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ANALYSIS OF REINFORCED CONCRETE STRUCTURES USING ANSYS NONLINEAR CONCRETE MODEL

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Abstract. *This paper considers the practical application of nonlinear models in the analysis of reinforced concrete structures. The results of some analyses performed using the reinforced concrete model of the general purpose finite element code Ansys are presented and discussed. The differences observed in the response of the same reinforced concrete beam as some variations are made in a material model that is always basically the same are emphasyzed. The consequences of small changes in modelling are discussed and it is shown that satisfactory results may be obtained from relatively simple and limited models.*

1 INTRODUCTION

Reinforced concrete structures are largely employed in engineering practice in a variety of situations and applications. In most cases these structures are designed following simplified procedures based on experimental data. Although traditional empirical methods remain adequate for ordinary design of reinforced concrete members, the wide dissemination of computers and the development of the finite element method have provided means for analysis of much more complex systems in a much more realistic way.

The main obstacle to finite element analysis of reinforced concrete structures is the difficulty in characterizing the material properties. Much effort has been spent in search of a realistic model to predict the behaviour of reinforced concrete structures. Due mainly to the complexity of the composite nature of the material, proper modelling of such structures is a challenging task. Despite the great advances achieved in the fields of plasticity, damage theory and fracture mechanics, among others, an unique and complete constitutive model for reinforced concrete is still lacking.

Many times specifically developed computer programs are used in finite element analyses of reinforced concrete structures. However, many general purpose codes commercially available provide some kind of material model intended to be employed in the analysis of concrete structures. Once general purpose computer codes are supposed to be more likely used as a design tool, an investigation of the capabilities of such codes seems to be of much concern.

The objective of this paper is to discuss the possibilities of different reinforced concrete models in practical use. It reports the results of some analyses performed using the reinforced concrete model of the general purpose finite element code Ansys. A series of analysis of the same structure has been performed, exploring different aspects of material modelling.

2 THE MATERIAL MODEL

The finite element code Ansys, version 5.3, has been used. Its reinforced concrete model consists of a material model to predict the failure of brittle materials, applied to a three-dimensional solid element in which reinforcing bars may be included. The material is capable of cracking in tension and crushing in compression. It can also undergo plastic deformation and creep. Three different uniaxial materials, capable of tension and compression only, may be used as a smeared reinforcement, each one in any direction. Plastic behaviour and creep can be considered in the reinforcing bars too.

Cracking and crushing are determined by a failure surface. Once the failure surface is surpassed, concrete cracks if any principal stress is tensile while crushing occurs if all principal stresses are compressive. The failure surface for compressive stresses is based on Willam-Warnke failure criterion, which depends on five material parameters. Tensile failure consists of a maximum tensile stress criterion, a *tension cutoff*. Unless plastic deformation is taken into account, the material behaviour is linear elastic until failure. When the failure surface is reached stresses in that direction have a sudden drop to zero, there is no strain softening neither in compression nor in tension. Two shear transfer coefficients, one for open cracks and other for closed ones, are used to consider the retention of shear stiffness in cracked concrete.

3 ANALYSES PERFORMED

A simply supported reinforced concrete beam subjected to uniformly distributed loading has been analyzed (figure 1). Only the longitudinal reinforcement has been considered.

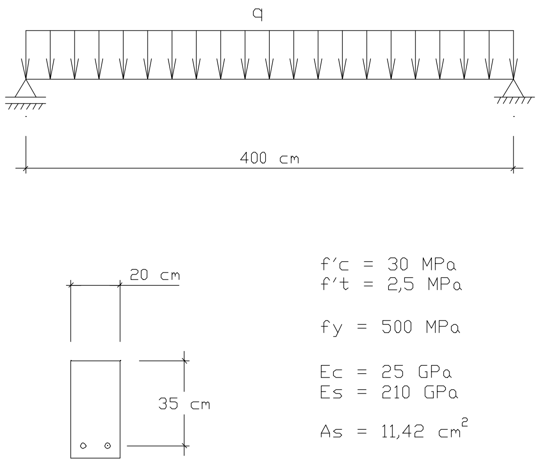

Figure 1 - The beam analyzed.

Due to transversal and longitudinal symmetry, a quarter of the beam has been discretized. Regarding meshes, two kinds of models have been used (figure 2): one adopting truss bars as discrete reinforcement connecting solid elements nodes; and the other composed uniquely of solid elements, some of which containing a smeared reinforcement.

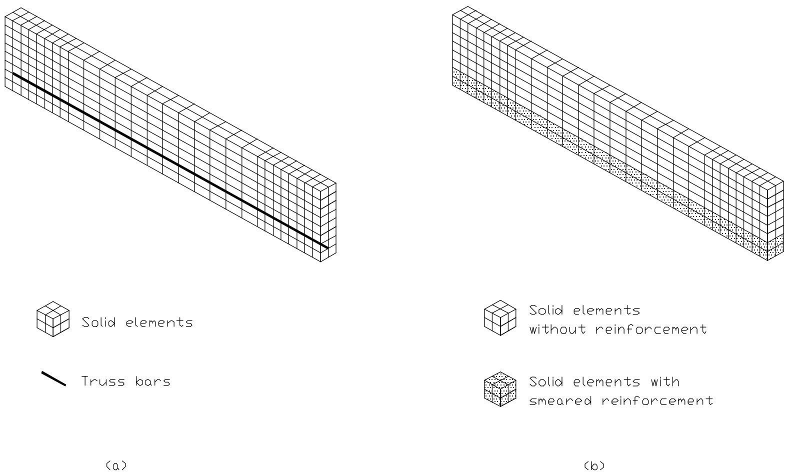

Figure 2 - Finite element meshes: a) with discrete reinforcement; b) with smeared reinforcement.

Solid elements have been used in beam modelling for they are the only ones that support the concrete model in Ansys. In fact, this seems to be the only major limitation to practical application of Ansys in reinforced concrete analysis.

Each mesh has been analyzed four times, according to four different material models. Linear elastic behaviour for both concrete and steel, the former capable of cracking in tension and crushing in compression, has provided the first model. In the second model crushing of compressed concrete has been disabled and an elastic perfectly plastic model based on Drucker-Prager yield criterion has been used instead. A multilinear uniaxial stress-strain relation, simulating a parabolic curve, has represented concrete compressive behaviour in the third model. Finally, crushing has been associated to the multilinear stress-strain curve in order to compose the fourth compressive model for concrete. Except those models in which concrete has been considered linear elastic and so has been the steel, the reinforcement has always been treated as elastic perfectly plastic. The analyses performed are summarized in Table 1.

Analysis	Concrete Model		Reinforcing steel model	
	Tension	Compression	Representation	Material model
Case 2f	Cracking	Linear elastic + crushing	Discrete	Linear elastic
Case 2m	Cracking	Elastic perfectly plastic (Drucker-Prager)	Discrete	Elastic perfectly plastic
Case 2k	Cracking	Multilinear work hardening (von Mises)	Discrete	Elastic perfectly plastic
Case 2L	Cracking	Multilinear work hardening + crushing	Discrete	Elastic perfectly plastic
Case 3m	Cracking	Linear elastic + crushing	Smeared	Linear elastic
Case 3n	Cracking	Elastic perfectly plastic (Drucker-Prager)	Smeared	Elastic perfectly plastic
Case 3p	Cracking	Multilinear work hardening (von Mises)	Smeared	Elastic perfectly plastic
Case 3o	Cracking	Multilinear work hardening + crushing	Smeared	Elastic perfectly plastic

Table 1 - Summary of models analyzed.

Drucker-Prager yield criterion has been considered associated to an elastic perfectly plastic behaviour for there is no other way it can be used in Ansys. This fact causes a certain incompatibility with the failure criterion for both are linear elastic and the phenomenon that occurs earlier, yielding or crushing, prevents the occurrence of the other.

The elastoplastic model with multilinear work hardening uniaxial stress-strain curve adopted a von Mises yielding criterion, so that it could not include the effect of hydrostatic pressure, but it has not been considered important to the structure being analyzed. Due to isotropy, concrete model for tensile stresses has been the same as that of compressive one when this plastic model was adopted but, as cracking capability has always been kept on, cracking in linear elastic phase should govern tensile failure in all analyses.

Associated flow rules have been used in all elastoplastic analyses.

4 RESULTS

As expected, once all models are quite similar, load-deflection curves show very close results at the early stages of load history for all analyses conducted. The initially linear relation experiments a small jump, with a sudden loss of stiffness, when cracking in concrete begins, followed by a nearly linear curve. The models containing smeared steel presented a smoother transition in this phase of stiffness degradation.

The differences between the models appear soon after service load. Linear elastic models

(Case 2f e Case 3m) quickly reach failure in compression zones and cannot converge to a solution anymore. As the steel has been assumed to behave linearly, failure of these models has occurred as soon as the failure surface has been reached by compressed concrete.

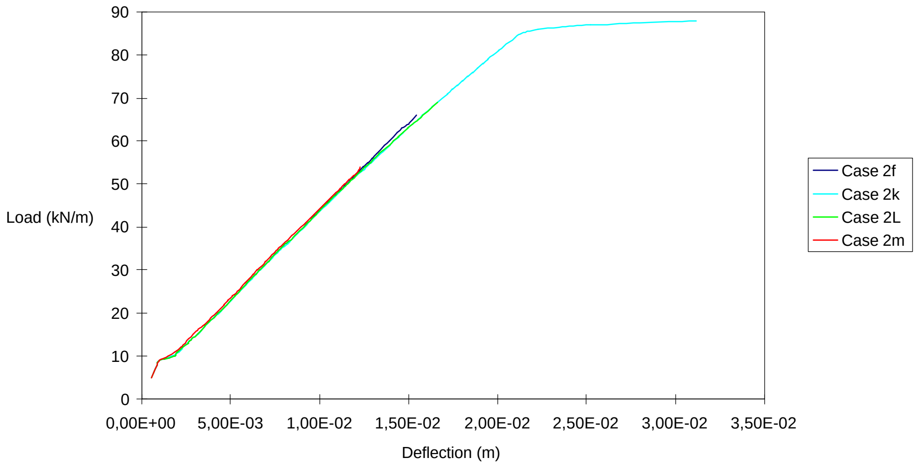

Figure 3 - Load-deflection curves for models with discrete reinforcement.

The elastic perfectly plastic model based on Drucker-Prager yield criterion with discrete reinforcement (Case 2m) has exhibited a somewhat similar behaviour, concrete yielding soon after service load. The beam ultimate load has not been reached. The ultimate load of this model was much smaller than that of the structure, although the load-deflection relations of the model and of the structure have followed very close paths. Failure should have occurred due to yielding of reinforcement, considering the amount of steel in the cross section of the beam. However, stresses in the reinforcing bars remained in the elastic range. It has happened because, once concrete in compression is linear until yielding, it has been able to resist to higher stresses than it would in reality as the nonlinear phase of stress-strain relation started. So, the failure of this model has been determined by crushing of compressed concrete.

Elastoplastic models with work hardening in compression and discrete reinforcement (Case 2k, Case 2L) have provided a longer load history. When crushing has been kept active (Case 2L) the failure of the model has still been premature. On the other hand, the model in which crushing of concrete has been disabled (Case 2k) has been able to generate a complete load-deflection diagram. In this case, failure of the model has been determined by yielding of reinforcing steel, as it should due to reinforcement ratio.

Models with smeared reinforcement presented essentially the same behaviour. Once the initial phase of crack opening, all models have assumed a nearly linear path of smaller stiffness than the initial. Once again the model with crushing associated to plasticity (Case 3o) did not reach loads much greater than service ones. The best results have come from the elastoplastic models, perfectly plastic (Case 3n) and with work hardening (Case 3p), which have been able to reach ultimate loads very close to the expected values, especially the model that followed a multilinear stress-strain relation in concrete compression.

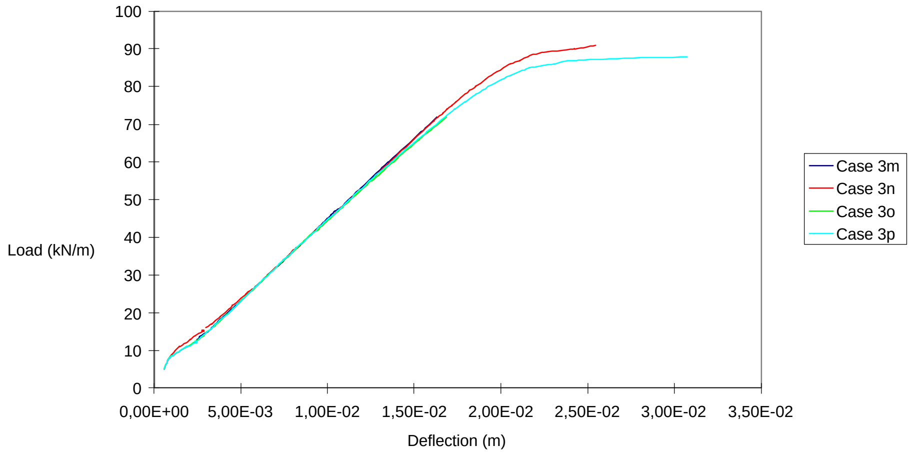

Figure 4 - Load-deflection curves for models with smeared reinforcement.

Regardless reinforcement representation, discrete or smeared, and despite the good concrete elastoplastic model behaviour, models combining crushing and plasticity have presented a quite early loss of convergence. This suggests the existence of some kind of incompatibility between yielding and failure in Ansys concrete model.

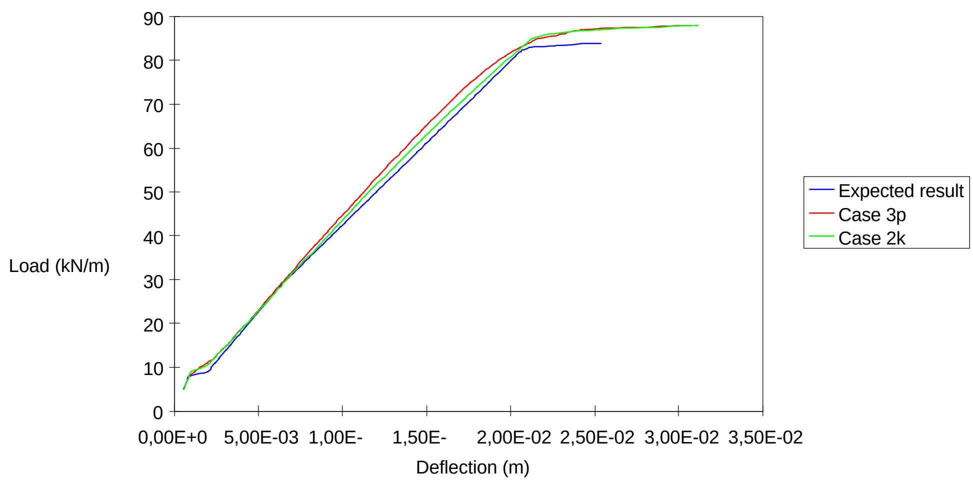

Figure 5 - Comparison between load-deflection curves of models with discrete reinforcement and smeared reinforcement.

The results of the analyses performed have been compared to a load-deflection curve derived from an analytically determined moment-curvature relationship. Comparison with experimental data, yet to be done, is the next step in the study. Future studies should also comprise the influence of the amount of reinforcement, as well as effects of shear retention factors and transverse reinforcement. Meanwhile, plotting of the analytical curve against the best results obtained leads to a very good agreement (figure 5).

Although the ultimate load has not been truly determinated, once analyses have been stopped simply due to lack of convergence, the obtained load-deflection paths compares quite well with the expected results in all load history (figure 5), so that the highest analyses loads may be considered the ultimate loads of the models and of the beam.

5 CONCLUSION

This study intended to investigate the possibilities of performing nonlinear finite element analysis of reinforced concrete structures using Ansys concrete model.

It can be observed in the load-deflection curves (figures 3 and 4) that the model for concrete in compression, although not of much importance to the curve's path, has played a major role in the achievement of the numerical solution from a certain load level on. Only nonlinear stress-strain relations for concrete in compression have made it possible to reach the ultimate load and determine the entire load-deflection diagram.

The good results attained suggest that, in spite of the relative simplicity of the analyzed structure and of the employed models, satisfactory prediction of the response of reinforced concrete structures may be obtained.

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