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Effects of Concrete Nonlinear Modeling on the Analysis of Push-out Test by Finite Element Method

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Abstract: This study considers the practical application of nonlinear models in the analysis of reinforced concrete. 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 push out test model as some variations are made in a material model that is always basically the same are emphasized. The consequences of small changes in modeling are discussed and it is shown that satisfactory results may be obtained from relatively simple and limited models.

Key words: Reinforced concrete, nonlinear analysis, finite element analysis, push-out, ANSYS

INTRODUCTION

Nowadays, concrete is largely employed in engineering applications. In most cases their properties are procedures based on experimental data. Although traditional adequate for ordinary design of reinforced concrete members, the computers and the development of finite element method have of much more complex systems in a much more realistic way. The main obstacle to finite element analysis of reinforced concrete is the difficulty in characterizing the material properties. Much effort has been spent in search of a realistic model to predict the behavior of reinforced concrete. A proper modeling of such member is a challenging task due mainly to the complexity of the composite nature of the material. 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 general purpose codes commercially available provide some kind of material model intended to be employed in the analysis of concrete structures, supposed to be more likely used as a design tool, an investigation of the capabilities of such codes seems to be of much concern (Bangash, 1989). The objective of this study 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 as a part of push-out test modeling. A series of nonlinear analysis of the push out-test model has been performed, exploring different aspects of reinforced concrete material modeling.

MATERIAL MODELING

The finite element code ANSYS, version 9.0, has been used, where the 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 can be included, having capability of cracking in tension and crushing in compression, also plastic deformation and creep can be considered. Three different materials, capable of tension and compression only, may be used as a smeared reinforcement, each one in any direction, which can also consider the plastic behavior and creep. Three different types of concrete modeling are available. The Drucker-Prager yield criterion, hence, cracking and crushing are determined by a failure surface and 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 (Kohnke, 2001 and Willam and Warnke, 1975). Although Zienkiewicz *et al.* (1975), recommended the use of the Drucker-Prager option for granular materials like soils, rock and concrete, the nonlinear elastic option is also considered to define the material behavior of concrete for the numerical study, by using multilinear elastic option (MELAS) available in ANSYS, because it allows greater flexibility in changing important parameters like the compressive and tensile strengths of concrete. The Multilinear Isotropic Option (MISO) is also used in describing the plasticity material behavior of concrete, which uses the von Mises yield criteria coupled with an isotropic work hardening assumption, which is often preferred for large strain analyses (Kohnke, 2001).

THE PERFORMED ANALYSES

The analysis of push-out test model, Fig.1, tested experimentally by Liu (2006) is conducted using finite element model, ANSYS model shown in Fig. 2, adopting the Shell 43 element to model steel beam web and flange and connectors and Solid 65 element to model the concrete. In the present study, two types of analyses are conducted firstly by using Solid 65 elements which containing a smeared reinforcement named as (smeared), secondly by using truss bars (Link 8) as discrete reinforcement connecting to solid elements nodes named as (discrete). Due symmetry only half model is discretized. The solid elements have been used in concrete slab modeling for they are the only ones that support the concrete model in ANSYS, which seems to be one of the major limitations to practical application of ANSYS in reinforced concrete analysis.

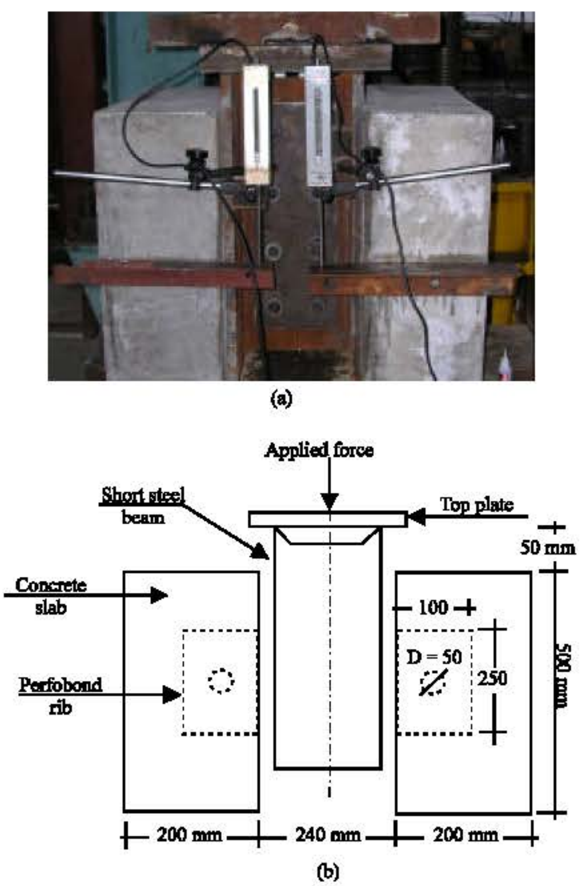

Fig. 1: The push out test model. a. Experiments specimen and b. push-out model geometry

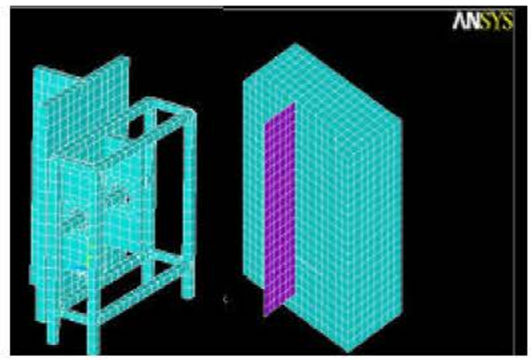

Fig. 2: ANSYS modeling

Each model has been analyzed five times, according to five different material models. Linear elastic behavior for both concrete and steel is needed to be used with all models. The cracking in tension and crushing of compressed concrete is capable based on Drucker-Prager (DP) yield criterion, which used as the first model, the second model adopting the Multilinear Elastic (MELAS) and the Multilinear Isotropic (MISO) is the third model adopted. An extra two model composed from combining Drucker-Prager with multilinear elastic (DP+MELAS) and combining Drucker-Prager with multilinear isotropic (DP+MISO) are also used. The uniaxial stress-strain relation, simulating a parabolic curve represented concrete compressive behavior is required. Therefore, two numerical expressions are used to predict the stress-strain curve for concrete using the numerical expression suggested by Hognestad (1951) given as:

$$f_c = f_c'\left[2\left(\frac{\varepsilon}{\varepsilon_0}\right) - \left(\frac{\varepsilon}{\varepsilon_0}\right)^2\right] \quad \text{for} \quad 0 < \varepsilon \le \varepsilon_0 \tag{1a}$$

$$f_c = f_c' - 0.15 f_c'\left[\frac{\varepsilon - \varepsilon_0}{\varepsilon_{cu} - \varepsilon_0}\right] \quad \text{for} \quad \varepsilon_0 < \varepsilon \le \varepsilon_{cu} \tag{1b}$$

Another expression suggested by Desayi and Krishnan (1964) is also used, given as:

$$f_c = \frac{E_c \varepsilon}{1 + \left(\frac{\varepsilon}{\varepsilon_0}\right)^2} \tag{2}$$

Where fc = stress in concrete, fc' = peak concrete stress, ε = strain in concrete, ε_0 = strain corresponding to peak concrete stress, ε_{cu} = ultimate concrete strain. And

Table 1: Summery of model analysis

Cases	Concrete model		Reinf.
A1	DP	Drucker-Prager	Discrete
B1	MELAS	Multilinear elastic	Discrete
C1	MISO	Multilinear isotropic	Discrete
D1	DP+MELAS	Drucker-Prager with Multilinear elastic	Discrete
E1	DP+MISO	Drucker-Prager with Multilinear isotropic	Discrete
A2	DP	Drucker-Prager	Smeared
B2	MELAS	Multilinear elastic	Smeared
C2	MISO	Multilinear isotropic	Smeared
D2	DP+MELAS	Drucker-Prager with Multilinear elastic	Smeared
E2	DP+MISO	Drucker-Prager with Multilinear isotropic	Smeared

the initial tangent modulus E_0 is then computed as: (Bangash, 1989)

$$E_o = \left.\frac{dfc}{d\varepsilon}\right|_{\varepsilon=0} = 2\frac{f_c'}{\varepsilon_o} \qquad (3)$$

The Bilinear Kinematic Hardening (BKIN) option assumes the total stress range is equal to twice the yield stress is used for steel beam in additional to the linear elastic option for all cases. The linear elastic is used for reinforcement. The analyses performed are summarized in Table 1.

RESULTS AND DISCUSSION

The main purpose of the present study is to investigate the type of concrete modeling that gives best simulation to the concrete behavior in linear and nonlinear case through comparing the results with experiments, aiming to produce the shear resistance of the connector investigated by push-out test. The concrete behavior is important in such type of study, since concrete's failure is the most common shape of failure in push out tests with perfobond connector. The push out test specimen, Fig. 1, is modeled and analyzed using concrete compressive strength of 54.6MPa and steel yield strength of 345MPa.

Effect concrete stress-strain relation: The two expressions given in Eq. 1 and 2 are tested to investigate the most applicable one, showing the results in Fig. 3.

The results show that expression (1) is more likely to be used for concrete nonlinear simulation, giving more ductile behavior of concrete. Therefore, it is employed in the analysis of the push-out test models.

The modeling analysis: The results of different models available on ANSYS to simulate the concrete behavior and analyzing the push out test model given in Table 1 are illustrated in Fig. 4 and 5 for discrete and smeared reinforcement, respectively. These figures show that the load-deflection curves show very close results at the early stages of load history for all analyses conducted, having

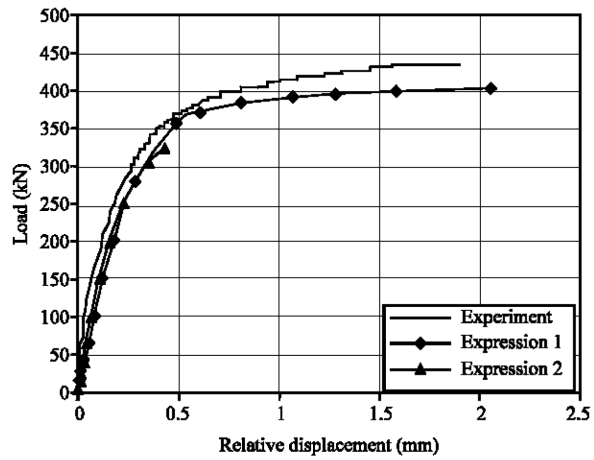

Fig. 3: Using different expressions to estimate concrete uniaxial stress-strain curve

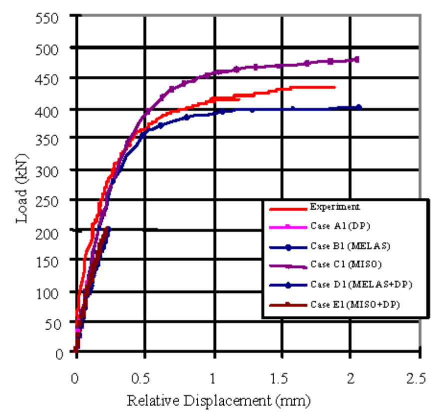

Fig. 4: Load-displacement curves of push out test using different models with discrete reinforcement

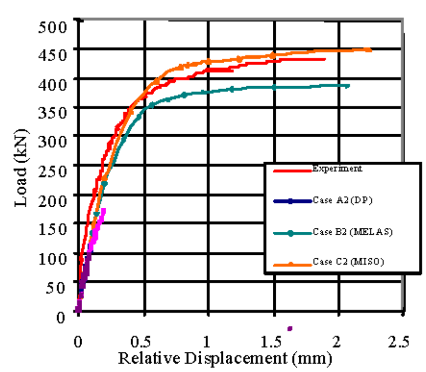

Fig. 5: Load-displacement curves of push out test using different models with smeared reinforcement

initially linear relation with a sudden loss of stiffness when cracking in concrete begins. The differences between the models appear soon after service load. Linear elastic models with Drucker-Prager option quickly reach to failure 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. The model based on Drucker-Prager yield criterion with discrete reinforcement has exhibited a somewhat similar behavior, with larger concrete yielding limits but also fail soon after service load. The ultimate load has not been reached in such cases as well as with all cases adopted the Drucker-Prager (DP) option for both the discrete and smeared reinforcement models. These are shown clearly by combining the Drucker-Prager (DP) yield criterion with both multilinear elastic option (MELAS) and Multilinear Isotropic Option (MISO). The results also show that more ductile failure can be produced using the Multilinear Elastic Option (MELAS) and Multilinear Isotropic Option (MISO) with very close path to the experiments but unconservative results is produced form MISO comparing with the MELAS option. The flexibility of the materials produced by using the MELAS option is more useful to produce nearest, conservative and save results of the push-out test by using finite element with the ANSYS options.

The comparison between the discrete and smeared reinforcement models' results are shown in Fig. 6. It also shows that the ultimate load of the smeared reinforcement model is smaller than the discrete reinforcement model.

However, it is clearly that modeling concrete using finite element method with the ANSYS options produce different results depending on the type of modeling adopted in the analysis, affecting on providing a longer load history. When cracking has been kept active the failure of the model has been premature. On the other hand, the model in which cracking of concrete has been disabled has been able to generate a complete load deflection diagram. In this case, failure of the model has been determined by crushing of concrete or yielding of reinforcing steel. 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 cracking did not reach loads much greater than service ones. The best results have come from the multilinear elastic models and multilinear isotropic, which have been able to reach ultimate loads very close to the expected values.

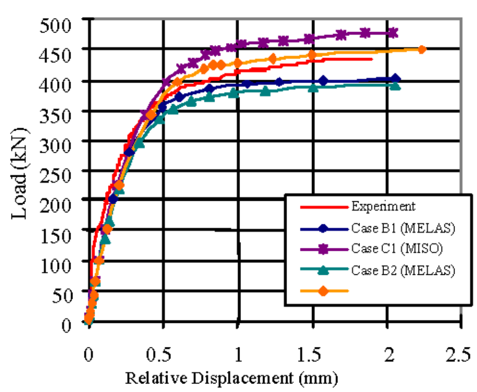

Fig. 6: Load-displacement curves of push out test using discrete and smeared reinforcement

Regardless reinforcement representation, discrete or smeared and despite the good concrete elastoplastic model behavior, 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. However, in ANSYS, 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 experimental results in all load history.

CONCLUSIONS

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 (Fig. 4-6) that the model for concrete has played a major role in the achievement of the numerical solution from a certain load level on. The multilinear elasticity and multilinear isotropic with 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 suggested that the multilinear elasticity can be employed to simulate the concrete in modeling the push-out test specimen satisfactory predicting the response of specimen to the applied load.

The study shows also that the expression suggested by Hognestad (1951), is more reliable to be employed in the analysis which allow for more ductile failure of concrete supporting generate a complete load deflection history.

More studies are suggested to be conducted to investigate the effect of concrete parameters such as compressive strength, modulus of elasticity, etc. on the overall behavior of concrete through finite element simulation.

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