Numerical Analysis of a Reinforced Concrete Slab-Column Connection Subjected to Lateral & Vertical Loading

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Abstract— ***Abstract*— Reinforced concrete flat slabs are widely used because of its economical nature. Flat slab structures show significant vulnerability under lateral and vertical seismic loading as punching shear failure may occur in the joints of slab and column. In this research, finite element analyses have been carried out to predict how much seismic loading a flat slab-column connection can endure. The vulnerability of the flat slab-column connection is checked through the analyses. The finite element analyses have been conducted with ABAQUS software because of its wide material modeling capability and customization property. Elastoplastic CDP model is used a material modelling for the reinforced concrete. It is found that thickness of the slab, reinforcement ratio, usage of bent bars, high strength materials are the important factors in punching shear failure in the slab-column connection.**

***Index Terms*— ABAQUS, Finite Element Analysis, Punching Shear Failure, Seismic Loading, Stress Analysis.**

I. Introduction

RECENTLY many experimental works has been done on reinforced concrete structures subjected to seismic loading. Strengthening of both modern and aging infrastructure is essential because of recent earthquake activities. In this paper we want to focus on a reinforced concrete slab-column connection subjected to lateral seismic loading at the top and vertical seismic loading at the bottom of the column. Many experiments have been performed to understand the behavior of the connection of a building. Performing experiment for a flat slab-column connection subjected to seismic loading requires more time and money. Such an experiment was performed by Robertson & Johnson [1] to determine the punching shear failure for a slab-column connection. In that experiment, six specimens were used. And for each specimen experimental setup was prepared and the specimens were subjected to lateral loading. In this research, we have analyzed the specimen one and applied both vertical and horizontal seismic loading. A.S. Genikomsou and M.A. Polak (2014) studied with the problem that can occur in flat slabs, are high stresses in the slab-column connection area that can result in a punching shear failure. In this paper, a 3-D analysis of the reinforced concrete slab with the finite element software ABAQUS using the damage-plasticity model is presented. The simulations of the reinforced concrete slab are compared to the behavior of a specimen that has been tested at the University of Waterloo. This study involves the investigation on the punching shear behavior of reinforced concrete slab-column connections without shear reinforcement.

Tomasz Jankowiak, Tomasz Lodygowski (2005) presents a method and requirements of the material parameters identification for concrete damage plasticity constitutive model. The laboratory tests, which are necessary to identify constitutive parameters of this model have been presented. Two standard applications have been shown that test the constitutive model of the concrete. The first one is the analysis of the three-point bending single-edge notched concrete beam specimen. The second presents the four-point bending single-edge notched concrete beam specimen under static loadings.

Fig.1. Example of Punching Shear failure in the buildings due to earthquake.

Juan Chen, Chengxiang Xu, and Xueping Li (2012) pointed out the seismic behavior of frame connections composed of special-shaped concrete-filled steel tubular columns and steel beam, finite element analyses were performed using ABAQUS compared against experimental data. In our research we mainly focused on the punching shear failure on slab-column connection subjected a flat slab to seismic loading. Punching shear failure occurs due to stress or high localized forces on a reinforced concrete slabs. In reinforced concrete, flat slab structures this occurs at column support point. Punching shear failure due to seismic loading has been a common phenomenon in recent earthquakes. Research activities in this field are relatively less.

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II. MATERIAL MODELING

A. *Concrete damage plasticity Model*

In the research of Genikomsou et al (2014) [2] it is said that, the concrete damage plasticity model is a continuum, plasticity-based, damage model, which assumes two main failure mechanisms: the tensile cracking and the compressive crushing. The model uses the yield function proposed by Lubliner et al. (1989) [3] and modification by Lee and Fenvas (1998) [4].

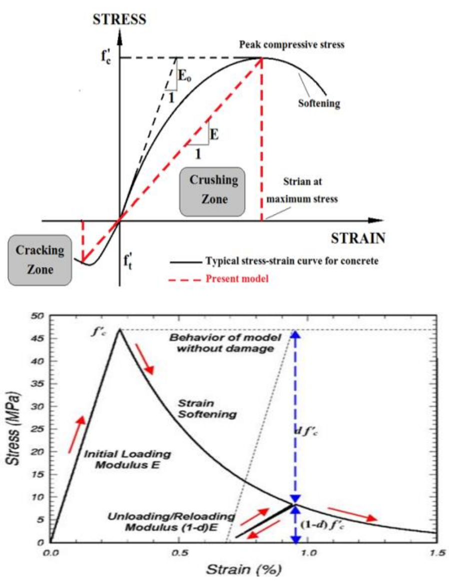


Fig. 2. CDP Model for compression & tension.

B. *Linier Elastic Plastic Model*

The material returns to its original shape when the loads are removed. Strain in these materials is small and stress is proportional to strain.

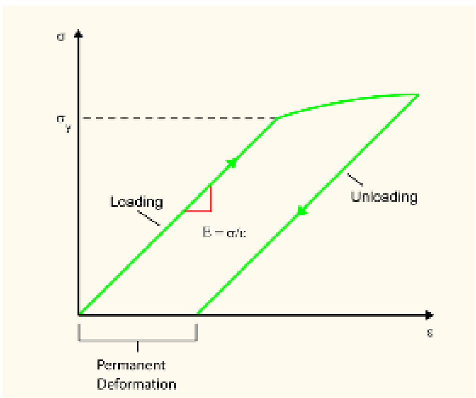


Fig. 3. Linear elastic plastic model.

III. SPECIMEN MODELING

A. *Slab-Column Joint Modeling*

An interior slab-column connection has been created using the co-ordinate system where the whole connection acted as the host element for the reinforcements. Concrete damage plasticity type model has been used here. Slab is placed with the thickness of 114mm and slab size is placed as 2743mm*3048mm. And the column size is placed as 254mm*254mm. And the height of the column is placed as 1524mm.

A. *Reinforcement Modeling*

Reinforcement of both slab and column has acted as the embedded element. The bottom slab reinforcements are placed at #10@356mm, #10@203mm, #10@152mm, #10@256mm & #10@356mm along the width of the slab and #10@356mm, #10@203mm, #10@152mm, #10@256mm & #10@356mm along the length of the slab. The top slab reinforcements are extended to one third of the slab. The top slab reinforcements are placed at #10@152mm along the width of the slab and #10@152mm, #10@127mm, #10@127mm & #10@152mm along the length of the slab. Four rebar are used in column and no tie bars are used. #20 reinforcement is used as the column reinforcement.

B. *Material property for slab & Column concrete*

TABLE I
PROPERTY FOR SLAB AND COLUMN CONCRETE

Property	Value
Density (kg/mm^3)	2.4×10^{6}
Young Modulus (MPa)	34400
Poison's Ration	0.23
Dilation Angle	38
Eccentricity	0.1
FB_0 / FC_0	1.16
K	0.67
Viscosity Parameter	8.5×10^{5}
Yield Strength (Compressive)	44
Yield Strength (Tensile)	2.2
Fracture Energy (N/mm)	0.09

C. *Material properties for reinforcement*

Rebar's density is 7.75E-6 kg/mm^3 And Young modulus 210000 MPa. Poison ratio was taken 0.3. T3D2 element has been used. Truss elements are rods that can carry only tensile or compressive loads. They have no resistance to bending; therefore it can be modeled as a truss**.**

D. *Meshing*

Every part was individually meshed for finite element analysis. Mesh size 10mm is used in the host element and 10mm is used in the embedded element. T3D2 elements are used. Total number of element is 12,656. Total number of node is 16,846. Total number of variables in the model is 50,538.

IV. STRESS DISTRIBUTION

A. *Stress Distribution Analysis for Different Loading Cases*

For the loading case 1 punching shear occurs at the critical perimeter according to ACI code where the top of the column is subjected to 1000 Hz of seismic loading. The critical perimeter is located at a distance of d/2 from the face of the column. The maximum shear stress at critical column is necessary to determine whether punching shear failure will occur or not. Stress distribution analysis has been done for various cases to find out the maximum stress at critical perimeter.

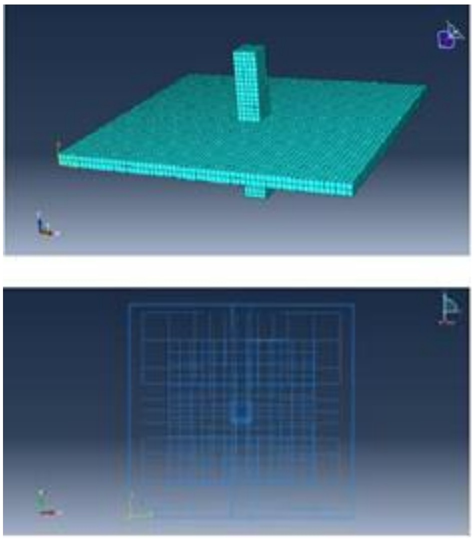


Fig 4. Meshing & Modeling of the slab-column joint, reinforcement.

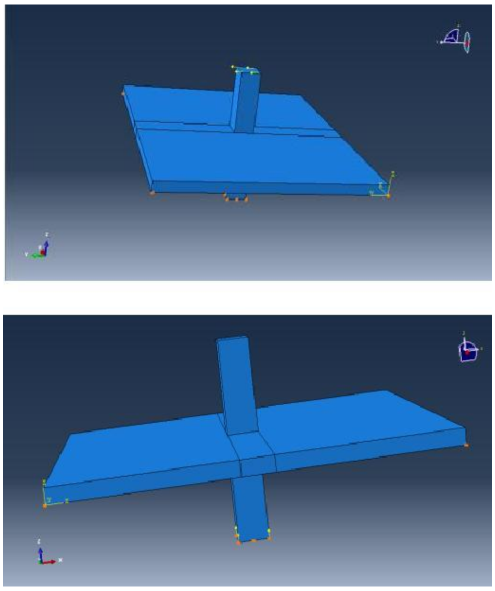


Fig 5. Seismic loading at the top and bottom of the column.

B. Von Mises & Tresca Stress Distribution

For the loading case 1 it is considered that the top of the column is subjected to 1000 Hz of seismic loading in the horizontal direction. Von mises & Tresca stress distribution analysis is done for an element situated in critical parameter of the flat slab.

For the loading case 2 it is considered that the top of the column is subjected to 2000 Hz of seismic loading in the horizontal direction. Von Mises & Tresca stress distribution analysis is done for an element situated in critical parameter of the flat slab. For the loading case 3 it is considered that the top of the column is subjected to 1000 Hz of seismic loading in horizontal loading & 1000 Hz of vertical Loading at the bottom of the column in vertical direction. Von mises & Tresca stress distribution analysis is done for an element situated in critical parameter of the flat slab.

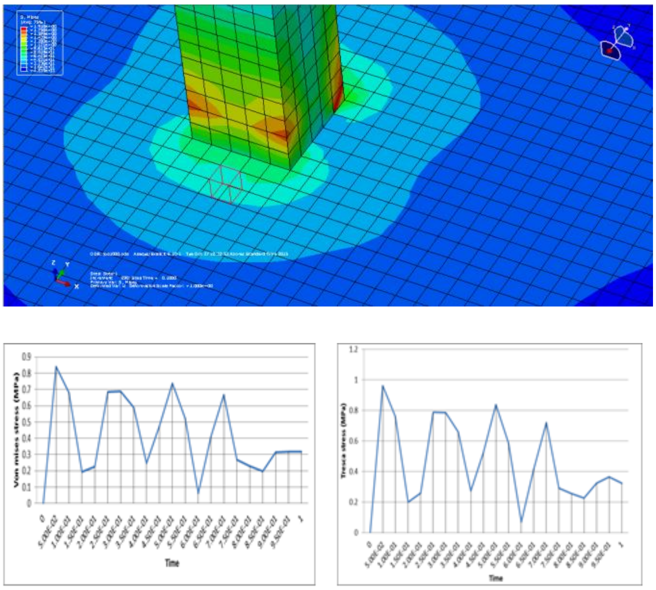


Fig 6. Contour plot of the slab column connection & Element at the critical parameter for Maximum stress distribution curve for case-1

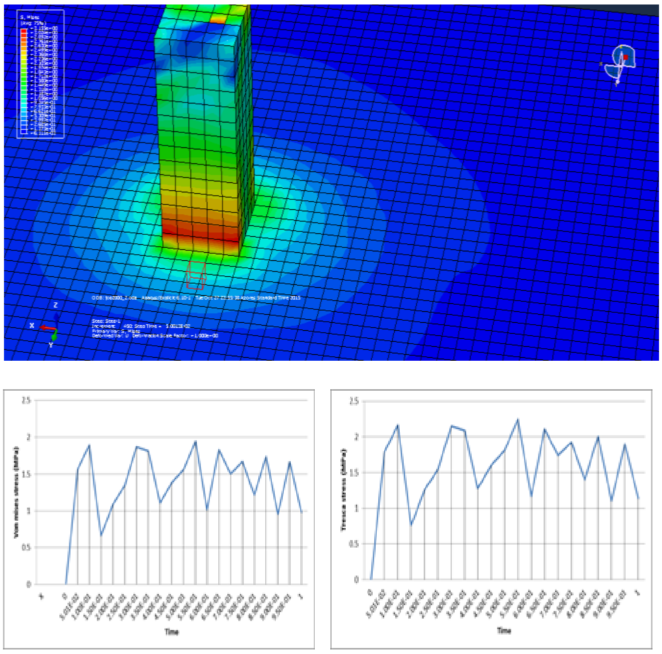
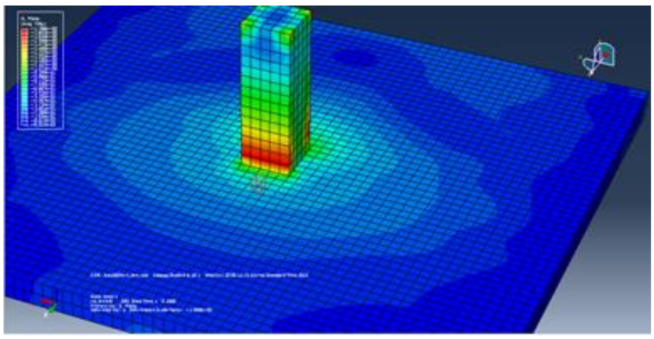


Fig. 7. Maximum stress distribution curve for case-2



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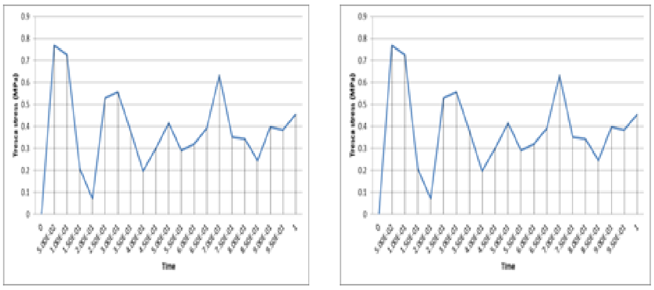

Fig. 8. Maximum stress distribution curve for case-3

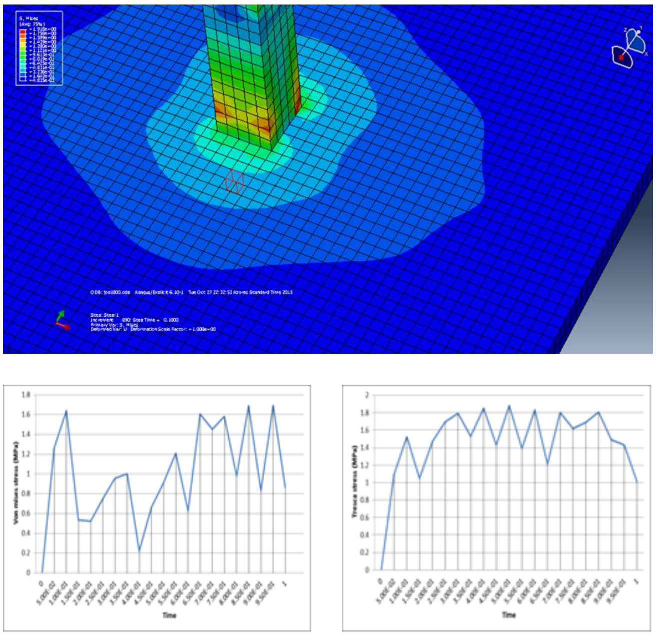

Fig. 9. Maximum stress distribution curve for case-4

C. Comparison with ACI Code

A value of 1.0 for the shear ratio would indicate that the connection is on the verge of punching shear failure according to the ACI Building Code.

The concrete shear stress is limited to the smallest of three concrete stress equations given in ACI 318 section 11.12.2.1

$$v_c = \frac{1}{3}\sqrt{f_c}$$

Shear ratio is the ratio of ultimate shear stress for the critical perimeter & concrete shear stress. If the ratio is 1 or greater than 1 then punching shear failure occurs.

V. RESULTS AND DISCUSSIONS

The results of the analysis have been summarized in Table II.

As from ACI building code it has been established that if shear ratio $\frac{v_n}{v_c} \geq 1$ then punching shear failure will occur.

From the tabulated chart it is seen that punching shear failure occurred for a slab-column connection subjected to 2000 Hz of cyclic loading laterally at the top of the column and combination of 2000 Hz of cyclic loading at the top of the column laterally and 2000 Hz of cyclic loading vertically at the end of the column.

TABLE II
EXAMPLE OF THE CONSTRUCTION OF ONE TABLE.

Cases	Stress Distribution	Ultimate stress v_N N/mm^2	Concrete stress v_c N/mm^2	Shear Ratio $\frac{V_n}{V_c}$	Chance of occurring Punching shear failure
Case-1	Von-Mises	0.88	1.81	0.49	Crack may develop & Punching shear failure is not imminent.
	Tresca	0.97	1.81	0.56	Crack may develop & punching shear failure is not imminent
Case-2	Von-Mises	1.97	1.81	1.09	Punching shear failure.
	Tresca	2.2	1.81	1.21	Punching shear failure.
Case-3	Von-Mises	0.69	1.81	0.38	Punching shear failure is not imminent.
	Tresca	0.78	1.81	0.94	Punching shear failure is not imminent.
Case-4	Von-Mises	1.7	1.81	1.09	Punching shear failure.
	Tresca	1.8	1.81	1.011	Punching shear failure.

VI. Conclusions

In this model Von Mises stress and Tresca stress distribution has been checked at the slab-column connection. It has been observed that it is possible to determine the behavior of a slab-column connection subjected to seismic loading. To minimize the effects of seismic loading the following should be taken into consideration –

- Increase the thickness of the slab,
- Increase the reinforcement ratio,
- Usage of bent bars,
- Usage of high strength materials.

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