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FINITE ELEMENT ANALYSIS OF SLAB - COLUMN JOINT UNDER LATERAL LOADING

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ABSTRACT

In flat plates, a brittle punching failure can rise in connections due to poor transfer capacity of shearing forces and unbalanced moments. Once, the punching shear failure occurs, the resistance of the structure is significantly reduced, which causes the separation of the column and slab which leads to collapse of the whole structure. In the present work, analytical investigations are carried out to study the performance of interior slab – column joints of reinforced concrete multi storey buildings. The connection between slab and column is an essential link in the load resisting mechanism of flat plate building. From the literature reviewed it is clear that paucity of information exists in the area of detailing of slab to column joint. Hence an attempt has been made to study the effect of detailing of slab – column joint under lateral loading. In order to study the performance of interior slab–column connection, a multistoried flat plate RC building has been analysed and one of the interior slab – column joints is designed. Seismic analysis is performed using the equivalent lateral force method given in IS 1893(Part 1):2002 [5]. Analytical modelling of the slab– column joint was carried out using finite element software package ANSYS [1]. The model is analysed under axial vertical load and varying lateral load at the top of the column. The critical stress resultants were observed at the slab – column joint.

Keywords: Flat plate; punching; slab – column joint; seismic analysis.

1. INTRODUCTION

Common practice of design and construction is to support the slabs by beams and support the beams by columns. This may be called as beam-slab construction. The beams reduce the available net clear ceiling height. Thus the slabs which are directly supported by columns are called Flat plates**.** The advantages of flat-plate floor system are numerous. It provides architectural flexibility, more clear space, less building height, easier formwork and shorter construction time. Hence it is mostly applicable for large span commercial buildings. For

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vertical loads, the structural performance and design of flat plates are well established. Under lateral loads, many aspects of behaviour of flat plates are uncertain.

Thus during earthquake an important problem existing in this system is punching shear failure of the slabs due to high concentration of stress in vicinity of slab- column connections. This failure type is very dangerous because of its brittle nature. Once, the punching shear failure occurs, resistance of the structure is significantly reduced, which causes separation of the column and slab, and then lead to collapse of the whole structure. The punching shear failure is illustrated in Fig. 1.

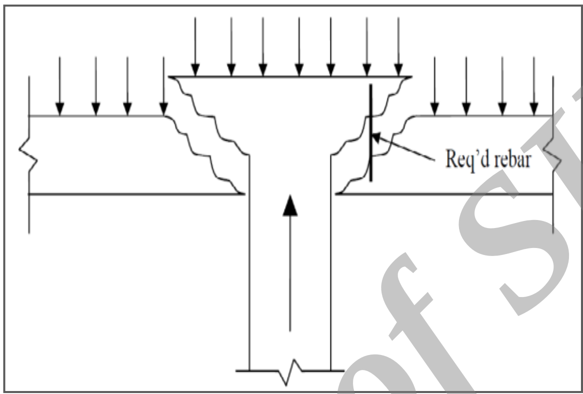

Figure 1. Punching Shear Failure

A critical design criterion for flat plates is the punching shear strength of the slab at the slab-column connections. To avoid adding drop panels or beams to increase the shear capacity of the slab, various types of shear reinforcement can be used in the slab around the connection.

The objectives of the present work are to develop nonlinear analytical models to study the behaviour of interior slab-column joint and to provide information to the designer about the stresses and displacement contours at the joint.

2. MODEL ANALYSIS

An eight storied flat plate building is modeled, analyzed and designed using STAAD.PRO[13] . Having designed the structure, one of the slab-column joint (marked in Fig. 2) is subjected to finite element modeling using the software ANSYS[1] (Version 11). Since the analytical model has to be validated through experimental results (Robertson et.al. 2002)[11] the scale factor of ½ has been adopted for the present work. The dimensions of slab-column joint are reduced to those which satisfy the laws of similitude (Cauchy's similitude law).

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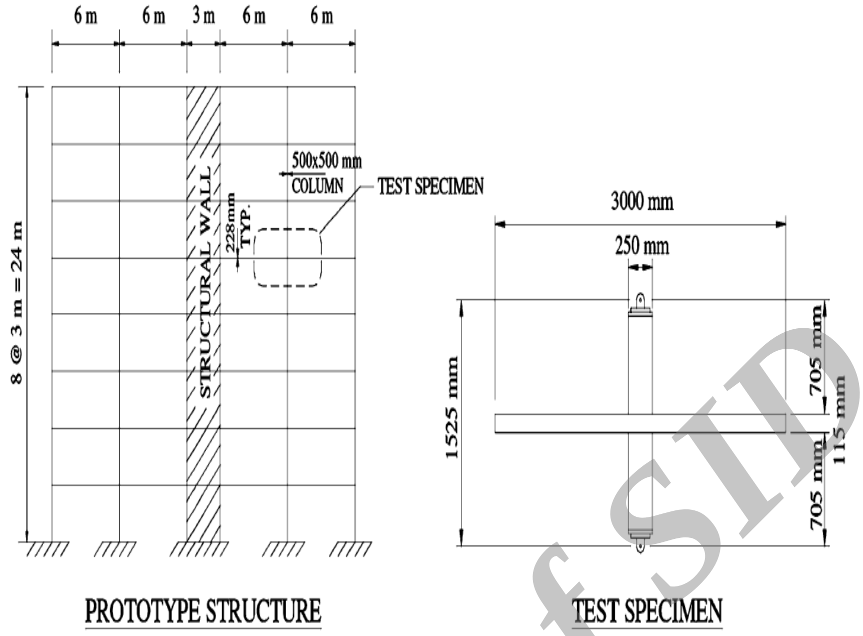

Figure 2. Layout of Slab-Column Joint

3. COMPUTATION OF DESIGN FORCES

The eight storey RC building in Zone III on medium soil was analyzed using STAAD.PRO (v8i) [13] and the shear forces, bending moments and axial forces in the interior column due to different load combinations were obtained. Seismic analysis was performed using Equivalent lateral force method given in IS 1893:2002.[5] Force resultants for the critical combination (1.5DL-1.5 EQZ) for the interior column were obtained and the design of slab has done for the critical load combinations.

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4. FINITE ELEMENT MODELING

The slab-column connection (1/2 scale) had been analyzed using the finite element software ANSYS (Version 11)[1]. Element Solid 65 is used to model the concrete while Link 8 element is used to represent the reinforcement.reinforcement layout of slab-column joint is shown in Fig. 3.

Sectional Properties (Real Constants)

The real constants considered for Solid65 element are volume ratio and orientation angles (in X and Y direction). Slab column joint with discrete reinforcement is considered for the present study. Hence the smeared reinforcement capability of the SOLID65 element is turned off for real constant set 2 (volume ratio and orientation angle were set to zero). The parameters

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considered for LINK8 element are cross sectional area and initial strain. The real constant values for LINK8 element used for modeling the models are as given in the Table 1.

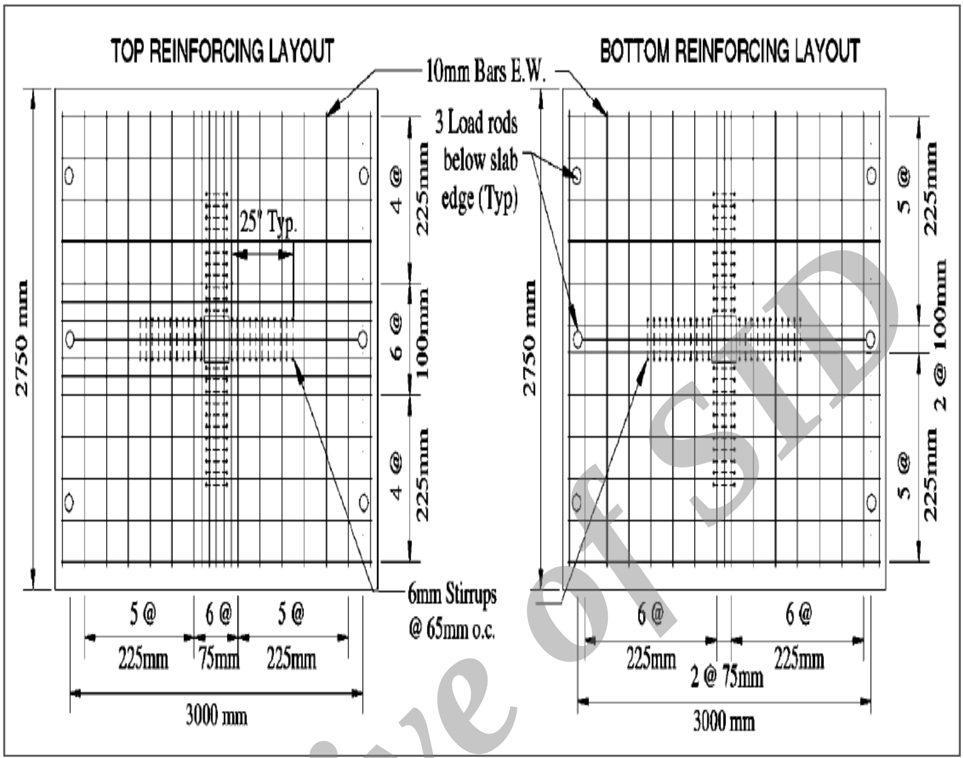

Figure 3. Plan of Slab-Column Joint

Table 1: Real constants for steel reinforcement (LINK 8 Element)

Element Type	Particulars of the Model	
LINK 8 (Transverse and longitudinal reinforcement of slab)	Cross sectional area (m^2)	$78.5x10^{-6}$
LINK 8 (Vertical reinforcement of column)	Cross sectional area(m^2)	$113.09\ x10^{-6}$
LINK 8 (Stirrup of column)	Cross sectional area(m^2)	$50.26x10^{-6}$

Material Properties

The average 28-day cube strength (f_{ck}) used for modeling is obtained from the available experimental data (35.4 MPa). The modulus of elasticity of the concrete (E_c) is taken as 5000 $\sqrt{f_{ck}}$ (IS 456:2000) [6] and the value is 2.9748 x 10^{10} N/m^2. The modulus of elasticity, yield stress and tangent modulus of reinforcement bars were given from the literature of Robertson et.al (2002).[11]

The value of Poisson's ratio and shear transfer coefficients for open and closed crack are assumed as given by QiZhang and Hussein 2004[15]. The material properties adopted for the model is shown in Table 2.

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Table 2: Material Properties

Element Type		Material Properties
		Linear Isotropic
Link-Spar8	EX	2.1×10^{11} N/m^2
	PRXY	0.3
		Linear Isotropic
Solid-Concrete65	EX	2.9748×10^{10} N/m^2
	PRXY	0.15
	Concrete	
Shear transfer coefficient for open crack		0.2
Shear transfer coefficient for closed crack		0.9
Uniaxial tensile cracking stress		3.71×10^{6} N/m^2
Uniaxial crushing stress		35.53×10^{6}N/m^2

Boundary Conditions

The column is assumed to be pinned at the base as shown in Fig. 4. The slab edges parallel to the loading direction were unrestrained as shown in Fig. 5. The slab-column joint is subjected to axial load and lateral load at the top of the column as shown in Fig. 6.

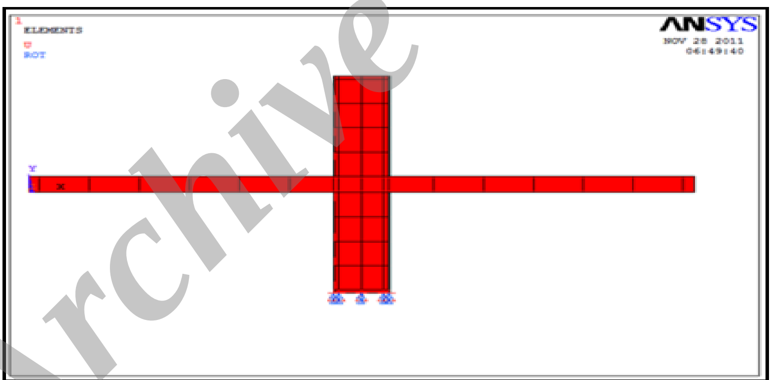

Figure 4. Boundary Conditions for the Column

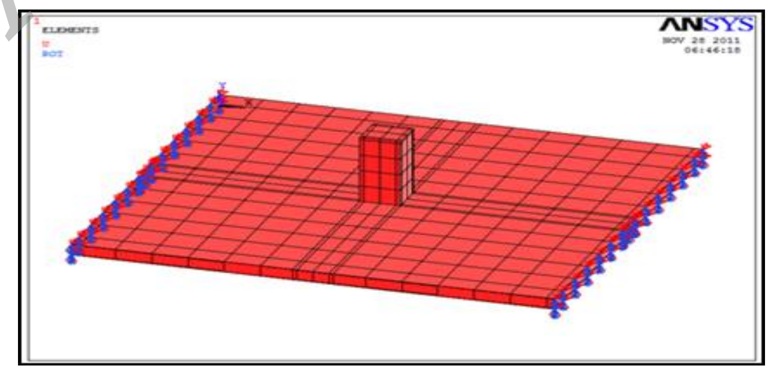

Figure 5. Boundary Conditions for the Slab

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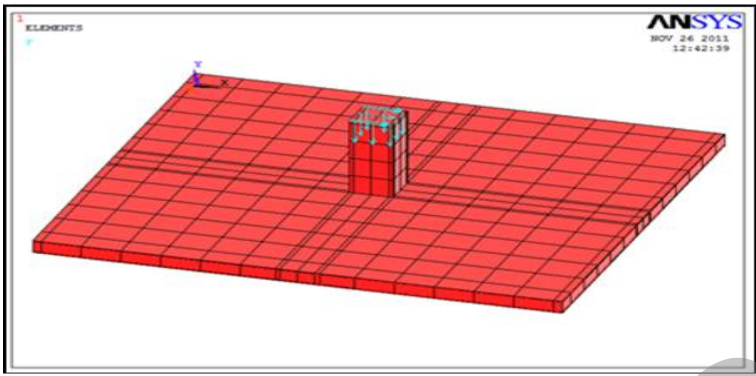

Figure 6. Loading Conditionsfor the slab –column joint

Modeling of Slab-column Joint

The slab-column joint is modeled using the element types and the material properties as explained in the previous sessions. Tavarez (2001) discusses three techniques that exist to model steel reinforcement in finite element models for reinforced concrete; the discrete model, the embedded model and the smeared model as shown in Fig. 7. In the present work, the discrete modeling of reinforcement has been employed. The reinforcement in the discrete model uses LINK 8 element that are connected to concrete mesh nodes. Therefore the concrete and the reinforcement mesh share the same node and occupy the same regions occupied by the reinforcement.

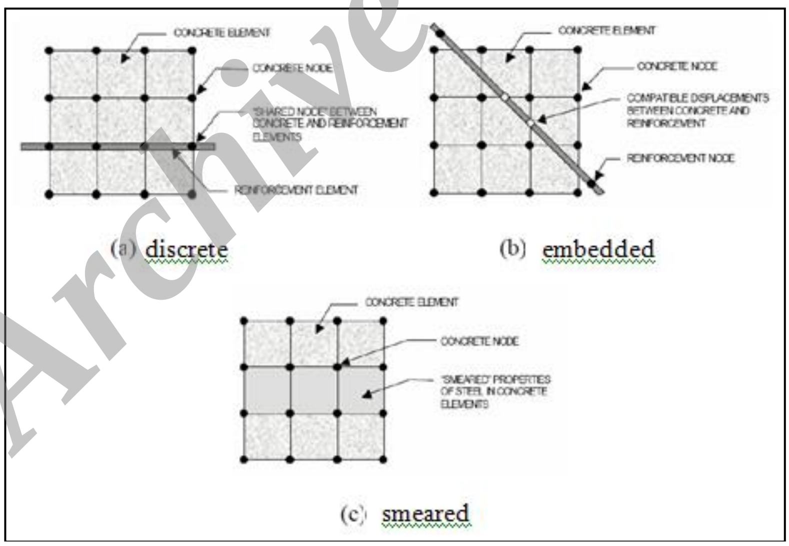

Figure 7. Models for reinforcement in reinforced concrete

The modeling details of slab-column joints are shown in the Fig. 8 and Fig. 9. The models were analyzedwith the axial loadings and lateral loads in the top point of the column.

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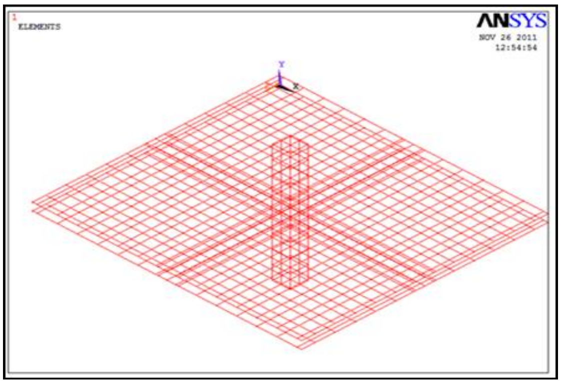

Figure 8. Reinforcement Details – 3D View

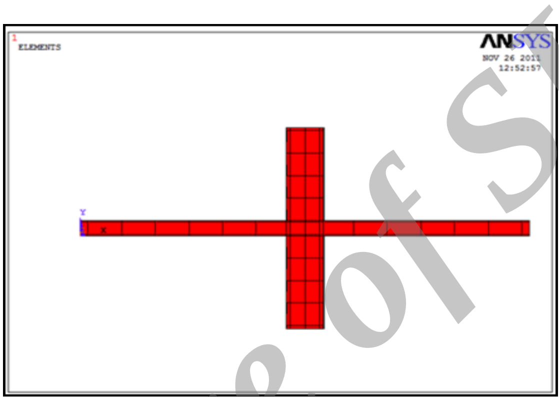

Figure 9. Slab-Column Joint-Elevations

Finite Element Analysis

The finite element analysis has been carried out for the slab column joint with discrete type of model subjected to cyclic loading so as to provide the equivalent of severe earthquake damage. The graphical user interface was adopted for applying the load. The loading was applied in 10 load steps with the convergence of 0.001.

Loading

The flat plate is subjected to in plane lateral cyclic load at the top of the column. The sequence of cyclic loading adopted for the study is shown in Fig. 10. The details of loading is shown in Fig. 11.

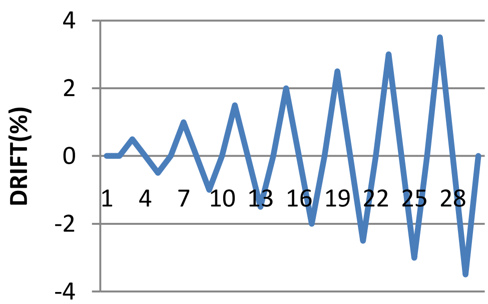

Figure 10. Lateral Displacement Routine

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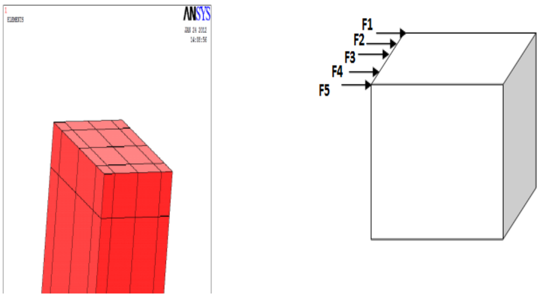

Figure 11. Loading details

5. RESULTS

Displacement Contours

The displacement contour of the slab-column joint is shown in Fig. 12. It can be observed that the deformation is higher at the junction of the slab-column joint.

Stress Contours

The variation in stress contours are shown in Fig. 13 and 14. From the stress contours it is clearly observed that the stress intensity is very high in the region of slab-column connection.

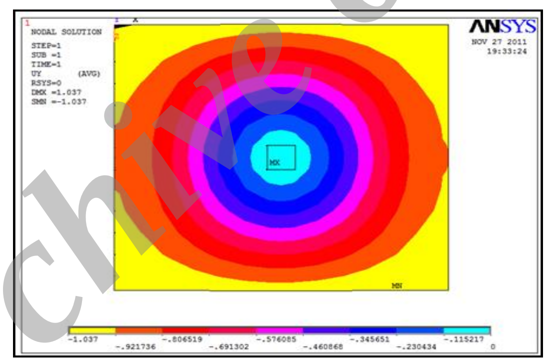

Figure 12. Displacement Contour (Y direction)

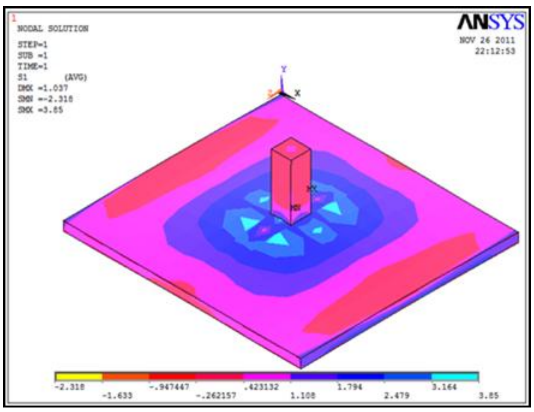

Figure 13 First Principal stress

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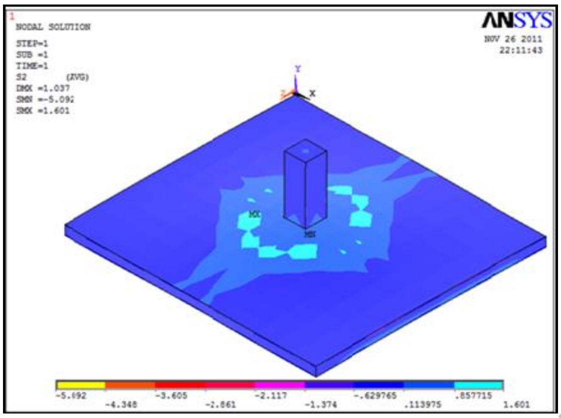

Figure 14. Second Principal stress

6. SUMMARY AND CONCLUSIONS

From the literature reviewed, it is observed that a critical design criterion for flat plates is the punching shear strength of the slab at the slab-column connection. To avoid adding drop panel or beams to increase the shear capacity of the slab, various types of shear reinforcement can be used in the slab around the connection. Shear reinforcement with adequate mechanical anchorage provide more ductility and drift capacity than conventional stirrups.

In the present study, an eight storey flat plate building is modeled using STAAD.PRO (Version 8i)[13]. Further one of the slab-column joint is analysed using the finite element software ANSYS (Version 11)[1] software. The analytical investigation mainly focuses on the performance of slab-column connection subjected to axial and lateral loading. The element types, sectional and material properties adopted for modeling in ANSYS[1] were discussed in detail. The analysis results were presented in the form of displacement contour and various stress contours. The analytical study shows that the maximum stresses and deformation occurs at the slab-column joint.

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