INVESTIGATION OF FINITE ELEMENT MODEL OF SLAB COLUMN CONNECTIONS UNDER ECCENTRIC LOAD

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ABSTRACT :

Concrete flat slab floors provide an elegant form of construction, which simplifies and speeds up site operations, allows easy and flexible partition of space and reduces the overall height of buildings. Unbalanced moments commonly occur in buildings with flat slabs, caused by unequal spans or loading on either side of the column. Differences of temperature or differential creep between two adjacent floors results in differential displacements of the top and bottom of the columns, which induce moments in the slab-column connection, even if the columns do not participate in the horizontal load resisting system. In the presence of such moments, the punching becomes unsymmetrical, and the punching strength of the slab decreases. This paper presents finite element analysis of slab-column connection in order to investigate the effect of eccentric load. Three-dimensional nonlinear finite element models had been created by the authors in order to simulate the behavior of the flat slabs which included the load-deflection response, the ultimate failure load and the crack pattern. The purpose of the present study is to quantify the effect of a moment on the punching load and to quantify the expected moments for typical configurations of internal columns in structures by using finite element analysis. Also the effectiveness of punching shear reinforcement in the presence of moment transfer has been investigated. Punching strength for slabs with various eccentricities according to provisions of different Standards for finite element models was investigated and its relevant results indicated that Canadian standard locates in a better safety zone. Also the effect of load eccentricity has been studied and indicated that eccentricity, would reduce the final load considerably.

KEYWORDS: Flat Slab, Slab-Column Connection, Finite Element, Eccentric Load.

1. INTRODUCTION

Flat slab construction in multi-storey structures offers advantages in terms of economy and reduced storey height. A slab-column connection in flat slab construction, however, is frequently subjected to a combination of high bending moments and high shear stresses, which can generate a punching shear failure. The problem with this failure mode is that it is brittle and catastrophic because of the inability of the concrete to support the large tensile stresses that developed. The failure surface is similar to that of a truncated cone or a pyramid around the column. The failure surface extends from the bottom of the slab, diagonally upward to the top surface. The angle of inclination with the horizontal face is depended on the slab and amount of reinforcement in it (Nilson, et al. 2003).

Unbalanced moments commonly occur in buildings with flat slabs, caused for instance by unequal spans or loading on either side of the column. Differences of temperature or differential creep between two adjacent floors results in differential displacements of the top and bottom of the columns, which induce moments in the slab-column connection, even if the columns do not participate in the horizontal load resisting system. In the presence of such moments, the phenomenon of punching becomes unsymmetrical, and the punching strength of the slab decreases.

The Finite-element technique has become the most widely accepted numerical technique in the engineering analysis. However it was not until the 1960s that researchers began to use this technique to aid in the analysis of the concrete structures (Ngo, 1967). Although since then there has been much work carried out in this area this technique has not been generally adopted in design. The main reason for this is that although there is a great amount of experimental data available on punching shear failure of the slabs, there has been little success in developing a universal theoretical model to predict the behavior of an arbitrary concrete structure (Vidosa, 1991). The nonlinear stress distribution in the connection is not clearly understood. Several previous attempts (Polak, 1998; Malvar, 1990) have had attempted to predict the failure of the slabs in punching shear using various FE models. The models presented here were developed to model the behavior of the experimental specimens discussed specifically.

This research project focuses on numerical models developed to predict the behavior of slab-column connections under eccentric loading. Three-dimensional nonlinear finite element models had been created by the authors (Kheyroddin, Hoseini Vaez and Naderpour2008) in order to simulate the behavior of the flat slabs which included the load-deflection response, the ultimate failure load and the crack pattern. The models were based on an eight-node isoparametric element. A parametric study had been carried out to look at the variables that can mainly affect the behavior of the models. The purpose of the present study is to quantify the effect of a moment on the punching load and to quantify the expected moments for typical configurations of internal columns in structures by using finite element analysis. Also the effectiveness of punching shear reinforcement in the presence of moment transfer has been investigated.

2. EXPERIMENTAL TEST

In order to verify the numerical analysis slab specimen tested by Kruger (Kruger, et al. 1998) was selected (Figure 1). The experimental slab-column connection was full scale model. The boundaries of the specimen were selected at the position of the line of contra-flexure so as to contain the hogging moment region around the column. The specimen support was considered as a simple support during the test on knife edges fixed on steel beams so that the edges are free to lift. The test set-up and loading arrangement are shown in Figure 1. The specimen was inversely placed. The testing arrangement was convenient for both loading and inspecting the slab for cracking during the test. The vertical load was applied centrally through the column stub, with the slab specimen simply supported along four edges to simulate an inverted isolated slab-column connection.

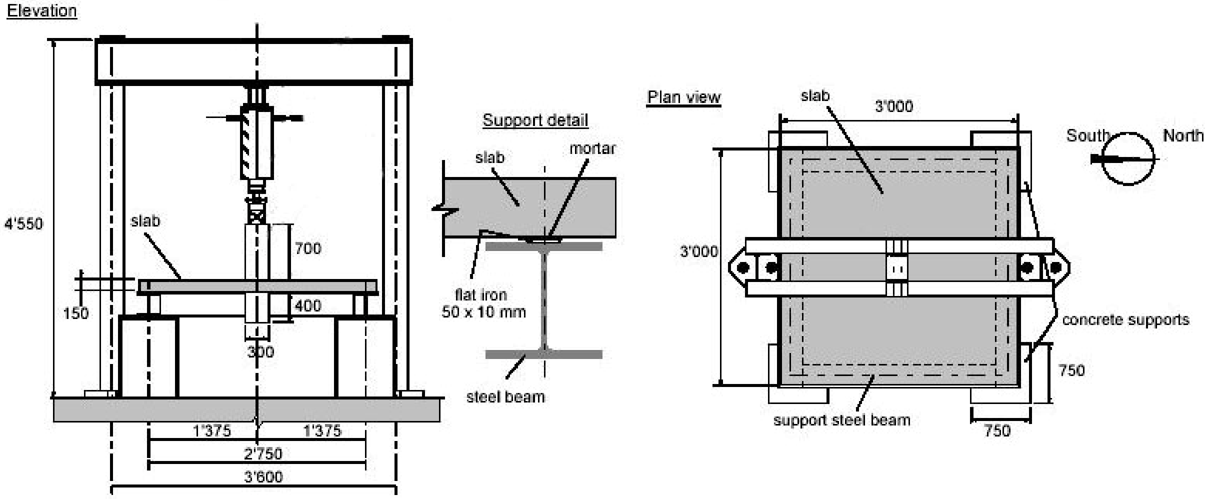

Figure 1 Test set-up and specimen.

3. FINITE ELEMENT MODELING

The previous study by the authors was focused on modeling both the load-deflection characteristics of the slabs and also the initial onset of cracking. The load was iterated step by step using the Newton-Raphson method. In the static analysis, the stress-strain relations of concrete were modified to represent the presence of a crack. Newton-Raphson equilibrium iterations were used for nonlinear analysis. A displacement controlled incremental loading was applied through a column stub. This was used to simulate the actual loading used in the experimental program. Small initial load steps were used for detecting the first crack in the connections. Then, automatic time stepping was used to control the load step sizes. Line search and the predictor-corrector methods were also used in the nonlinear analysis for accelerating the convergence (Kheyroddin and Naderpour, 2008). The failure of the connection was defined when the solution for a small displacement increment did not converge. Consequently, the finite element model was constructed following the above-mentioned assumptions and considerations.

The main focus of these analyses is to model the load-deflection behavior of the specimen P0A that was given above. The numerical models were developed in two different groups. One of these groups consisted of three layers of elements in the depth of the slab with smeared reinforcement throughout, and about the other, just for the bottom layer, smeared reinforcement defined.

The study was carried out to look at the effect of the volume of smeared reinforcement on the behavior of the slab. It was possible to establish the relationship between the volume ratio and section area of the reinforcement. However, the problem with specifying a volume of smeared reinforcement in a three-dimensional analysis was that, it was very difficult to relate the volume directly to the cross-sectional area of reinforcement present in the experimental specimen. Calculating the volume ratio to the section area ratio of the reinforcement for the shapes of solid elements generated was difficult. If the mesh under consideration was uniform with cubic elements throughout this relation is simple, the cross-sectional area being exactly equal to the volume specified.

Uniform mesh with cubic elements was used in preliminary analyses but the results didn't have accuracy. In the finite element of concrete structures, it was important to select an appropriate mesh size to meet the requirement of accuracy and computation speed; however, considering the mesh layout used in the present models was the same. The density of the mesh was increased under the area of loading and gradually reduced towards the edges of the slab. Therefore, as the mesh was not uniform, it was necessary to carry out a parametric study and look at the effect of the volume of smeared reinforcement present. This problem did not occur in the discrete reinforcement modeling currently being conducted.

The load-deflection curves for the best model taken from each of the groups were compared below (Figure 2). On examination of the plots, it was obvious that the best approximation is given by group I. For these slabs high volume ratios, such as 0.045, increase the stiffness of the elements considerably and an optimum volume ratio of 0.028 was found to give the best approximations of the load-deflection curve for the experimental specimen. It should be noted that this value was approximately three times more than the percentage of main steel in the experimental specimen, which indicates the influence of geometry of volume mesh. It was noticed that for similar values of the reinforcement volume ratio in the bottom layer, the deflection of the slabs decreased and the final load supported by the slab also decreased. Similar results were noticed in the case of group II slabs, where the load-deflection curves for the models were not as good approximations as those obtained using group I models.

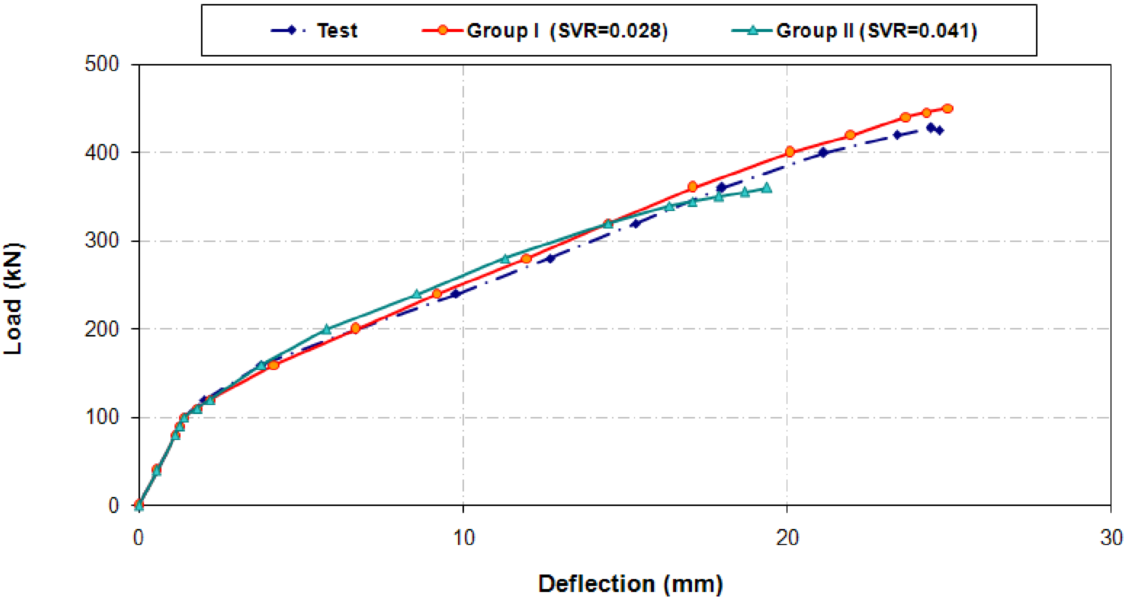

Figure 2 Comparison of load-deflection curves.

4. APPLYING ECCENTRIC LOAD ON MODELS

Because of unsymmetrical loading, unequal spans or boundary conditions, moment transfer from slab to column is practically always present in flat slabs. The presence of moments reduces the punching resistance of slabs. To investigate this phenomenon, a special shape was given to the column stub so that it was possible to apply the axial force with an eccentricity about 150 and 300 mm (Figure 3). Figure 4 shows load-deflection curves of slab models with eccentricity zero, 150 and 300 mm. On examination of the plots, it is obvious that the decrease in ultimate load is about 26% for an eccentricity of 150 mm and 38% for 300 mm. In continue the influence of strengthening the slab in the central zone with increasing steel volume ratio for models with eccentricity zero, 150 and 300 mm is investigated. In this case, the steel volume ratio in the central zone of models increased up to 30%. The steel volume ratio for central zone of strengthened model was 0.0364 and for peripheral zone was 0.028. Figure 5 shows the strengthened models curve against the un-strengthened models curve. From comparison of load deflection curves, it is obvious that the curve slope for the strengthened models is higher than the other curves. Also, the deflection and the final load supported by the strengthened slab models increased.

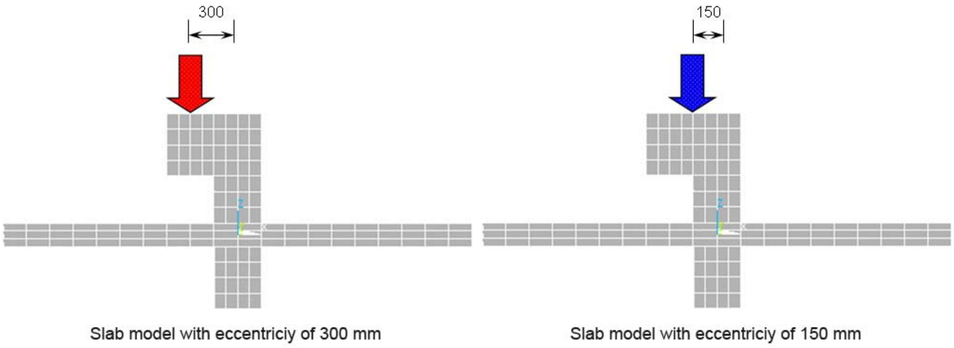

Figure 3 Slab models with different eccentricities.

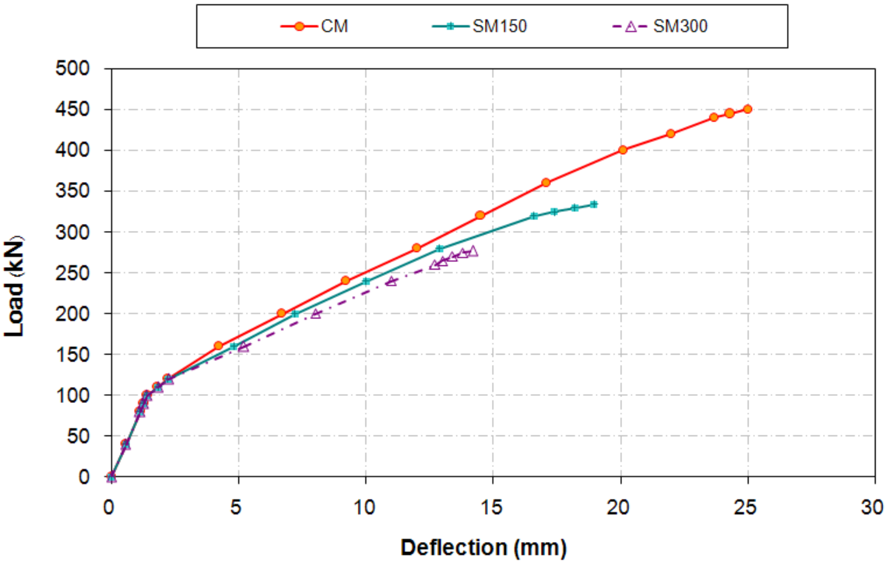

Figure 4 load-deflection curves for different slab models.

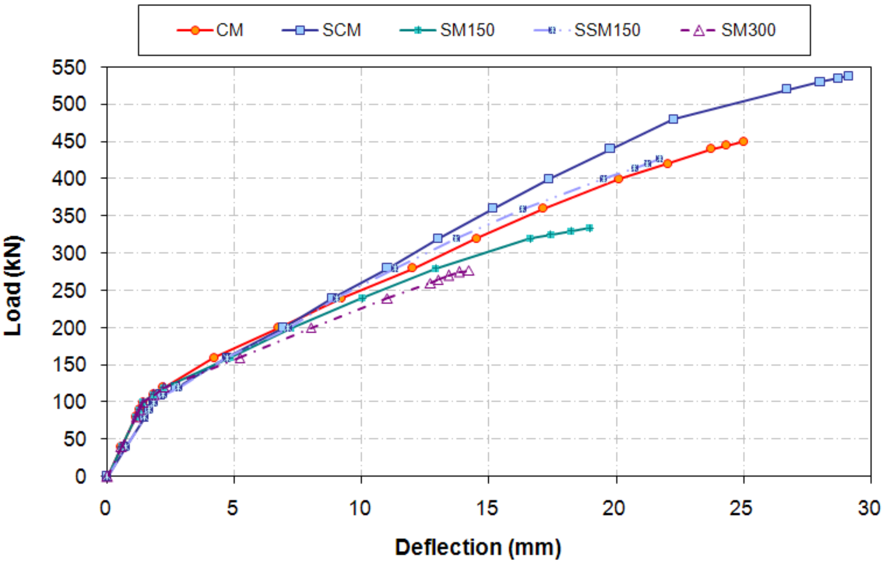

Figure 5 Comparison of load-deflection curves for different models.

Table 1 gives the ultimate load and the reduction compared with the control model and strengthened control model. The eccentricity has a strong influence on the ultimate load. The decrease in ultimate load is about 26% for an eccentricity of 150 mm and 38% for 300 mm. Strengthened Models increase ultimate load up to 20-28% that depends on amount of eccentricity.

Table 1. The effect of different eccentricity.

Models	**Un-strengthened slab models**			**Strengthened slab models**	
	CM	**SM150**	**SM300**	**SCM**	**SSM150**
Eccentricity (mm)	0	150	300	0	150
Steel volume ratio in the central zone	0.028	0.028	0.028	0.0364	0.0364
Steel volume ratio in peripheral zone	0.028	0.028	0.028	0.028	0.028
Ultimate load (kN)	450	334	277	538	427
Decrease in ultimate load with respect to Control Model	0%	26%	38%	0%	5%
Decrease in ultimate load with respect to Strengthened Control Model	16%	38%	49%	0%	21%

5. THE EFFECT OF ECCENTRICITY PROPOSED BY STANDARDS

These standards were examined with regard to their provisions concerning punching shear. The form and the parameters are similar. However the value of these parameters varies significantly, the table 2 shows the predicted punching strength for the slabs without eccentricity according to these codes. Figure 6 shows a comparison between the finite element models and these two codes. From the curves, it is obvious that Canadian standard locates in a better safety zone, while American standard is more economical in this case.

Table 2. Punching strength for slab with out eccentricity according to American and Canadian codes.

Code	**ACI 318 (USA)**	**CSA (Canada)**
V (kN)	300.5	289.3
Eccentricity take into account	Yes	Yes

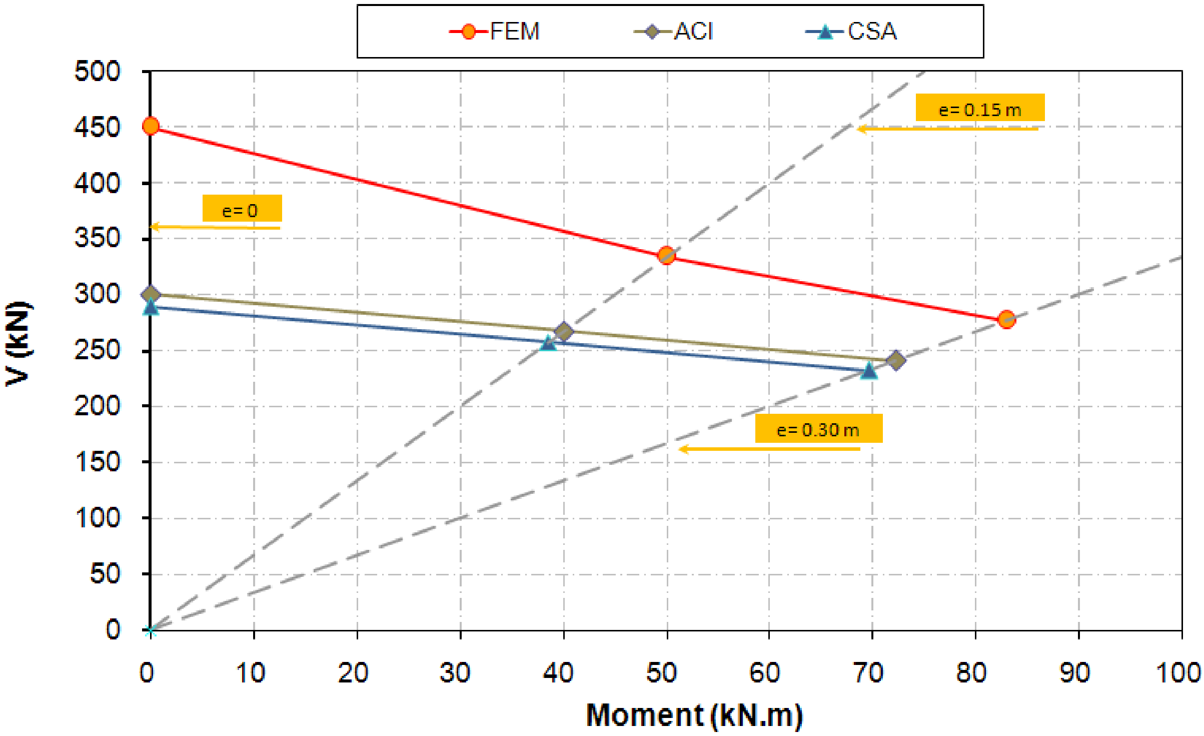

Figure 6 Comparison the effect of eccentricity according Codes with FE Model.

6. CONCLUSIONS

The numerical investigations provided good agreement between the predicted and the available test results of the ultimate load and associated deflection. It is important to select an appropriate mesh size to meet the requirement of accuracy and computation speed. It is necessary to carry out a parametric study and look at the effect of the volume of smeared reinforcement, if the mesh is not uniform. This problem does not occur in the discrete reinforcement modeling. The slab model of group I provides the closest results compared with the experimental test. Although the smeared models do give accurate approximations, their behavior is slightly different. The pre-cracking branch of the different curves follows the experimental results very closely. Beyond cracking, the models of group II appear stiffer. The eccentricity has a strong influence on the ultimate load. The decrease in ultimate load is about 26% for an eccentricity of 150 mm and 38% for 300 mm. With comparison punching strength for slab with different eccentricity according American and Canadian standards against Finite Element model, it is obvious that Canadian standard locates in a better safety zone, while American standard is more economical in this case.

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