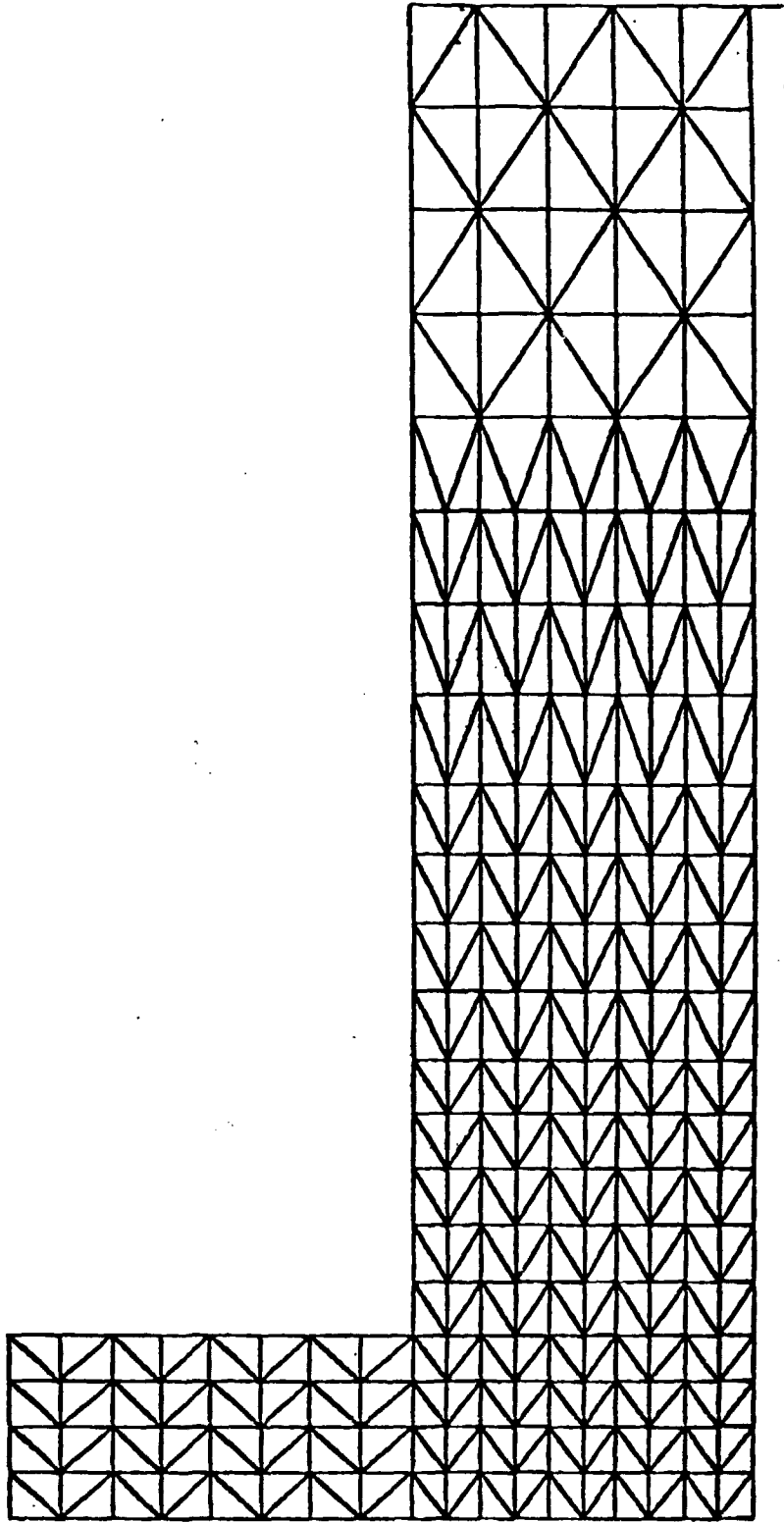


Fig. 3 - Linearization of experimental curves



1