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A 3D analysis of reinforced concrete structures by the finite element method

Claure, J.D., Campos Filho, A.
Universidade Federal do Rio Grande do Sul, CPGEC, Porto Alegre, RS, Brazil

ABSTRACT: In this work fundamental features of a computational model, based on the finite element method, for the analysis of concrete structures are presented. The study comprehends short and long-term loading situations, where creep and shrinkage in concrete are considered. The reinforcement is inserted in the finite element model using an embedded model. A smeared crack model is used for the cracking of concrete, which considers the contribution of concrete between cracks and allows the closing of the cracks. The computational code MPGS (Multi-Purpose Graphic System) is used, to make easy the analysis and interpretation of the numeric results.

1 INTRODUCTION

The design and the execution of new structures of reinforced concrete require a continual advance in the investigation of its behavior. The finite element method is definitely the numerical procedure most used for the analysis of this kind of structure. By this method it is possible simulate numerically the performance of reinforced concrete structures. This work presents a computational model for the three-dimensional analysis of reinforced concrete structures, using the finite element method. This model was developed by Claure (1994).

2 FINITE ELEMENT MODEL FOR THE ANALYSIS OF ELASTO-VISCOPLASTIC MATERIALS

The computational model, presented in this work, is based on Hinton (1988). It allows to analyze reinforced concrete members with elasto-viscoplastic behavior. The behavior of material is represented by a rheological model composed by a spring in series with a set formed by a dashpot and an element of friction in parallel.

The computational program is divided in two different parts to allow an easier calibration of elasto-viscoplastic models. At first, the time-response of the structure is determinate. The deformation state of the structure elapsed some time from load application is computed. An overlay model is included to assert an adequate representation of the actual concrete behavior during time. Thus, concrete is composed by five layers, which have the same deformations. Each layer has different properties, and the total stress is obtained by sum of the correspondent parcel of each one. In this step, materials have viscoelastic behavior.

In the second part, the response of the structure for an instantaneous load is determinate. In this step, the state of deformations of the structure, when time (fictitious) tends to infinite, is computed. This steady state corresponds to the response of the structure with elastoplastic behavior.

3 FINITE ELEMENT MODELS USED FOR CONCRETE AND REINFORCEMENT

3.1 *Finite elements for concrete*

In order to model the concrete, two types of isoparametric three-dimension finite elements are utilized: a linear and a quadratic, both of the Serendipity's family. These elements have eight and twenty nodes. Each node has three degrees of freedom, which correspond to the translations in the direction of the xyz axis from the global system of coordinates.

3.2 *Finite elements for reinforcement*

There are basically three ways to include reinforcing bars in a finite element model for the analysis of reinforced concrete structures: the distributed, the discrete and the embedded.

In the first one, the steel is distributed uniformly into the concrete element. It is assumed perfect adherence between steel and concrete. This model is advantageous when reinforcement is heavily distributed, like in plates and shells.

In the discrete model, the reinforcement is represented by truss elements, which integrate the mesh of two-dimensional finite elements used on the concrete representation. This model has the disadvantage that the mesh itself limits the arrangement of the reinforcement bars.

In this work, the embedded model was chosen. This model considers that bars of reinforcement are lines of a stiffer material inside concrete elements. A unique field of displacements over the domain of the element is used. Thus, reinforcing bars may be put in any position into concrete elements, without introduce any additional unknown to the problem. Perfect bond between concrete and steel is also assumed.

The methodology presented by Elwi and Hrudey (1989) is adopted to calculate the stiffness matrix for reinforcement. The segments of reinforcing bars, contained in each finite element of concrete, are determinate automatically.

4 CONSTITUTIVE MODELS FOR MATERIALS

4.1 *Model for compressed concrete*

Before cracking, an elastoplastic model with hardening is assumed to represent concrete behavior. This elastoplastic model is composed by a failure criterion, by a yield criterion and by a hardening rule. The selected failure criterion was proposed by Ottosen (1977). The compressed concrete is idealized as a material with isotropic hardening, and it is assumed that yield surfaces present the same shape of the failure surface. The hardening rule is defined by the relation between effective stress and effective plastic deformation.

4.2 *Model for cracked concrete*

A smeared crack model was adopted in this work. Such model needs the following items: a cracking criterion, a rule for representing the collaboration of concrete between cracks, and a shear transfer rule across the crack. This model was established as presented by Hinton (1988). It assumes that the loss of tensile strength in concrete occurs gradually after cracking. A reduced value is assigned to the shear modulus corresponding to the crack plane to take into account the shear transfer capacity of cracked concrete.

4.3 *Constitutive model for steel*

In reinforced concrete structures, steel bars resist fundamentally to efforts in its direction. Therefore, it is enough to know its uniaxial behavior. A stress-strain curve, bilinear or three-linear, are adopted for steel.

5 TIME-DEPENDENT PROPERTIES OF CONCRETE

When concrete is subjected to long term loading, it suffers besides instantaneous strain a further one that develops with time. This strain is due to creep. Thus, even under constant stress, concrete strain increases with time.

This phenomenon occurs more strongly immediately after stress application. It is attached to phenomena of several kinds, which are related with water circulation in the mass of concrete and its dissipation to exterior.

A concrete member, in the open air, suffers a decrease of volume during hardening process, which is called shrinkage. This strain is independent on the applied stress and it is attached to a phenomenon similar to creep. Thus, it is related to the water that in one hand hydrated the constituent cement and, on the other, stay free into the concrete mass.

The rheological model, assumed to represent time-dependent behavior of concrete, is a chain of Maxwell units. Thus, this chain is formed by an association of units, composed by a spring in series with a viscous dashpot. The procedure, presented by Bazant (1974), is used in parameters determination. Relationships for time-dependent effects of concrete from CEB-FIP Model Code 1990 are used to calibrate this model.

Deformations by shrinkage of concrete are treated as imposed strains to the structure. Such as creep, shrinkage does not generate directly stresses in concrete. The variation of stresses in concrete is computed by deducting from total strain, the part of strain, which was originated directly by shrinkage.

6 COMPARISON WITH EXPERIMENTAL RESULTS

To verify the accuracy of model, results are compared with values, determinate experimentally, for a reinforced concrete beam ET1, tested by Leonhardt and Walther (1962). This simply supported beam was subjected to two instantaneous point loads. Fig. 1 presents the comparison for maximum deflection, determinate by computational model with experimental values. In Fig. 2, average stress from four stirrups, which stand close to the support, are compared. At follow, Fig. 3 illustrates stress distribution in concrete for a load of 100 kN. This figure was obtained with the utilization of MPGS software (Multi-Purpose Graphic System, Cray Research, 1993), which is available in the CESUP/UFRGS.

In Fig. 4, values computed by the program are compared with experimental results obtained by Gobetti, Campos Filho and Campagnolo (1983). These results correspond to reinforced concrete beams subjected to a uniformly distributed long term load. The figure shows the development of maximum deflection for V5 and V6 beams. This load was applied during a period of sixty days.

The properties of materials and the geometric characteristics of beams, used in analysis, were extracted from original papers.

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REFERENCES

Bazant, Z.P. & Wu, S.T. 1974. Rate-type creep law of aging concrete based on Maxweel chain. *Matériaux et Constructions*. 37(7):45-60.

Claure, J.D. 1994. *Análise tridimensional elasto-viscoplástica de estruturas de concreto armado através do método dos elementos finitos.* Porto Alegre: CPGEC/UFRGS.

Cray Research, Inc. 1993. Multipurpose Graphic System (MPGS). Reference Manual. APR-5525 5.1.

Elwi, A.E. & Hrudey, T.M. 1989. Finite element model for curved embedded reinforcement. *Journal of Engineering Mechanics Division*, ASCE. 115(4): 740-745.

Gobetti, L.C.W., Campos Filho, A. & Campagnolo, J.L. 1983. *Análise teórico-experimental das deformações em vigas de concreto armado.* Porto Alegre: CPGEC/UFRGS, 56 p.

Hinton, E. 1988. *Numerical methods and software for dynamic analysis of plates and shells.* Swansea: Pineridge Press. 550p.

Leonhardt, F. & Walther, R. 1962. Beitrage zur Behandlung der Schubprobleme im Stahlbetonbau. *Beton und Stahlbetonbau.* 57(7):161-173.

Ottosen, N.S. 1977. A failure criterion for concrete. *Journal of Engineering Mechanics Division*, ASCE. 103(4):527-535.

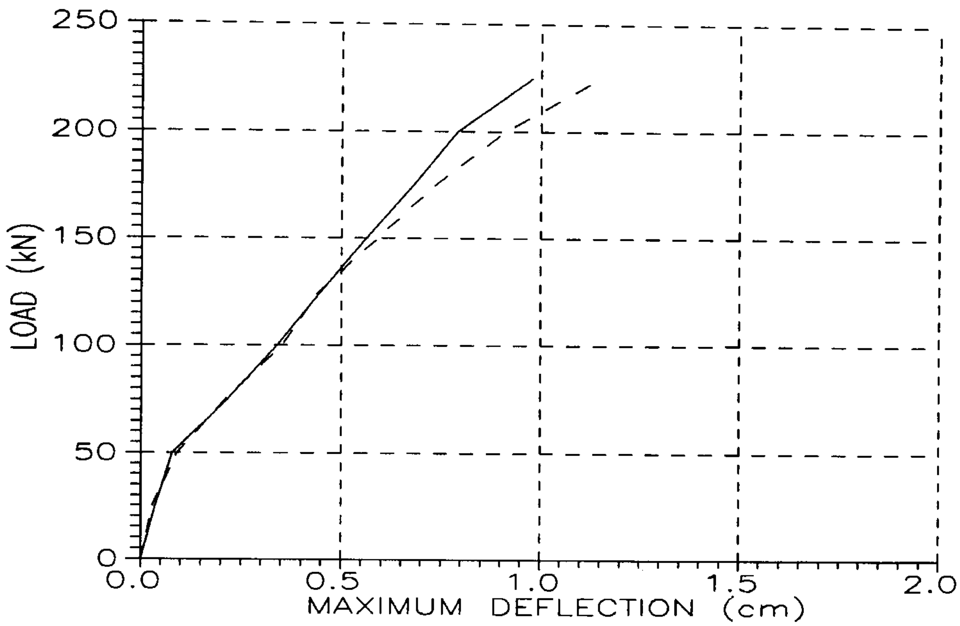

Figure 1 - Curves maximum deflection-load for ET1 beam

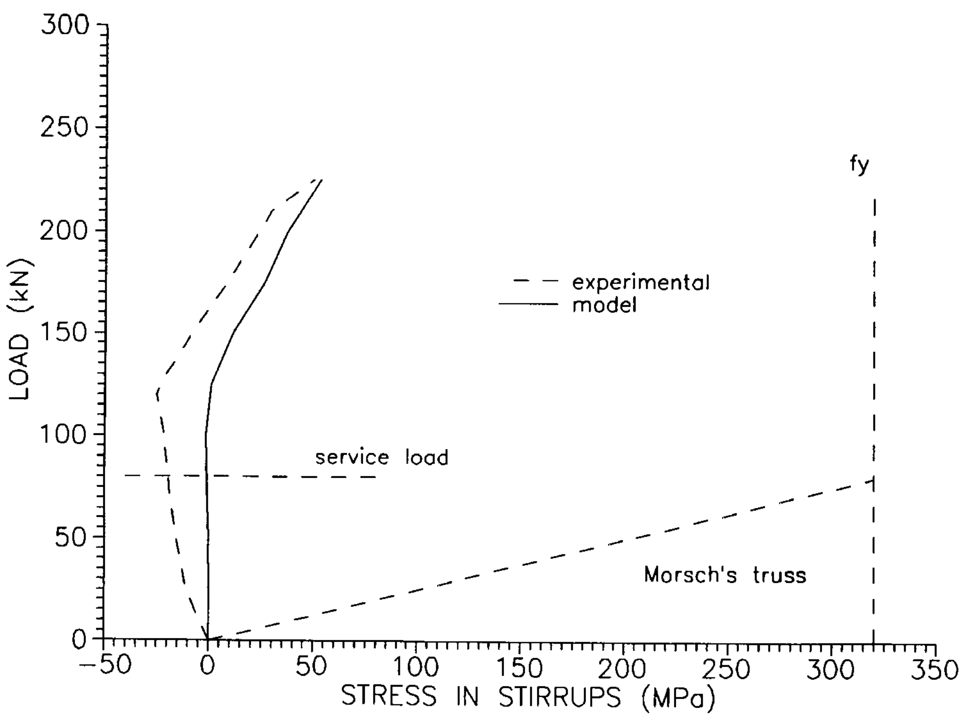

Figure 2 - Curves stress in stirrups-load for ET1 beam

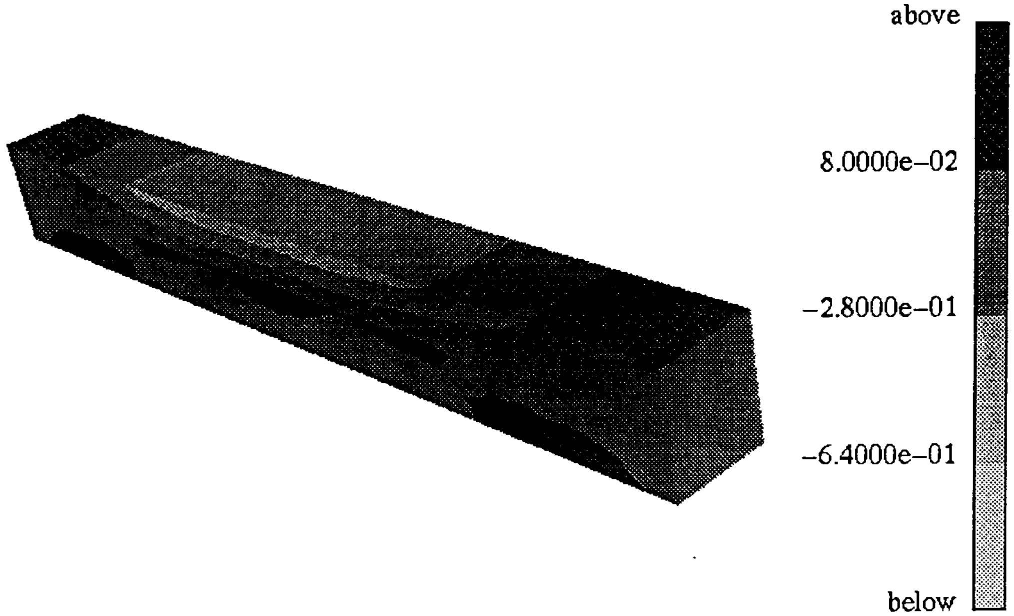

Figure 3 - Stress distribution on ET1 beam for a load of 100 kN

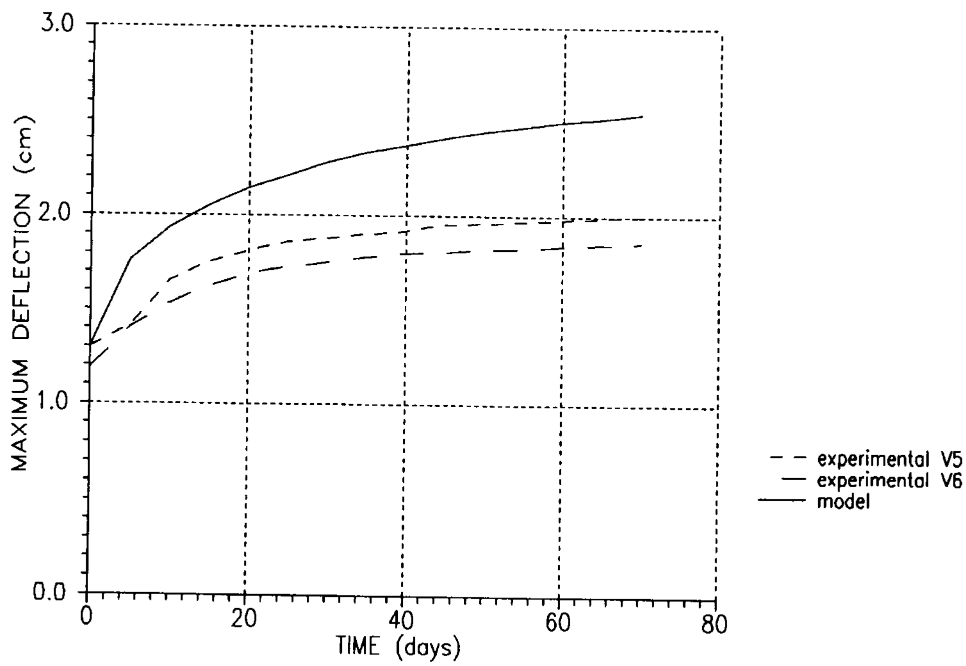

Figure 4 - Curves maximum deflection-time for V5 and V6 beams