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Study of Punching Shear in Flat Slab System Subjected to Seismic Load

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Abstract: *Flat-slab structural systems have large applicability due to their functional and economic advantages. Flat plate slabs exhibit higher stress at the column connection and are most likely to fail due to punching shear rather than flexural failure. To avoid shear failure, realistic analytical or experimental studies must investigate parameters influencing the punching strength. Flat plates were subsequently developed, with no drops and no column capitals and due to the cheaper formwork required, they were popular for residential and office buildings. The computer program ETABS is used to model columns and slabs as frames respectively. The present analytical study investigates the influence of some of the parameters governing the behaviour of connections under punching shear: concrete strength, column aspect ratio, slab thickness, and gravity loading. Parametric studies on depth-to-span ratio & column aspect ratio have been carried out using equivalent static analysis to investigate the influence of these parameters on punching shear capacity of the column connections, which proved to be the governing criteria to prescribe drift limits for flat plate systems in seismic zones.*

Index Terms - *Depth-to-span ratio, flat slab, punching shear, ETABS*

I. INTRODUCTION

The simplest definition of flat slab systems can be stated as "buildings in which slabs are supported directly on columns". As per is 456-2000, "the term flat slab means a reinforced concrete slab with or without drops, supported generally without beams, by columns with or without flared column heads". Flat plates refer to flat slabs without drop panels and column heads. Flat-slab (or plate) reinforced concrete systems have become a common sight in most the developing countries, including India. A good number of commercial and office buildings around many Indian metro cities have been observed to adopt a flat-slab system because they are relatively inexpensive to construct and because of the reduced story heights and open floor plans that are possible with such framing. A typical six story residential type open ground reinforced concrete flat slab is considered. The equivalent static analysis was performed for which flat slab model for concrete is taken. This process is repeated for various depth to span ratio, influence of drop on punching shear stresses are being studied. This study particularly emphasized on predicted mode of failure and punching shear capacity. The modes of failure were based on structural response. i.e., deflection, crack pattern and stresses in steel and concrete which agree with analytical observations. Parametric study using equivalent static analysis is performed to carry out the strength and distribution of forces.

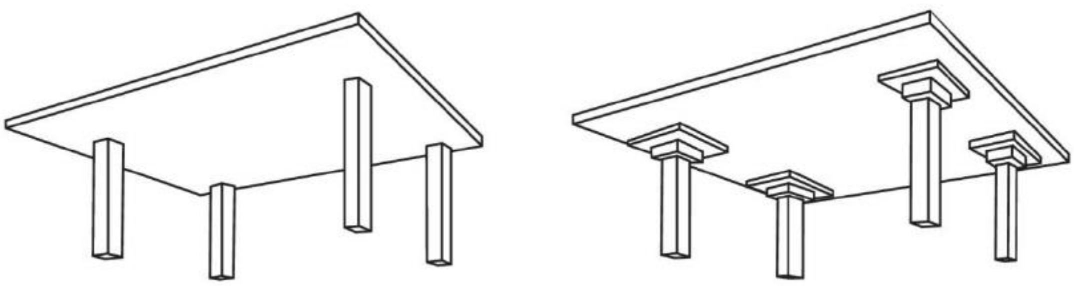

Fig.1 Flat plate with drop and without drop

A typical flat plate punching shear failure is characterized by the slab failing at the intersection point of the column. This results in the column breaking through the portion of the surrounding slab. This type of failure is one of the most critical problems to consider when determining the thickness of flat plates at the column-slab intersection. Accurate prediction of punching shear strength is a major concern and absolutely necessary for engineers so they can design a safe structure.

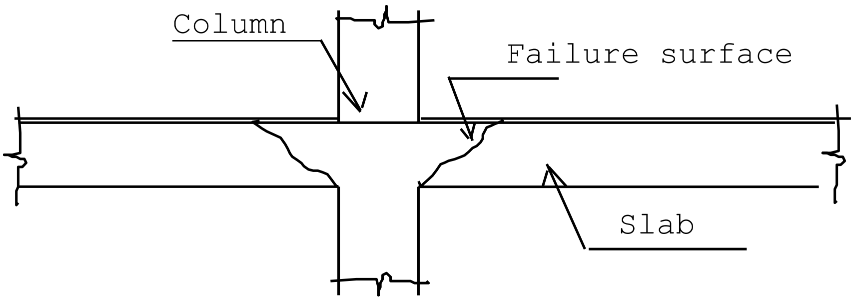

Fig.2 Punching failure surface of flat slab.

II. LITERATURE REVIEW

"Punching shear behaviour of slabs with varying span-depth ratios", John, L. And David, M.(2012)
Stated that punching shear strength of an interior slab column connection increases as the column aspect ratio(shorter side of column or longer side of column) increases. The shear stress resistance of slab column connection decreases as column side length to slab depth ratio increases. The shear stress resistance of slab-column connection decreases as column side length to slab depth ratio increases.

"Parametric study on seismic behaviour of exterior reinforced concrete flat plate column connection", Kashliwal A. and Dasgupta K.(2012)
Worked on finite element model of flat slab and column connections under seismic loading and studied the influence of various parameters on punching shear. Reported that the high strength concrete improves the punching shear strength by delivering the higher forces through the slab column connection. Many design procedures are based on the normal strength of concrete. Therefore, it is necessary to use high strength concrete. Based on extensive experimental and analytical studies it is intended to prescribe the design guidelines of structure in the high seismic zone.

III. METHODOLOGY

In this study, six Story residential type open ground reinforced concrete building with flat plate system(with drop and without drop model) is taken. Analysis has been carried out by ETABS software. The structural properties and external load details are mentioned. Plan and elevation of the structure fig.5 along with dimension are Table.2. To study the effect of various parameters on the shear stress in flat plate buildings, a six-storey Reinforced Concrete structure is considered. It consists of four bays in both X and Y directions.
To study the static behavior of building equivalent static method analysis is carried out. It is a stepwise equivalent static procedure primarily used to govern the response of a structure at every individual step. It is a static procedure in which the magnitude of structural loading increased incrementally with a certain predefined pattern accordingly. With the increase in the magnitude of structural loading, failure modes and weak links are found.

3.4 Parametric study of punching shear strength

In the parametric study, the displacement values Δ of the building are normalized with respect to height of the building (H_b) and punching shear capacity of the flat plate exterior column connections (τ) are normalized with respect to design shear strength of connection $\tau_c = 0.25(f_{ck})^{(1/2)}$ as per Indian concrete code IS:456 (IS456,2005). The shear capacity curve so obtained is based on the shear stress model as discussed earlier which ensure that flexural yielding does not occur anywhere in the vicinity of connection a priori. In other words, the only mode of failure available in concrete section is shear failure.

Analysis of structures in ETABS

- The analysis of flat and conventional slab structure has been done by using ETABS software package.
- Before analysis all the required elements of the structure needs to be defined earlier like material properties, loads, load combinations, size of members, response spectrum etc.
- Once the analysis has been done we can extract the results like displacement, storey shear, bending moment, drift ratio, axial forces for comparing the performance of flat and conventional slab building.
- The following flow chart shows the steps involved in the analysis by ETABS.

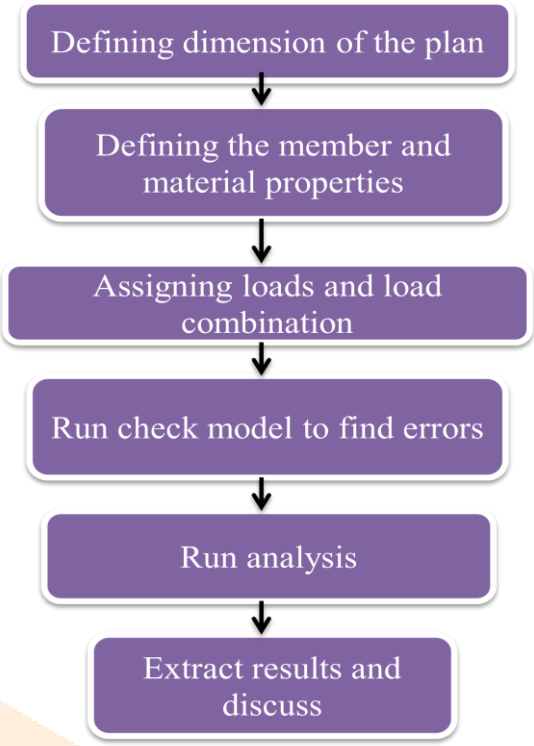

Fig.3 Steps used in Analysis of Structure in ETABS

IV. PERFORMANCE ANALYSIS

The flat slab is a two-way reinforced concrete slab that usually does not have beams and girders, and the loads are transferred directly to the supporting concrete columns.
Depth to span ratio (D/L) is varied by changing the thickness of depth of flat slab for the constant span. Punching shear strength of the corner as well as interior junctions is obtained with the varying depth to span ratio of flat slab for a particular grade of concrete, loads.

The parameter which has been considered in this section to study the mechanism of punching shear strength is the aspect ratio of column where the punching shear capacity of the intermediate as well as corner connection is obtained with the varying aspect ratio of column for a particular grade of concrete and thickness of plate.

Displacement is varied by changing the thickness of depth of flat slab for the constant span. Punching shear strength is obtained with the varying depth of slab of flat slab for a particular grade of concrete, loads.
Following assumptions are considered:

1. Model details
   No. Bays along X axis- 4
   No. Bays along Y axis- 4
   Spacing along X axis - 6m
   Spacing along Y axis - 8m
   Floor Height - 3.5m
   Size of column - 450mm X 500mm
   Slab thickness - 180mm
   No. of Stories - 6 stories

2. Load details

   i. Gravity load

Live load - 3.0kN/m² at typical floor
-1.5 kN/m² on terrace
Dead load - 1.5 kN/m²
Concrete grade - M25
Rebar material - Fe415

   ii. Seismic load

Zone factor - V (0.36)
Response reduction factor- 5

Importance factor- 1

Soil Type- II

3. Column Aspect Ratios

The analysis has been performed for the various aspect ratios;

Column dimensions 550mm x 550mm; β = 1
Column dimensions 550mm x 530mm; β = 1.03
Column dimensions 550mm x 450mm; β = 1.2
Column dimensions 550mm x 400mm; β = 1.38
Column dimensions 550 mm x 300 mm;β = 1.83

4. Depth to span ratios

The analysis has been performed for the various depth to span ratios;

Thickness of plate =180 mm; d/L = 0.03
Thickness of plate = 200 mm; d/L = 0.33
Thickness of plate = 225mm; d/L = 0.04
Thickness of plate = 250 mm, d/L = 0.042
Thickness of plate = 275mm; d/L = 0.046
Thickness of plate = 300mm; d/L = 0.050
Thickness of plate = 325 mm; d/L = 0.054

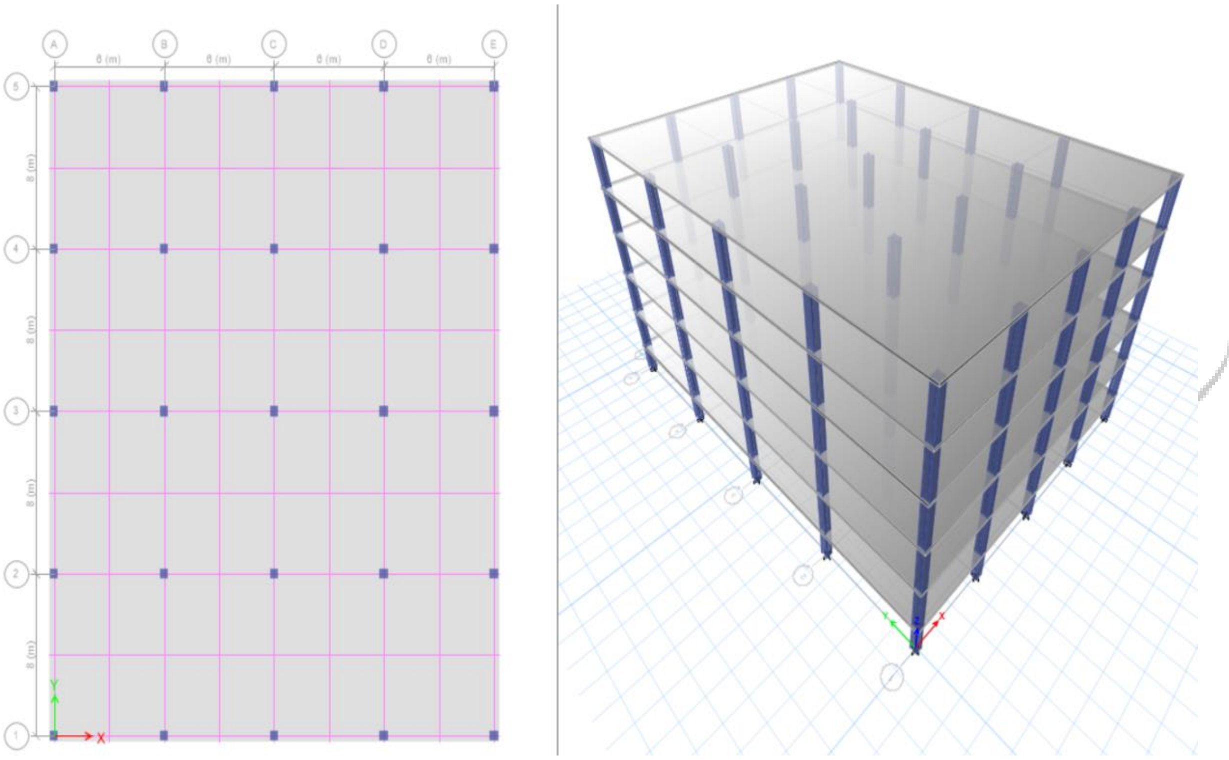

Fig. 4 Flat slab models - Without drop model

V. RESULTS & DISCUSSIONS

The sections below deal with the observations and interpretations obtained from Equivalent static analysis. The results which are obtained depend on the equivalent static model. The various parameters influencing the punching shear strength of flat plate system are concrete strength, flexural reinforcement, column aspect ratio, slab thickness, gravity loading and shear reinforcement. The investigation of these parameters by analytical or experimental studies will lead to a better understanding so as to avoid the shear failures. In the present work the behavior of punching shear strength is investigated considering some parameters namely concrete strength, column aspect ratio, slab thickness and gravity loading of the flat plate system under equivalent static analysis. Consequently provisions can be made to avoid a shear failure. The results and discussions obtained from the present work pertain to flat plate systems only in the vicinity of columns at the corner and intermediate connections of the building.

where,

Δ - Displacement values

Hb - Height of the building

$\tau/\tau c$- Shear stress to the allowable shear stress in concrete

D/L- Depth to span ratio

$$\tau_c = 0.25(f_{ck})^{(1/2)}$$

Table no. 1 Corner connection with varying aspect ratio

	Shear Force				
Column size	550x300	550x400	550x450	550x530	550x550
Δ / H_h	β=1.83	β=1.38	β=1.2	β=1.03	β=1
0.002	0.067	0.067	0.084	0.09	0.12
0.005	0.19	0.208	0.24	0.26	0.33
0.008	0.29	0.312	0.36	0.38	0.52
0.01	0.31	0.36	0.41	0.46	0.6
0.012	0.35	0.384	0.46	0.52	0.67
0.013	0.35	0.408	0.46	0.52	0.67

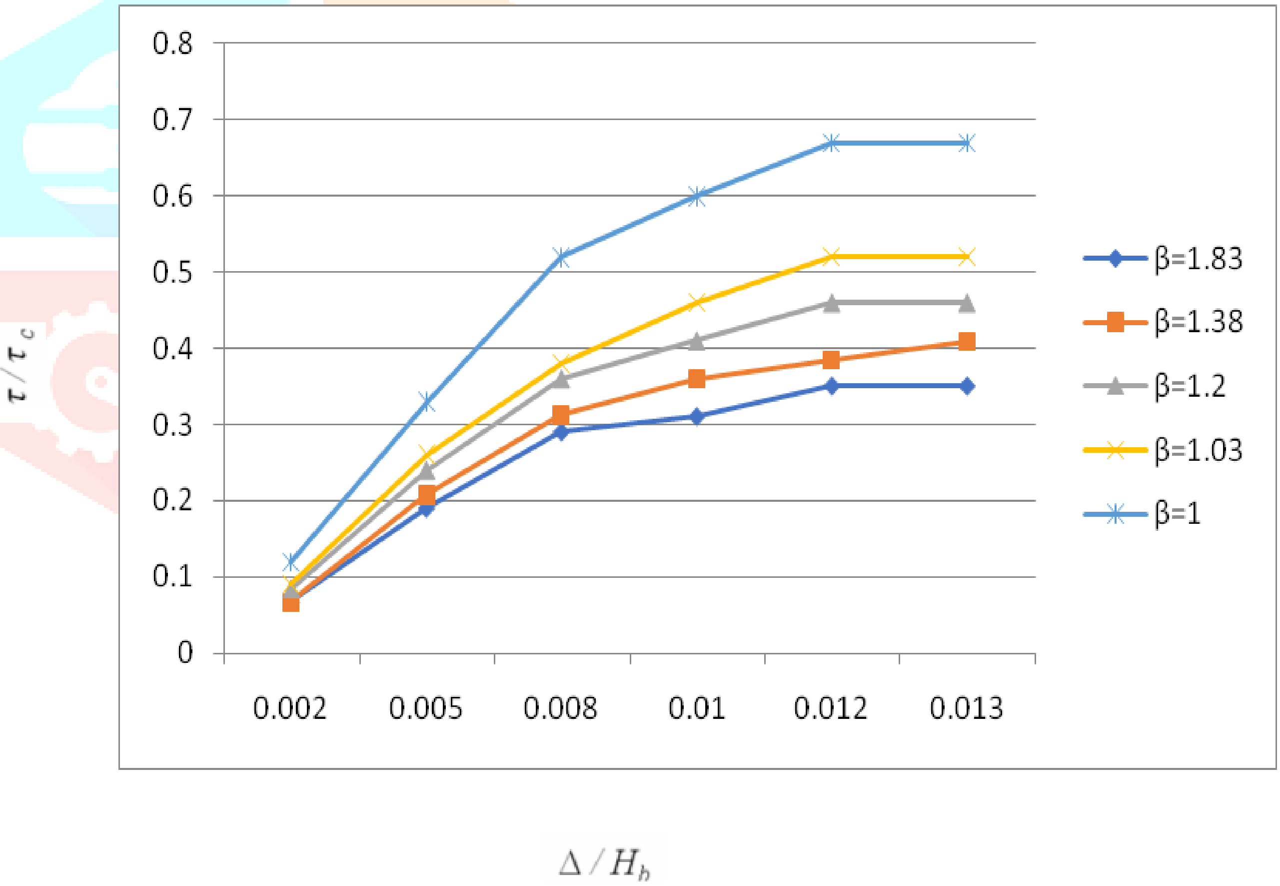

Fig.5 Punching shear capacity of Corner connection with varying column aspect ratio.

Table no. 2 Interior connection with varying aspect ratio

	Shear Force				
Column size	550x300	550x400	550x450	550x530	550x550
Δ / H_b	β=1.83	β=1.38	β=1.2	β=1.03	β=1
0.002	0.14	0.16	0.192	0.2	0.24
0.005	0.4	0.44	0.528	0.56	0.672
0.008	0.6	0.64	0.768	0.88	1.06
0.01	0.68	0.76	0.912	1	1.2
0.012	0.76	0.88	1.06	1.12	1.34
0.013	0.67	0.79	1.01	1.1	1.3

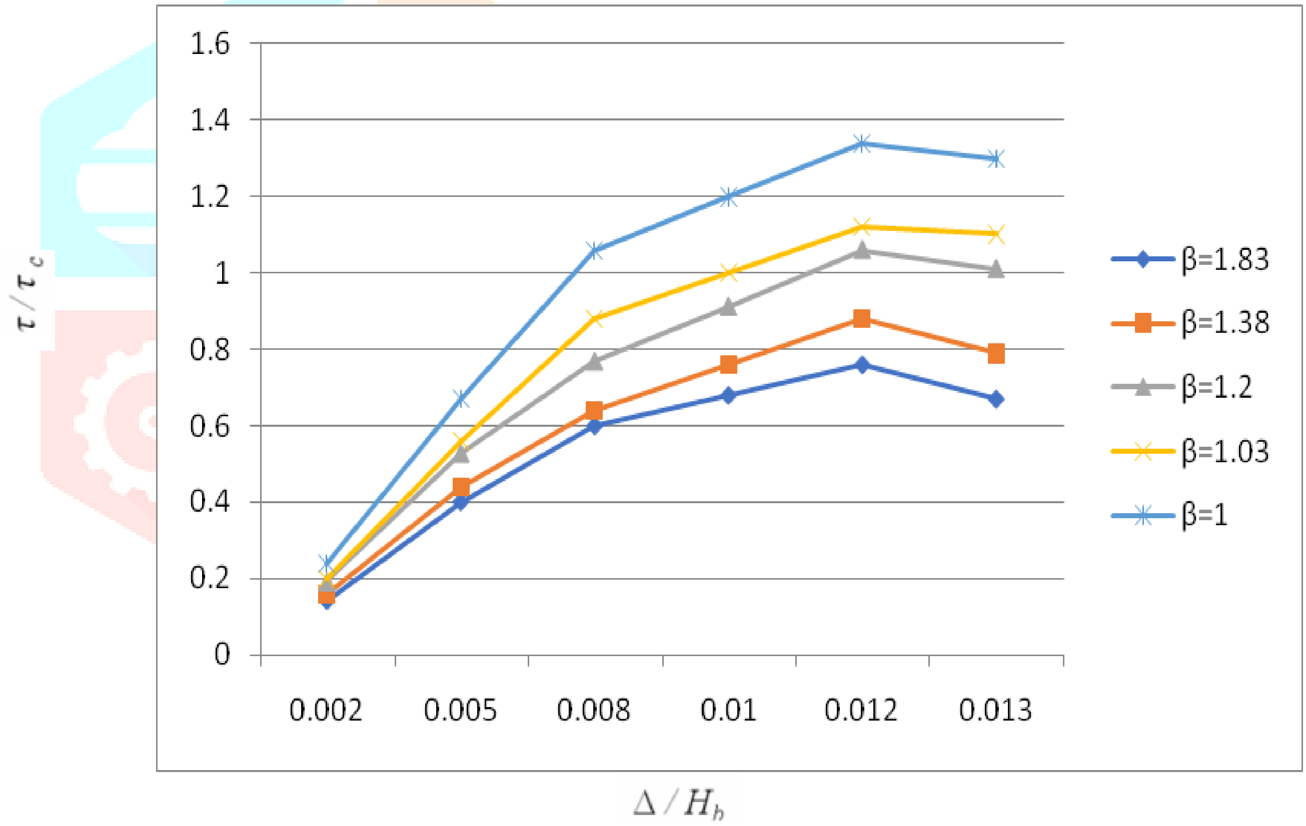

Fig.6 Punching shear capacity of interior connection with varying aspect ratio.

Table no. 3 Corner connection with depth to span ratio

	Shear Force						
Depth	180	200	225	250	275	300	325
Δ / H_h	D/L= 0.03	D/L= 0.033	D/L= 0.038	D/L= 0.042	D/L= 0.046	D/L= 0.05	D/L= 0.054
0.002	0.192	0.2	0.23	0.264	0.312	0.4	0.528
0.005	0.41	0.5	0.576	0.72	0.96	1.2	1.44
0.008	0.608	0.72	0.84	1.08	1.44	1.84	2.16
0.01	0.768	0.84	0.96	1.32	1.68	2.08	2.64
0.012	0.801	0.93	1.08	1.44	1.84	2.4	2.88
0.013	0.8	0.93	1.08	1.44	1.84	2.4	2.88

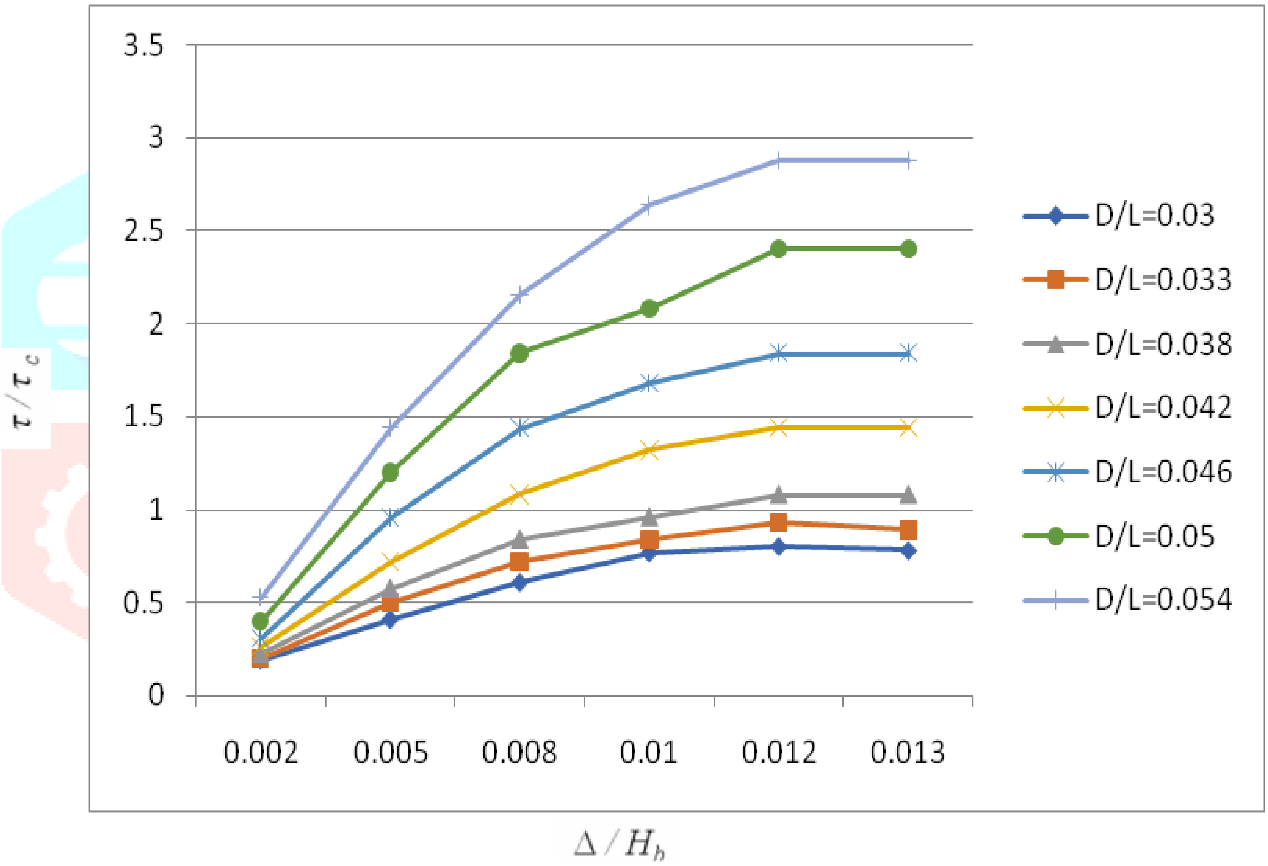

Fig. 7 Punching shear capacity of corner plate column connection with varying depth to span ratio

Table no. 4 Interior connection with depth to span ratio

	Shear Force						
Depth	180	200	225	250	275	300	325
Δ / H_b	D/L= 0.03	D/L= 0.033	D/L= 0.038	D/L= 0.042	D/L= 0.046	D/L= 0.05	D/L= 0.054
0.002	0.18	0.24	0.32	0.44	0.52	0.68	0.88
0.005	0.52	0.68	0.96	1.2	1.6	2	2.4
0.008	0.76	0.92	1.4	1.8	2.4	3.04	3.6
0.01	0.96	1.2	1.6	2.2	2.8	3.44	4.4
0.012	1	1.4	1.8	2.4	3.04	4	4.8
0.013	1	1.4	1.8	2.4	3.04	4	4.8

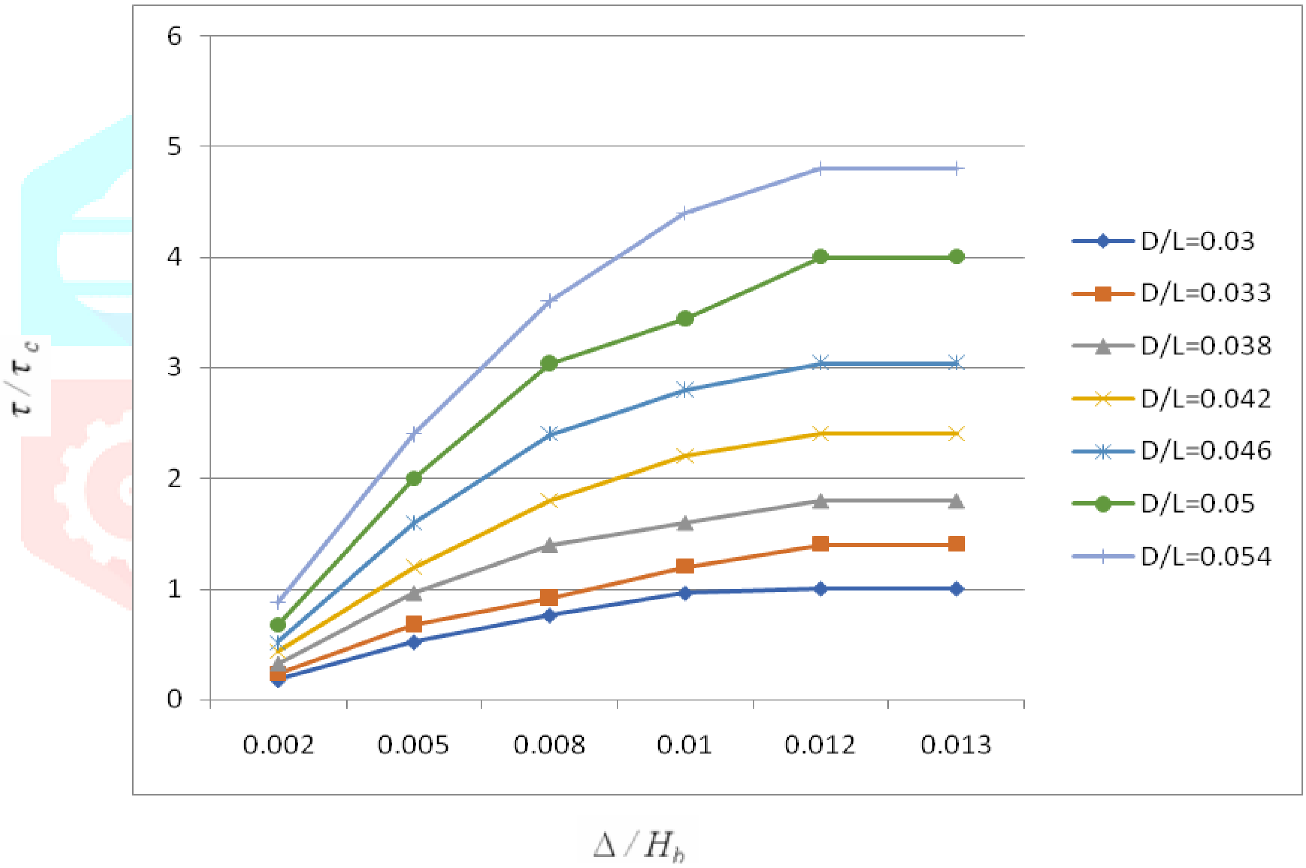

Fig 8 Punching shear capacity of intermediate plate column connection with varying depth to span ratio

Table no. 5 Exterior connection with depth to span ratio

	Shear Force						
Depth	180	200	225	250	275	300	325
Δ / H_b	D/L= 0.030	D/L= 0.033	D/L= 0.038	D/L= 0.04	D/L= 0.046	D/L= 0.05	D/L= 0.054
0.002	0.216	0.288	0.384	0.44	0.52	0.68	1.05
0.005	0.624	0.816	1.152	1.2	1.6	2	2.88
0.008	0.912	1.2	1.68	1.8	2.4	3.04	4.32
0.01	1.15	1.44	1.92	2.2	2.8	3.44	5.28
0.012	1.2	1.68	2.16	2.4	3.04	4	5.76
0.013	1.2	1.68	2.16	2.4	3.04	4	5.76

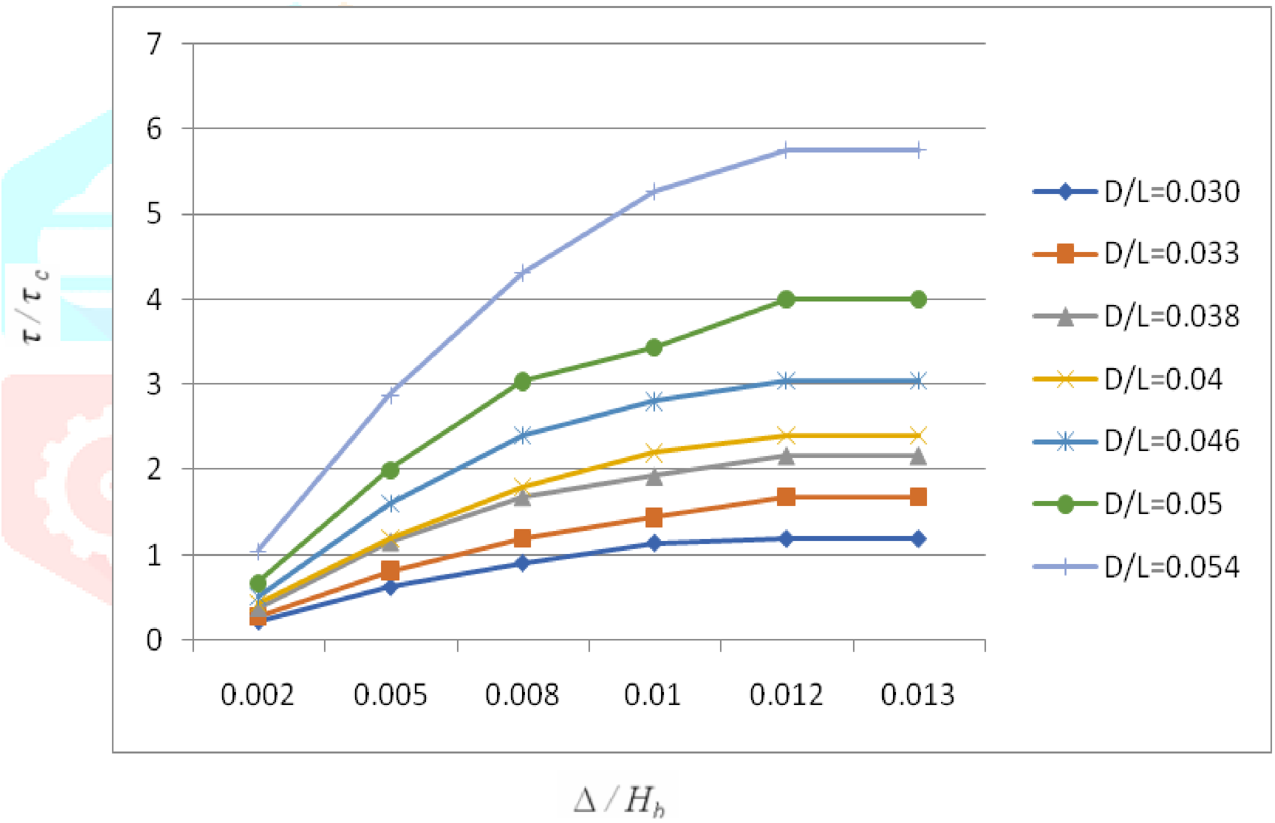

Fig.9 Punching shear capacity of exterior connection with varying Depth to span ratio

Table 6 Displacement of the building

	Stories						
Depth	180 mm	200 mm	225 mm	250 mm	275 mm	300 mm	325 mm
Story 1	2.444	2.595	2.784	2.974	3.163	3.353	3.542
Story 2	24.938	26.484	28.415	30.348	32.282	34.215	36.151
Story 3	65.944	70.036	75.146	80.261	85.375	90.489	95.61
Story 4	119.504	126.922	136.189	145.461	154.734	164.007	173.289
Story 5	180.227	191.42	205.403	219.395	233.386	247.377	261.38
Story 6	243.834	258.985	277.913	296.85	315.787	334.724	353.674

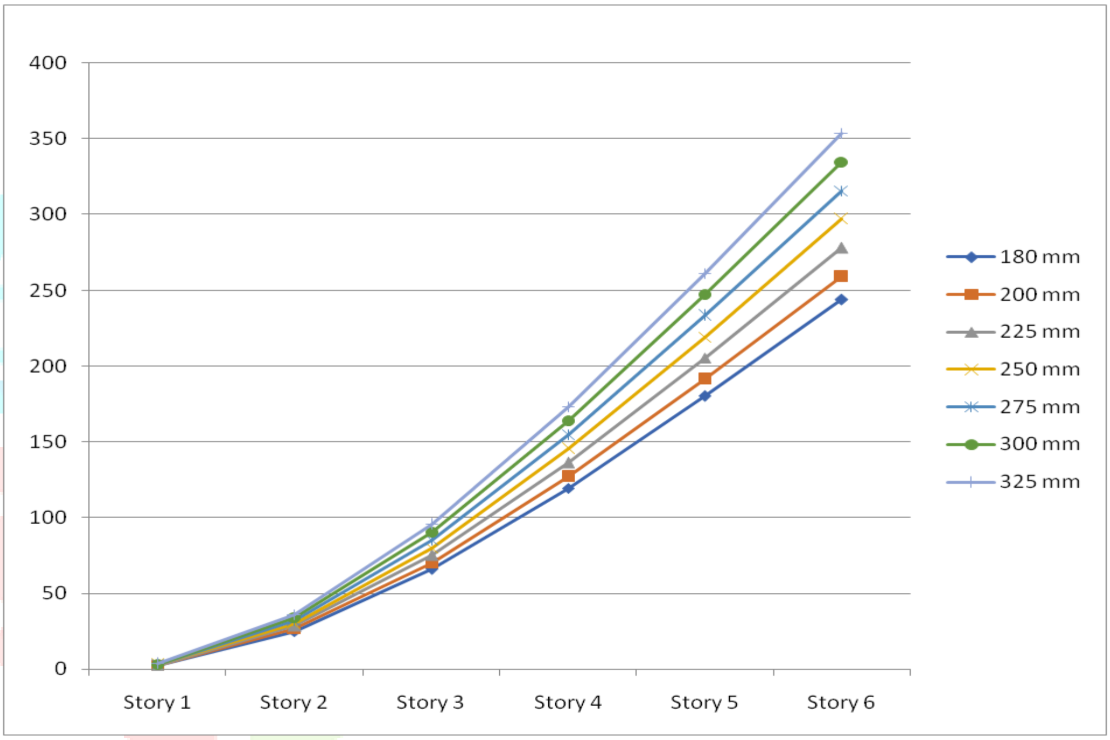

Fig.10 Displacement of the structure with varying thickness of the slab

VI. CONCLUSION

Aspect ratio and span-to-depth ratio showed significant influence on the punching shear capacity of the flat plate at intermediate and corner column connection.

- As column aspect ratio increases, the shear strength around the flat plate column connections decreases.
- In column aspect ratio for corner and interior connection, it is evident that the maximum shear capacity is achieved in a drift range of 1.2% to 1.3%
- The shear capacity increased with increasing in overall depth to span ratio for both intermediate and corner connection.
- The shear capacity of the connection is found to be maximum for D/L= 0.054.
- As depth to span ratio increased, shear capacity increased but after post peak shear strength it become constant.
- Displacement of structure gradually increased as the depth to span ratio increased.

VII. SCOPE OF FUTURE WORK

- In the present study the equivalent static analysis is undertaken for the Flat-plate system to find out the influence of parameters namely aspect ratio and span to depth ratio where the gravity loading kept constant on punching shear capacity for the intermediate as well comer connections. The above mentioned objectives have been addressed in the work.
- The other governing factors such as flexural reinforcement, post tensioned, pre- tensioned, drop panel, without drop panel and shear reinforcement can be considered in future for the better understanding of the influence of punching shear on the behavior of flat-plate systems.
- Secondly, this thesis made use of ETABS, to perform analysis. As a scope of future work, more software can be used to perform nonlinear analysis. As a scope of future work, more sophisticated nonlinear finite element software packages can be used to model the connections.

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