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STRUCTURAL ANALYSIS OF REINFORCED CONCRETE STRUCTURES UNDER MONOTONOUS AND CYCLIC LOADINGS: NUMERICAL ASPECTS

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STRUCTURAL ANALYSIS OF REINFORCED CONCRETE STRUCTURES UNDER MONOTONOUS AND CYCLIC LOADINGS : NUMERICAL ASPECTS

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INTRODUCTION

The structural analysis of reinforced concrete structures is usually performed either by means of simplified methods of strength of materials type i.e. global methods, or by means of detailed methods of continuum mechanics type, i.e. local methods. For this second type, some constitutive models are available for concrete and rebars in a certain number of finite element systems. These models are often validated on simple homogeneous tests. Therefore, it is important to appraise the validity of the results when applying them to the analysis of a reinforced concrete structure, in order to be able to make correct predictions of the actual behaviour, under normal and faulty conditions. For this purpose, some tests have been performed at "I.N.S.A. de Lyon" on reinforced concrete beams, subjected to monotonous and cyclic loadings, in order to generate reference solutions to be compared with the numerical predictions given by two finite element systems :

- CASTEM, developped by C.E.A./.D.EM.T.
- ELEFINI, developped by "I.N.S.A. de Lyon".

EXPERIMENTAL STUDY

The experiments are divided into two parts :

- beams under monotonous loading,
- beams under cyclic loading.

Beams subjected to monotonous loading

The beams used in these tests are either over-reinforced in order to obtain a ruin characterized by concrete crushing or under-reinforced, in order to obtain a ruin characterized by steel plastification. The beams are subjected to an increasing four-points bending type load. Typical sizes are shown on figure 1. The results obtained are presented in terms of load-deflection (at the middle of the beam) curves and load-rebars strains curves [1].

Beams subjected to cyclic loading [2]

For these tests, two identical beams (geometry, concrete, rebars) have been considered. A low resistance concrete has been selected in order to obtain a high strain level. The reinforcement comprises four carbon steel longitudinal rebars, the material behaviour of which can be approximated by an elastic - perfectly plastic model. Figure 2 shows the geometry and reinforcements.
The beams are subjected to an alternate cyclic four-points bending type load.
For the first beam, the amplitude of the first cycle corresponds to the first visible cracking. Then, strain gauges are placed on the concrete, as well as cracks opening displacment transducers (see figure 3). Subsequently, 350 cycles at an increased load level are performed. Finally, three cycles close to the ultimate monotonous load are apply.

1055 H 1 MILLARD

For the second beam, the first cycle is the same as for the first beam. Then, five cycles close to the ultimate monotonous load are performed.

Note that during the test, the displacement at the middle of the beam is monitored.

Some major results are presented here for the first beam : Figure 4 shows the load versus deflection curve and figure 5 shows the load versus crack opening and closing. A small increase of the deflection can be observed after the 350 cycles (from 19 mm to 22 mm) while the crack opening is stabilized (0.3 mm). For the lasts 3 cycles, additional cracking is important.

CONCRETE MODELLING

Two different concrete models based on plasticity theory implemented in two different computer codes : CASTEM and ELEFINI, have been used. They are described below.

Concrete modelling in CASTEM [3][5][6]

We describe here the concrete model in the special case of a bidimensionnal plane stress analysis, which is supposed to be valid for the beam computation.

In the traction domain, the concrete is supposed to be elastic in a convex domain defined by the maximal principal stress. Once the limit traction stress in one direction is reached , this direction is memorized. Beyond this limit, strain softening is assumed, as shown on figure 6.

Additionnal cracks can only happen in a direction orthogonal to the first one. The crack opening is also memorized and the concrete resistance in compression is effective only when the crack is closed . In the compression domain, a classical Drucker-Prager criterion, with associated flow rule and isotropic softening is assumed. The yield surface is then defined as a multi-criterion domain.

Concrete modelling in ELEFINI [2][4]

Under biaxial traction and traction-compression stresses, the concrete is elastic in a convex domain limited by a Nadai criterion, with isotropic softening :

$$f_1 = (\sigma, k) = \sqrt{\frac{2}{3} J_2} + a_1 \frac{I_1}{3} - b_1 F_1 (k) \leq 0$$

It is also the case in compression, the criterion being then :

$$f_2 = (\sigma, k) = \sqrt{\frac{2}{3} J_2} + a_1 \frac{I_1}{3} - b_2 F_2 (k) \leq 0$$

Parameters a_i, b_i are calculated directly from the concrete limit stresses in traction, traction-compression and compression.

COMPARISON OF COMPUTATIONS WITH TEST RESULTS

Structural analysis of beams under monotonous loading

In both computer analysis, simple linear triangle elements have been used. The calculations assume a perfect contact between concrete and rebars.

The results are shown on figure 7. A very good agreeement with experimenal values is obtained for both codes.

Structural analysis of beams under cyclic loading

The first cycle has been computed. It is not symmetric because of the influence of the dead weight. The limit values of the cycle are well reproduced by the computations (see figure 8). Differences appear in the unloading and reserve loading sequences.

During this cycle, the only non-linearity is due to concrete cracking (the rebars remain elastic). Therefore CASTEM predict an unloading through the origin as can be seen on figure 8. Then the second cycle (i.e. the first of the 350 identical cycles) has been calculated. A slight difference is observed on the maximum deflection for the maximum load, while the width of the hystereris loop is in better agreement (see figure 9). When the number of cycles increase, the discrepancies between experimental and calculated results increases because no cyclic degradation effect is accounted for in the models.

CONCLUSION

The comparison between experiments and computations on reinforced concrete beams has enlighted the following points :

- for monotonous bending loading, the predictions are fairly good up to 80 % of the ultimate load,
- for cyclic bending loadings, the models must be improved on one hand to treat correctly the concrete behaviour under reverse loading after traction, and on the other hand to incorporate some cyclic effects which can affect significantly for example the junction between concrete and rebars or the shear resistance of the concrete cracks.

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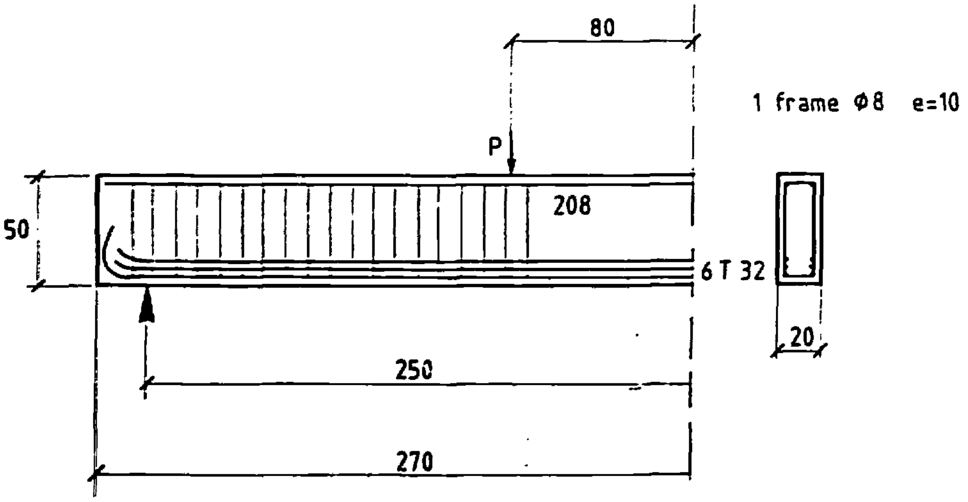


FIGURE 1

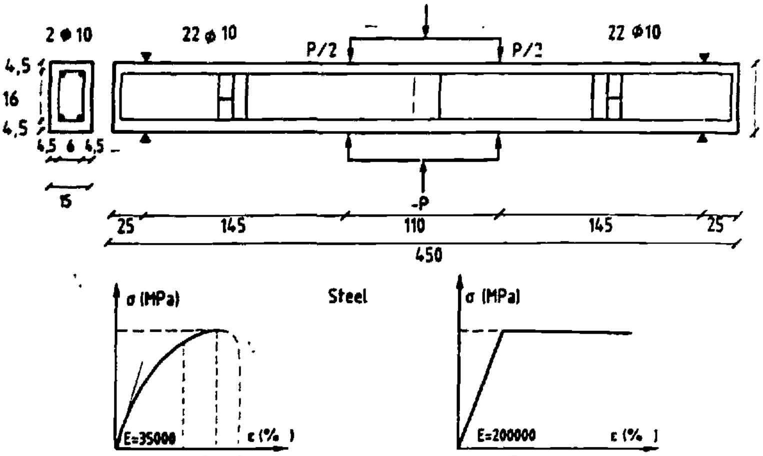


Fig. 2 : Geometry and reinforcement

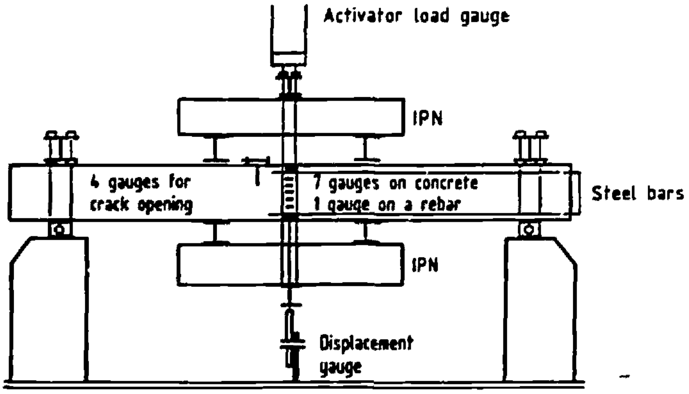
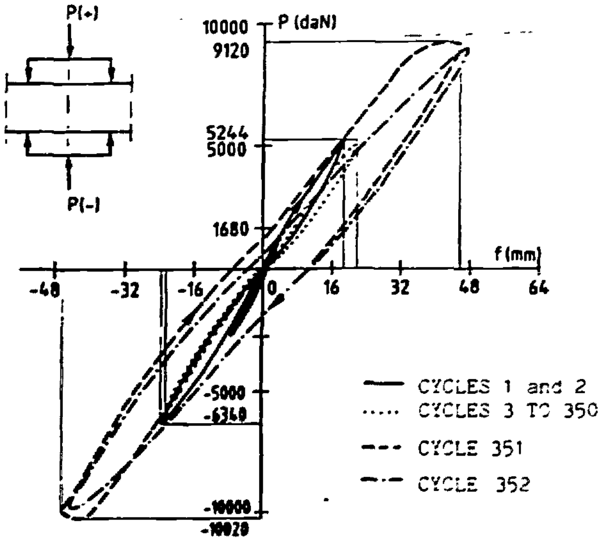


Fig. 3 : Test facility

Fig. 4 : Beams under cyclic loading load versus deflection



1055 H 4 MiLLARD

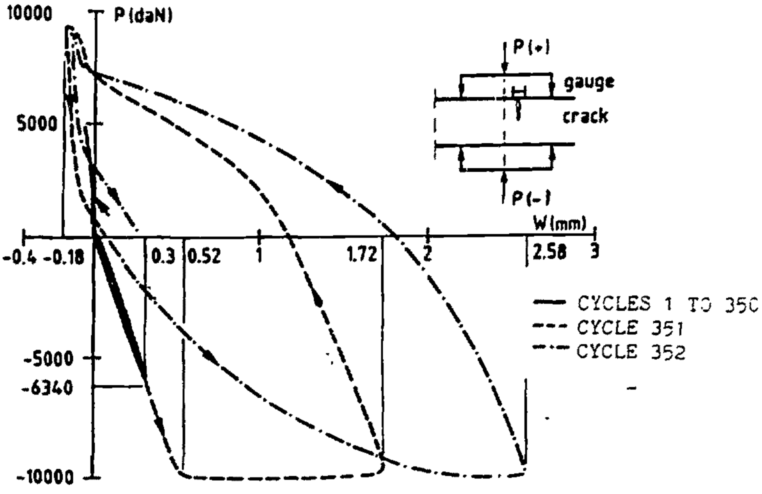


Fig. 5 - BEAMS UNDER CYCLIC LOADING
LOAD VERSUS CRACK OPENING

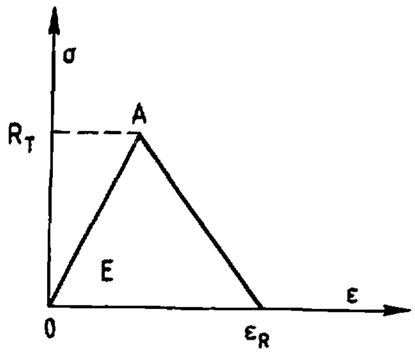


Fig. 6 - TENSILE UNIAXIAL BEHAVIOUR

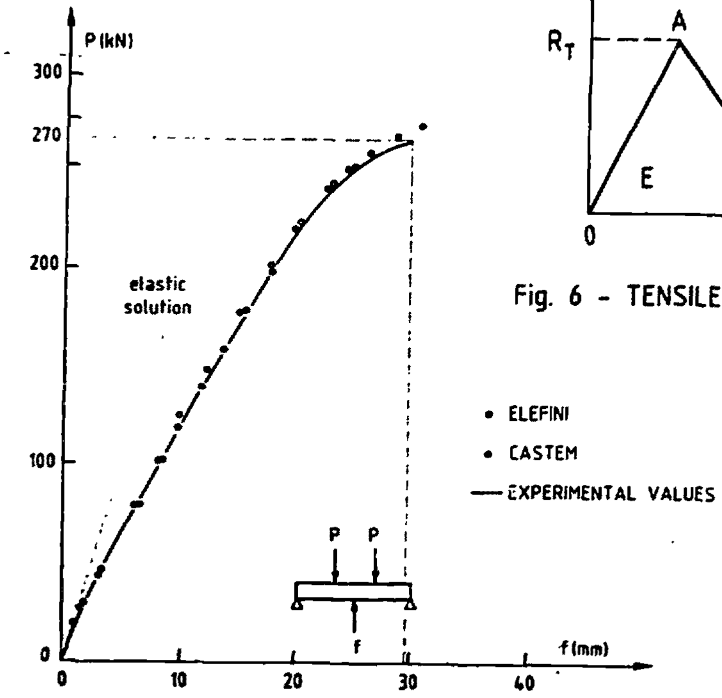


Fig. 7 - BEAM UNDER MONOTONOUS LOADING
LOAD VERSUS DEFLECTION

1055 H 5 MILLARD

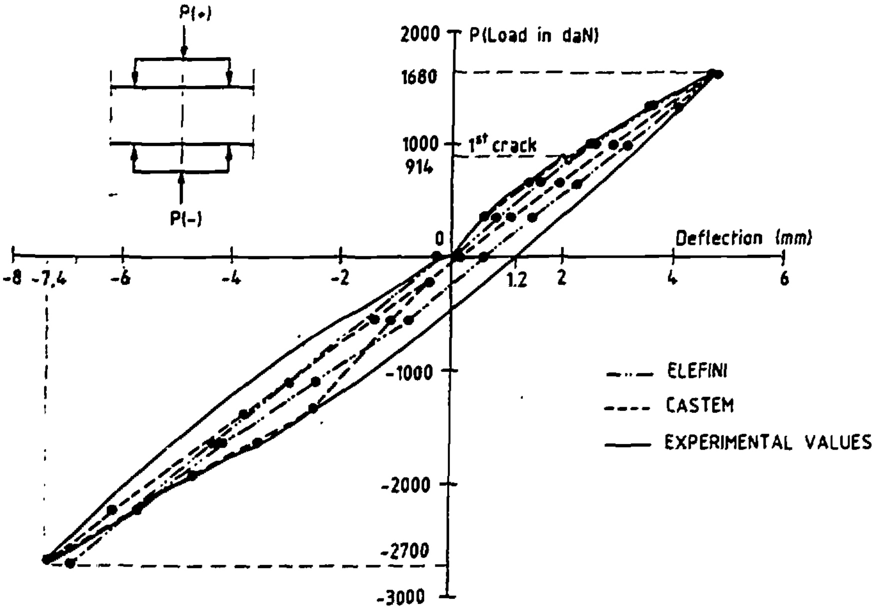


Fig. 8 - BEAM UNDER CYCLIC LOADING RESULTS FOR THE FIRST CYCLE

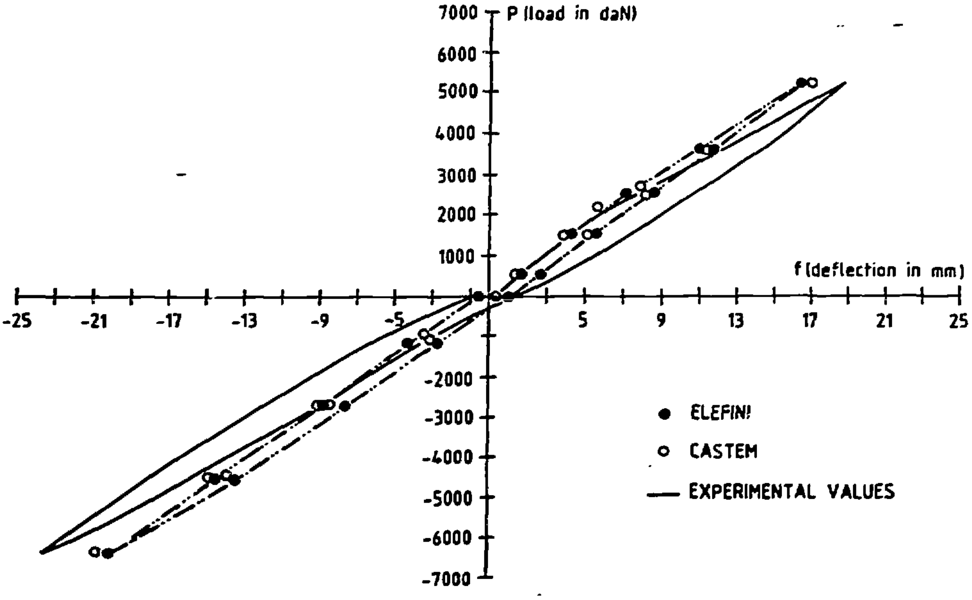


Fig. 9 - BEAM UNDER CYCLIC LOADING RESULTS FOR THE SECOND CYCLE

1055 H 6 MILLARD