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NONLINEAR FINITE ELEMENT ANALYSIS FOR REINFORCED CONCRETE SLABS UNDER PUNCHING LOADS

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ABSTRACT

This paper presents an implementation of a three-dimensional nonlinear finite element model for evaluating the behavior of reinforced concrete slabs under centric load. The concrete was idealized by using eight-nodded solid elements. While flexural reinforcement and the shear were modeled as line elements, a perfected bond between solid elements and line elements was assumed. The nonlinear behavior of concrete in compression is simulated by an elasto-plastic work-hardening model, and in tension a suitable post-cracking model based on tension stiffening and shear retention models are employed. The steel was simulated using an elastic-full plastic model. The validity of the theoretical formulations and the program used was verified through comparison with available experimental data, and the agreement has proven to be good. A parametric study has been also carried out to investigate the influence of the slab thickness on column-slab connection response

Key words: Centric Loading; Slab Thickness; Punching Shear; Slabs; Finite Element.

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1. INTRODUCTION

Reinforced concrete slabs are one of the important elements in most structural systems; they are relatively thin structural elements, whose main function is to transmit the vertical loading to their supports. Flat plates or beamless slabs have no beams, column capitals or drop panels, which make formwork very simple and widely used, but the great disadvantage of flat plates or slabs Supported by columns is that they are highly susceptible to punching shear failure under concentrated loads, compared with slabs supported by beams or walls. Slab thickness considered as a control parameter affecting slab column connection strength. Most of excremental researches intended to investigate specimens with the same thickness. The lack of a factor for size effect in the ACI 318-08 equations for the punching shear strength provided by concrete in slabs is a limitation of the code. The evidence presented in this paper demonstrates conclusively that a size factor is urgently needed for the safe design of slab.

The effect of the slab thickness on the punching shear resistance had been recognized as early as 1938 by Graf11 who reported that the shear strength at punching found in a 500 mm thick slab is more or less the same as the shear strength of beams failing in shear, which is approximately half the punching shear strength of a two-way slab with a slab thickness of 150 mm. In 1948, Richart came to the conclusion that the shear stress at failure decreases considerably with increasing effective depth of the tested footings. Recent experiments by Guandalini and Muttoni confirm this trend. An investigation into the size effect was also recently reported by Li. Unfortunately, these tests had small span-depth ratios that were further reduced for the thicker slab. Therefore, the results of this test series only allow for limited conclusions in regard to a size factor.

2. FINITE ELEMENT FORMULATION

Test slabs were typically discretized using 12x12 mesh of nearly equal-size 3-D isoparametric elements, Solid65 as shown in Figure.5-1. Four layers of elements were used to idealize the slab thickness. The top and bottom layer represent the top and bottom concert cover and the in between two layers accounted the slab thickness. The column stub was represented as shown in the figure to simulate the actual shape and dimensions of column stub of test specimens. The slabs were analyzed as simply supported along the four sides to simulate the experimental set-up. Referring to ANSYS technical manual, the three-dimensional isoparametric element Solid65 was adopted to model the concrete element. The Solid65 element is capable of cracking in tension and crushing in compression. This element is similar to the one recommended by H.M. Marzouk and Zhiwei Chen [1993], who introduced a three-dimensional, 8-node isoparametric element. Solid65 element is defined by eight nodal points each having three translational degrees of freedom x, y, and z (and no rotational deformations), along with a 2 x 2 x 2 Gaussian Integration Scheme which is used for the computation of the element stiffness matrix. The element can represent one solid material (concrete), and up to three impeded reinforcing bars with different material properties. The geometrical characteristics of the 3-D Solid65 element are shown in Fig. 5-2. Both linear and non-linear responses of the concrete were included. For the linear stage, the concrete is assumed to be an isotropic material up to cracking. For the non-linear segment, the concrete may undergo plasticity. Cracking may take place up to three orthogonal directions at each integration point. The software package "Ansys10" allows steel reinforcement to be defined using the smeared reinforcement approach, in which the amount of reinforcement is defined by specifying a volume ratio and orientation angles of the rebar. In this study, the reinforcing bars were idealized using a 2-node bar (linear) element (Link8).

3. ANALYTICAL PROCEDURES

The numerical solution scheme accounted for non-linear analysis was an incremental load procedure. For each load increment, an iterative solution performed was a combination of the high convergence rate of the standard Newton-Raphson method and the low cost of the modified Newton-Raphson method in which the stiffness was reformulated every loading step. The convergence criterion used was based on the iterative nodal displacement where only transitional degrees of freedom were considered. The criterion is:

$$\psi / R \leq \phi$$

Where Ψ is the norm of the iterative displacement and R is the norm of total displacement. The convergence tolerance, ϕ of a range between 0.02 and 0.05 was found to yield satisfactory results. The load level at which the convergence criterion was not fulfilled, indicating numerical instability, has been regarded as the analytical ultimate load of the test specimen.

4. SLAB SPECIMENS

Four slab specimens (S1, S2, S3 and S4) of rectangular shape with dimensions of 1200x1200 mm and with a column stub located at specimen center with dimensions of 200x200 mm. all specimens reinforced with the same reinforcement steel (12Ø18/m tension and 12Ø18/m in compression). The cube concrete strength was taken as 35.0Mpa for all specimens. Slab thickness investigated in this study ranged from 100 mm to 160 mm. it should be mentioned that the slab specimen, S2 with thickness 120 mm was investigated experimentally by Ahmed Salah (MSc thesis Benha Univ. - 2008). This specimen considered as a control specimen to verify the analytical results.

5. RESULTS OF NON-LINEAR FINITE ELEMENT ANALYSIS.

5.1. Crack Patterns

Outputs for NLFEA are shown in Figure.1; these figures indicate the cracks propagation for Specimen S1 as example. As shown, following of the cracks formation shows propagation of the radial cracks from the column corners. These cracks followed by formation of some tangential cracks. By increasing load the radial cracks propagate towards the slab corners and the tangential cracks spread at larger perimeters, agreeing with experimental observations.

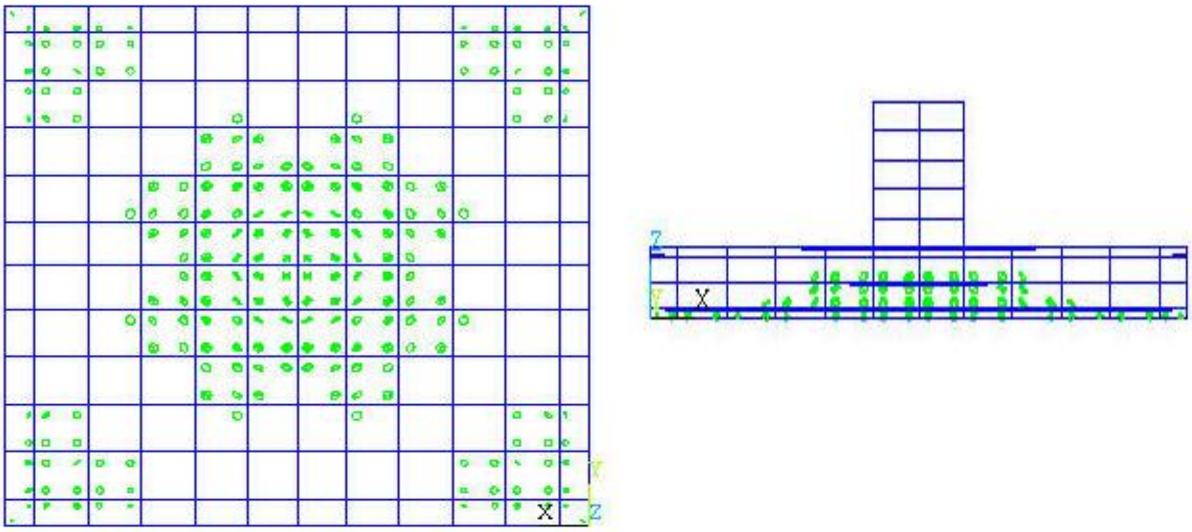


Figure 1 Crack Pattern for Slab Specimen

5.2. Load-Deflection Behavior

Referring to Figure.2, the NLFEA good estimation of the central deflection throughout the loading stages for most of the test specimens was achieved. Also, the analysis failed to predict the post-peak behavior for some test slab specimens especially those undergo sudden punching failure. It obvious that slab thickness had a noticeable effect on load deflection response of slab specimens. Slab with higher thickness exhibited higher stiffness. Also at the same level of loading displacement decreased as the slab thickness increased.

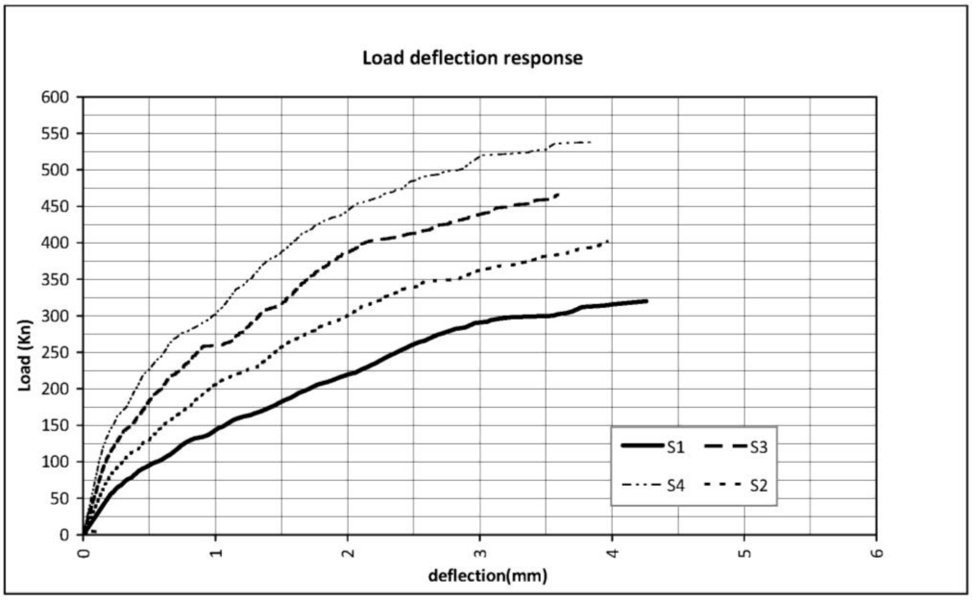
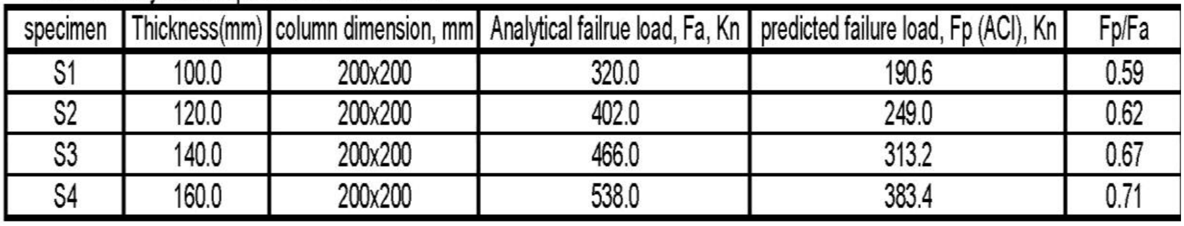


Figure 2 Load Deflection Relationship for Slab Specimens

5.3. Ultimate Failure Load

Table.1 indicting the analytical ultimate failure loads with corresponding predicted by ACI318-08 without any safety factor. The ratio between predicted strength and analytical were ranged from 0.59 and 0.71. The conservative prediction of ACI provisions may be attributed to the lesser extent of size factor in pouching shear formula.

Table.1 Analytical and predicted ultimate loads



specimen	Thickness(mm)	column dimension, mm	Analytical failrue load, Fa, Kn	predicted failure load, Fp (ACI), Kn	Fp/Fa
S1	100.0	200x200	320.0	190.6	0.59
S2	120.0	200x200	402.0	249.0	0.62
S3	140.0	200x200	466.0	313.2	0.67
S4	160.0	200x200	538.0	383.4	0.71

6. CONCLUSIONS

Analytical study of slab specimen of thickness varied between 100 mm and 160 mm are presented. The most important conclusions from these experiments are:

Slab thickness exhibited a noticeable effect on pouching shear behavior of flat slabs; slab thickness should be adopted in punching shear formula as size effect.ACI provisions for punching shear strength predicted a very conservative punching shear capacity; code formula should be refined to account the slab thickness as a size effect parameter in punching shear formula.

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