International Journal on Recent and Innovation Trends in Computing and Communication
Volume: 6 Issue: 1

ISSN: 2321-8169
49 – 54

Analysis of Flat Slab Connection System for Seismic Loads

Sumedha
M. Tech Scholar, Civil Department
MRIEM, Rohtak
Haryana, India
sumedhabalhara46@gmail.com

Naveen Hooda
Associate Professor, Civil Department
MRIEM, Rohtak
Haryana, India
hoodanaveen723gmail.com

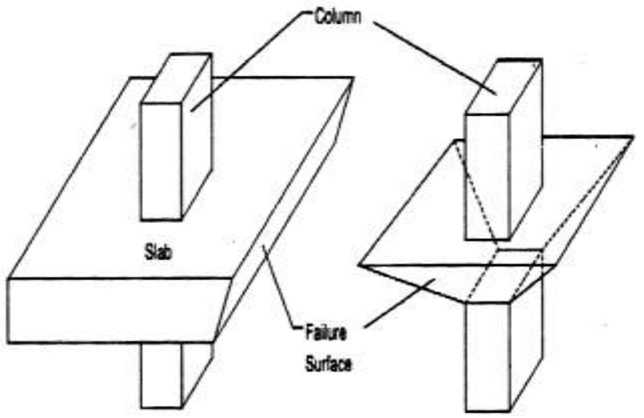
Abstract: Flat slab structural systems have a large applicability due to their functional and economic advantages. As such, a good number of commercial and office buildings around many Indian metro cities, in India, have been observed to adopt flat-slab system. Initially, the reinforced concrete flat slabs had drops, and columns with capitals, and were considered to be the structures of choice for warehouse construction and heavy loads because shear was not a problem. Flat plates were subsequently developed, with no drops and no column capitals, and due to the much cheaper shuttering required, they became popular for residential and office buildings. But, till date the analysis of flat-slab systems has been a problem due to its complex load transfer mechanism and failure patterns. Flat plate slabs exhibit higher stress at the column connection and are most likely to fail due to punching shear rather than flexural failure. Thus, the vulnerability to punching shear failure has caused structural engineers to rethink the design of slab-column connections in new flat-plate frames constructed in areas of high seismicity. To avoid shear failure, parameters influencing the punching strength should be clearly investigated by realistic analytical or experimental studies. The present analytical study investigates the influence of some of the parameters governing the behavior of connections under punching shear which are concrete strength, column aspect ratio, slab thickness, gravity loading. Firstly, modelling of the whole building is carried out using the computer program SAP 2000 V [14] with columns and slabs modeled as frame and shell elements respectively. Parametric Studies on aspect ratio and depth-to-span ratio have been carried out using displacement control nonlinear static pushover analysis to investigate the influence of these parameters on punching shear capacity of the intermediate and corner column connection which proved to be the governing criteria to prescribe drift limits for flat plate systems in seismic zones.

Keywords- *Flat-slab, Seismic performance, Perimeter beams*

*****

I. Introduction

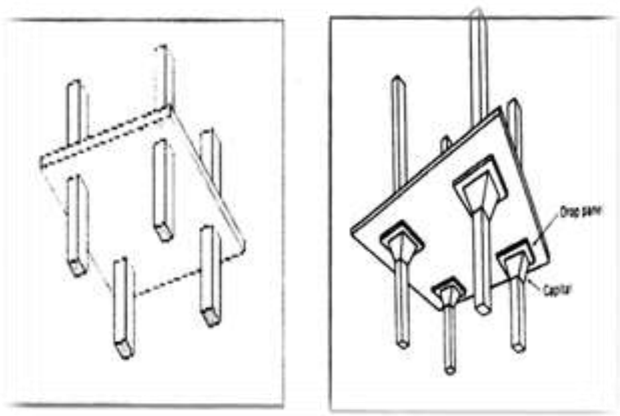
Flat slab system is being adopted in many buildings presently due to the advantage of reduced floor heights to meet the economical and architectural demands. The rising popularity of flat slabs system can be attributed to several factors. Besides being a highly economical venture (since beams are absent), concrete flat slab floors provide an elegant form of construction which simplifies and speeds up site operations, allow easy and flexible portion of space and reduce overall height of the building, better lightening and ventilation, easy arrangement of pipes and wires under slabs and easy formwork[3]. In design and engineering practice, the selectively defined design of space, design of structure, speed and efficiency of realization represent an extraordinarily important factor for the Investor. This assertion is supported by the fact that the flat-slab RC system has lately been increasingly imposed as a more acceptable and more attractive structural system in the world and in Macedonia as well. What is rational and optimal for these flat-slab structures is that they enable simple design, pure and clear space with absence of beams (the role of the beams is transferred to the RC floor slab), faster construction and time saving [1][5]. The system consists of columns resting directly on floor slabs for which sufficient strength and ductility should be provided to enable sustaining of large inelastic deformations without failure. The absence of beams, i.e., the transferring of their role to the floor RC structure which gains in height and density of reinforcement in the parts of the hidden beams, the bearing capacity of the structural system, the plate-column and plate-wall connection, all the advantages and disadvantages of the system have been tested through long years of analytical and experimental investigations [9]. For the last 20 to 30 years, the investigations have been directed toward definition of the actual bearing capacity, deformability and stability of these structural systems designed and constructed in seismically active regions [4]. The paper displays part of the results from analyses of six types of structural systems for a prototype of a residential building in Skopje for the purpose of defining the seismic behavior and resistance of flat-slab structural systems. In general, the strength of connection is governed by the strength of the two mechanisms namely beam action or two-way action. Two types of shear failures have been observed in slabs of slab-column framed systems [10]. The first is a "one-way" or "beam-type" shear failure, as shown in Figure 1(a), which involves an inclined crack extending across the entire width of the slab. The other failure mode, which often governs the slab design, is referred to as a "two-way" or "punching" shear failure, shown in Figure 1(b). This failure involves a truncated cone or pyramid-shape surface around the column. In regular concrete slabs, the angle of inclination of the truncated pyramid-shape surface with the slab failure plane typically ranges between 20 and 45 degrees. Shear failure of flat-plate-column connection may have a catastrophic effect. Thus, the connection needs to be properly checked to avoid shear failure in any circumstances. In slab-column frames located in regions of high seismic risk, the connections must be capable of transferring gravity loads while the structure undergoes earthquake-induced lateral displacements [14]. These displacements, besides inducing an unbalanced moment, could also translate into large inelastic rotations in the connections, which have the potential to decrease connection punching shear capacity. The detrimental effect of lateral displacements on connection strength may therefore lead to the need for shear reinforcement in slab-column connections that otherwise would be capable of resisting the imposed shear stresses [7][8].



(a) One-Way Shear Failure (b) Two-Way Shear Failure
Figure 1 Shear Failures of Slabs [2]

II. LITERATURE SURVEY

The introduction of reinforced concrete flat slab system is significant advancement in building technology, but the historical literature on their development is ambiguous. The clear advantages of concrete flat slab system made a revolutionary success, years before a rigorous theoretical understanding of their behavior [13].



(a) (b)

Figure 2 (a) Flat-plate structure (b) Drop panel and column head in Flat-plate structure

The flat-slab systems considered as one of the special reinforced concrete structural forms possess many advantages in terms of architectural flexibility, use of space, easier formwork and shorter construction time. However the structural efficiency of the flat-slab construction is hindered by its poor performance under earthquake loading. This undesirable behavior has originated from the insufficient lateral resistance due to the absence of beams or shear walls in the flat-slab system. This gives rise to excessive deformations that cause damage in nonstructural members even when subjected to earthquakes of moderate intensity. Earthquakes are the most insidious of all natural disasters, putting aside man-made disasters. The susceptibility of an urban area to life and property loss in a major earthquake is immense and thus the performance of flat-slab structures during earthquakes has demanded increasing attention [12]. High shear stresses around the supporting columns, due to the transfer of shearing forces and unbalanced moments between slabs and columns, can lead to abrupt punching shear failure at loads less than the flexural design capacity. Punching shear failure of flat-plate system may lead to progressive collapse of the entire structure with catastrophic effects. This effect may get further enhanced when the flat system is subjected to seismic loading. Seismic loading increases the punching shear stresses substantially, making the plate-column connection more prone to shear failure. The mechanism by which high punching shear stresses develop due to seismic loading, the distribution of punching stresses when subjected to unbalanced moment and the factors influencing the behavior of punching shear strength of the flat-plate column connection is being studied for the present work.

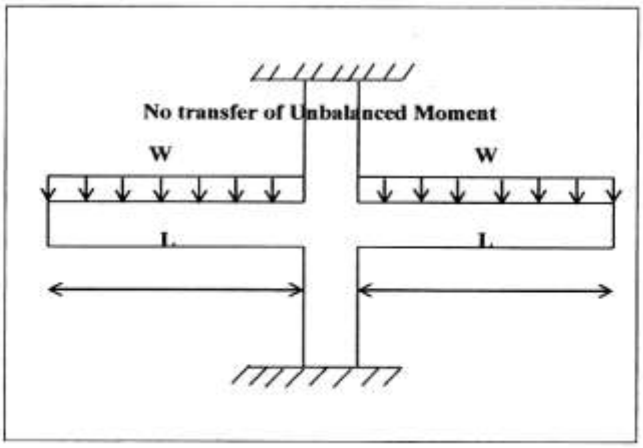


Figure 3 Symmetric loading and length of span with balanced moment condition at flat plate-column connection.

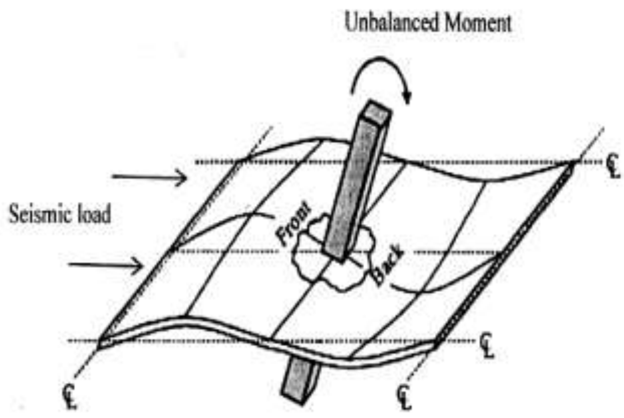


Figure 4 Flat-plate column connection subjected to unbalanced moment. [6]

III. METHODOLOGY

A. Objective of Work

Understanding seismic behavior of flat plate systems need to make flat-plate column connections can be suitably modeled. With help of SAP 2000 software nonlinear push analysis of RC flat plate building will be executed. Improvement of the empirical models of punching shear leads to strength of model. Through investigation of the governing parameters of punching shear mechanism particularly under strong seismic loading. Nonlinear parametric study is undertaken for the designed section to find out the influence of various parameters on punching shear capacity and thereby prescribed design guidelines for safe construction of flat plate systems in seismic zones.

B. Modeling of Flat Plate Building

The 3-D modeling of the typical flat plate building is carried out in SAP2000 V 14 using finite shell and frame element. In the Entire Building Model, the plates (or slabs) are modeled as 4-noded thin shell elements and the columns as 2-noded frame elements (Figure 5). Foundation soil is assumed to be hard soil and hence soil-surface interaction is not modeled. The footing is modeled as rigid joint with all the six degrees of freedom (translations Ul, U2 & U3 and rotations Rl, R2 & R3) restrained.

C. Building Details

In the present study hypothetical six storied "residential type" open ground RC Hat plate building (Figures 6 and 7) is considered. The size of column is 400mmx400mm and slab (or plate) of overall depth 200 mm is taken (common for both roof plate and floor plate). The material properties of structural members are shown in Table I

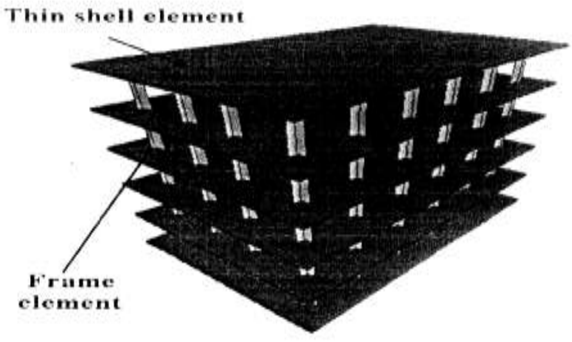


Figure 5 Perspective view of the entire RC Flat Plate Building

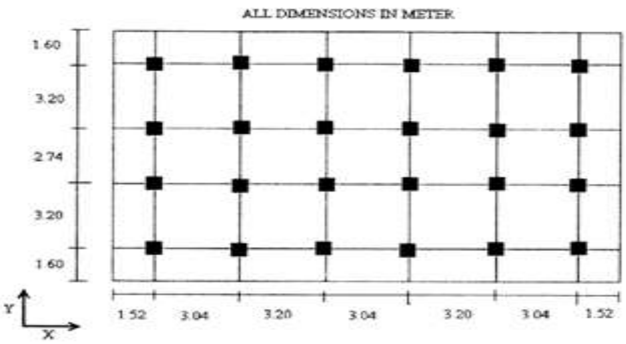


Figure 6 Plan view of Flat Plate RC Building

D. Structural Dimension

Column Dimensions

According to the Thumb Rule (P.C. Varghese, Advanced Reinforced Concrete Design)

1/12 of longer span or 1/8th to 1/9th of storey height

1/12 x 3.20 m = .251 m = 251 mm.

1/8 x 3.04 m = .38 m = 338 mm

Adopt: 400 mm x 400 mm

Slab Thickness

As per IS 456, 2000:

Minimum thickness = 125 mm

L_{eff} / 20 = d = .152 mm = 152 mm (assuming simply supported slabs)

d' (effective cover) = 25 (clear cover) + 20/2 = 35 mm

Minimum cover prescribed by IS code for slabs is 20 mm

D = (152 + 35) = 187 mm.

Adopt: D = 200 mm

E. Loading Pattern and Load Combinations

Apart from the self-weight, the flat plate system is subjected to an imposed load of 1.75 kN/m^2 on roof floor and 4.50 kN/m^2 on other floors [IS 875-1987, Part 2]. In the limit state design of reinforced concrete structures, the following load combinations shall be accounted for lateral load resisting elements oriented along orthogonal direction to seismic load as per IS 1893, 2002. The load combination taken is 1.5(DL+IL) where, DL and IL stand for the response quantities due to dead load and imposed load respectively.

Table I: Material Properties used for the RC Flat Plate Building

Material	Mass Density (kg/m^3)	Unit Weight (kg/m^3)	Grade	Modulus of Elasticity(kN/m^2)	Poisson's Ratio
Concrete	2,548	25	M 25	25000000	0.20
Steel	7,850	77	Fe 415	20000000	-

F. Calculation of Loads on Flat Plate Building

Dead Loads

As per IS 875-Part-1

Self-weight of slab = 25 x .200 = 5 kN/m^2

Floor finish, partition walls etc = 1.5 kN/m^2

Roof finish =1 kN/m2 (Partition walls not provided)

Total = 6.5 kN/m (on floor)

= 6 kN/m^2 (on roof)

Imposed Loads

As per IS 875 - Part-2

Type of Building: Residential Building

Prescribed load on roof (inaccessible) = 0.75 kN/m^2

Prescribed Imposed load on floor = 3 kN/ m^2

Total static load on slab = Dead load + Imposed Load

= 6.5 + 3 kN/m^2

= 9.5 kN/m^2 (on floor)

= 6.75 kN/m^2 (on roof)

 ISSN: 2321-8169
49 – 54

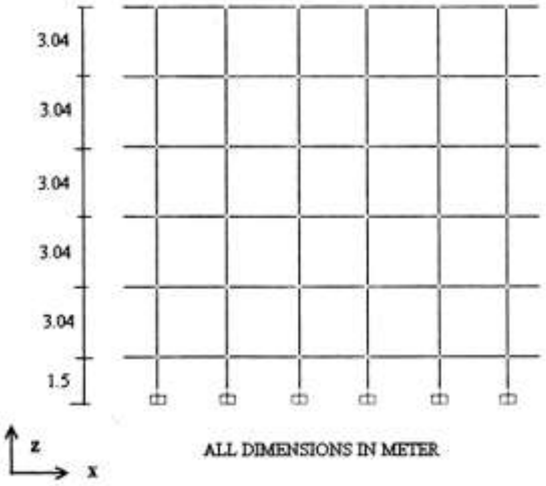


Figure 7 Typical sectional elevation of Flat Plate RC Building

IV. EXPERIMENTAL RESULT

The sections below deal with the observations and interpretations obtained from the nonlinear static pushover analysis. The results which are obtained depend on the nonlinear model which includes material nonlinearity as discussed in the previous chapter. 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.

A. Column Aspect Ratio

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, thickness of plate and gravity shear ratio. The aspect ratio is varied only by changing the width of the column. The depth of the column (in the direction of pushover) is kept the same. Thus with the decrease in the width of the column the aspect ratio, β (longer dimension/ shorter dimension) increases.

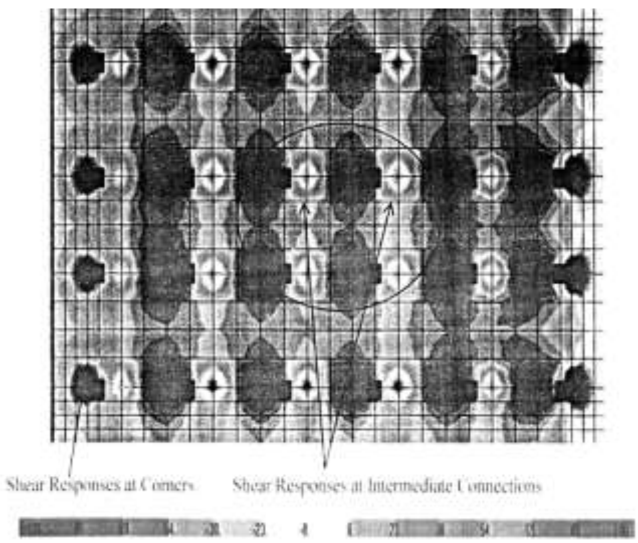


Figure 8 Shear stress distribution in the flat plate system for aspect ratio, $\beta = 2$

B. Intermediate Connection with varying Aspect Ratio

The general trend of the graph depicts that with the increase in the aspect ratio, B the punching shear strength around the flat plate column connection decreases till the peak strength is reached and beyond the peak shear strength, the trend reverses. Beyond peak strength, the shear capacity of the connection having the least aspect ratio falls steeply in comparison to the connection having larger aspect ratios.

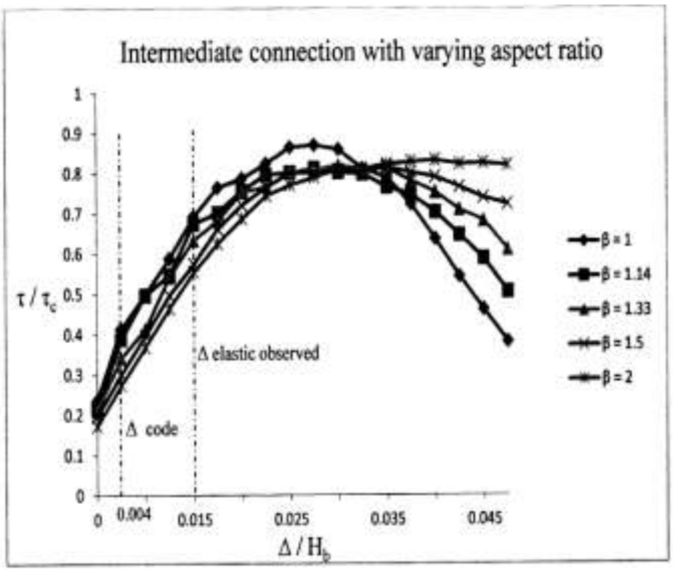


Figure 9 Punching shear capacity of flat-plate intermediate column connection with varying aspect ratio

C. Corner Connection with varying Aspect Ratio

The punching shear capacity of the corner connection with varying aspect ratio of the flat slab system is being represented in (Figure 10). The behavior of the corner connection depicts that the trend of the graph with the low aspect ratios (β = 1, 1.14 and 1.33) falls steeply than high aspect ratios (β = 1.5 and 2) which is alike to the behavior of the intermediate connections but the peak shear strength is found to higher in the case of comer connection in the range of 1 to 1.3 times of design shear capacity of connection (τ_c) due to torsional resistance offered by the corner connection.

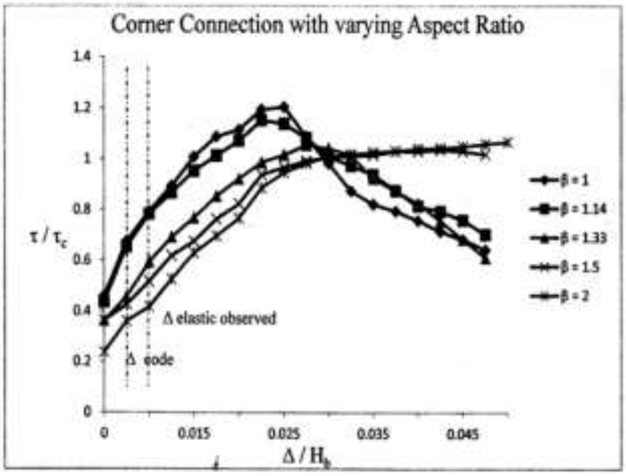


Figure 10 Punching shear capacity of flat-plate corner column connection with varying aspect ratio

ISSN: 2321-8169
49 – 54

D. Depth to Span Ratio:

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

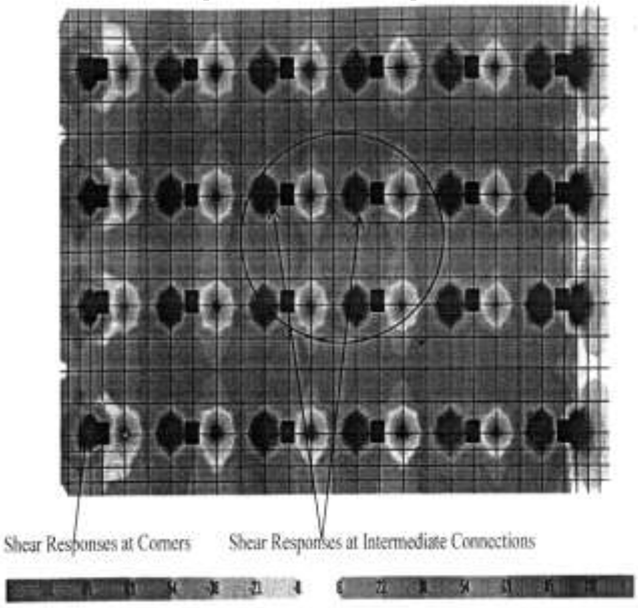


Figure 11 Shear stress distributions in the flat plate system for depth to span ratio, d/L 0.15

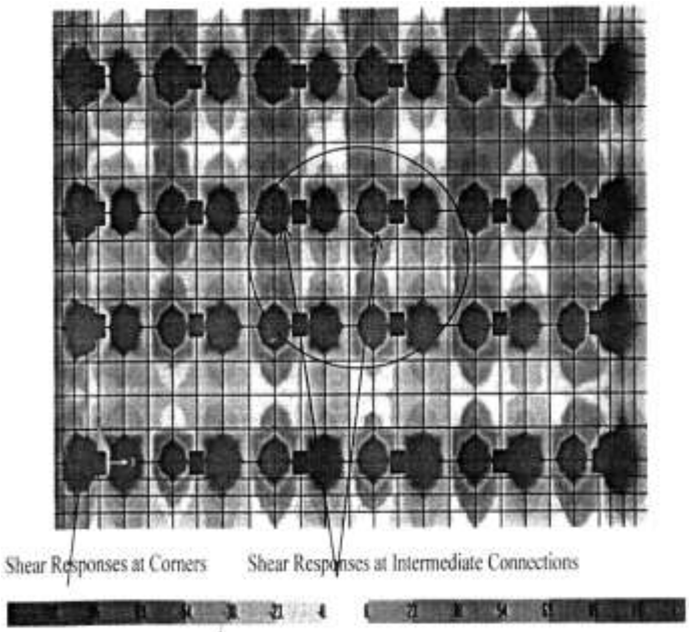


Figure 12 Shear stress distribution in the flat plate system for depth to span ratio, d/L = 0.03.

E. Intermediate connection with varying depth to span ratio

The response of the intermediate connection with varying depth to span ratio is represented in the form of curves (Figure 13) depicting the variation of punching shear capacity for various thickness of plates. Slabs are geometrically similar but due to size effect i.e. thickness of plate there is significant effect on the behavior of the system. The thicker slab has a lower rotation capacity and fails in a rather brittle manner whereas thinner slab exhibits a more ductile behavior. The graph shows a general trend that with the increase in the depth to span ratio (d/L), the shear capacity is increased.

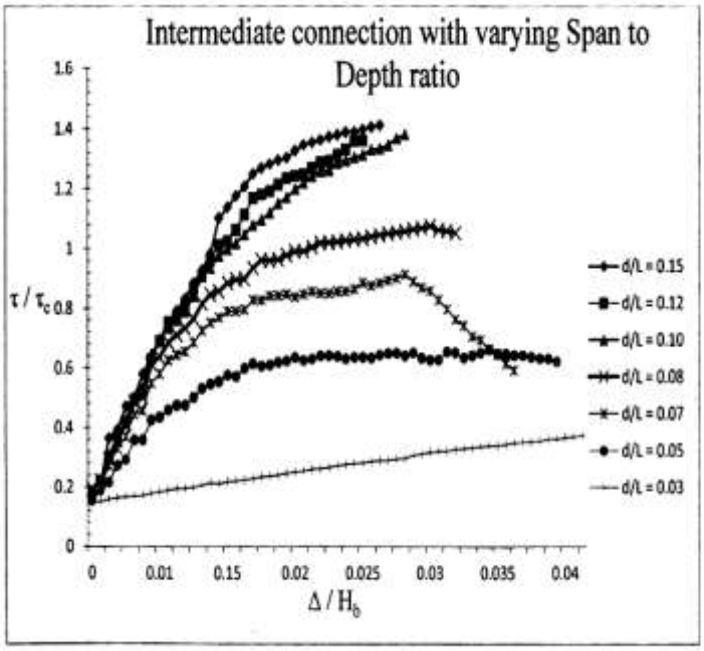


Figure 13 Punching shear capacity of intermediate plate column connection with varying depth to span ratio

F. Corner connection with varying depth to span ratio

The response of punching shear capacity to varying depth to span ratio for the corner connection of the flat plate system is represented in (Figure 14). The graph shows a general trend that with the increase in the depth to span ratio (d/L), the shear capacity is increased. With the increased thickness of the flat plate the level of shear at which the failure occurs diminishes but the slope for the thinner slabs remains approximately the same being observed form the trend of the curves for d/L = 0.03 and d/L = 0.05.

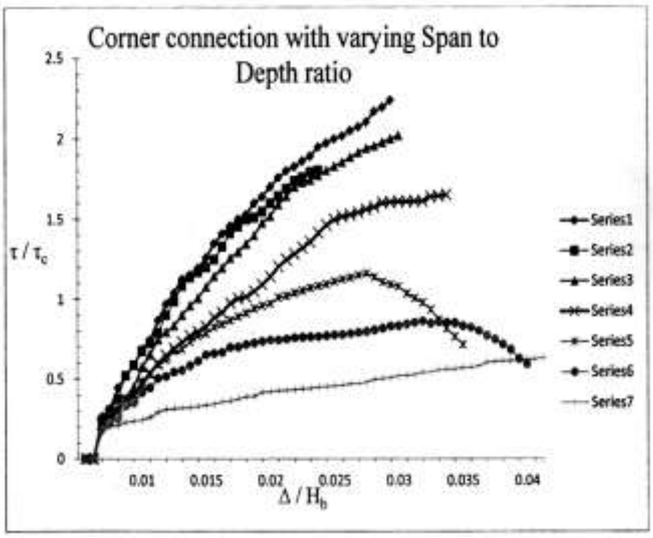


Figure 14 Punching shear capacity of corner plate column connection with varying depth to span ratio

V. CONCLUSION

Desertion work carried out on SAP 2000 (V 14.0) and research work classified as nonlinear parametric analysis. Nonlinear parametric study is undertaken to find out the influence of various parameters on the punching shear capacity of flat plate systems and thereby prescribe design guidelines for safe construction of flat plate systems in seismic zones. With increase in aspect ratio, B (longer dimension/ shorter dimension) the punching shear strength around the flat plate column connection both for intermediate and corner decreases till the peak shear strength is reached. With increase in the aspect ratio the peak shear strength shifts towards right and the peak occurs at higher values of lateral drift. The peak shear strength for intermediate connection is found to be of the order of 0.8 to 0.9 times of design shear capacity of connection (τ_c) whereas the peak shear strength in the case of corner connection is found to higher in the range of 1 to 1.3 times of design shear capacity of connection (τ_c). The increase in the punching shear stresses in the case of corner connection is observed because at the corner columns additional torsional moment gets generated because of loading on only one side of the connection leading to the susceptibility to punching shear failure. The shear capacity increased with increasing overall depth by span ratio for both intermediate and comer connection. For values of d/L less than 0.08, the punching shear capacity of the connection showed a ductile trend while for d/L values above 0.08, the connection appeared to undergo abrupt failure in shear because the thicker plate has lower rotation capacity which causes them to fail in brittle manner. Thus it can be observed that the ideal thickness of plate for the flat-plate building can be given as the ratio of d/L = 0.08 and thus for a span of 3.0 m thickness of the slab can be 250 mm because for the ratios lower than 0.08 the mode of punching shear failure is ductile and the higher ratios the failure mode is brittle. The elastic drift limit ($\Delta_{elastic}$) is found to be independent of aspect ratio, span to depth ratio. For aspect ratio in case of intermediate connection $\Delta_{elastic}$ observed is 1.5% whereas it decreases to 1% in case of comer connection. For span to depth ratio $\Delta_{elastic}$ observed is 1% of the height of the building Thus it is found that $\Delta_{elastic}$ is independent of the geometry of the connection.

REFERENCES

[1] Abhijeet Kashliwal, (2011) "Seismic Behaviour of Reinforced Concrete Flat-Plate Systems", A Mater of Technology Thesis report, IIT Guwahati.

[2] Cheng, M.Y., (2009) "Punching Shear Strength and Deformation Capacity of Fibre Reinforced Concrete Slab-Column Connections Under Eatrhquake Type Loading", A Doctor of Philosophy Dissertation, The University of Michigan.

[3] Dilger, W.H., (2000) "Flat slab-column connections", Structural Engineering Material, Vol. 2, pp. 386-399.

[4] Gasparini, D. A., (2002) "Contributions of C.A.P. Turner to development of reinforced concrete flat slabs 1905-1999", Journal of Structural Engineering, 128, No 10, pp 1243 -

[5] Megally, S. & Ghali, A., (2000) "Seismic behavior of slab-column connections" Canadian Journal of Civil Engineering, pp. 84-100.

[6] Park, H. & Choi, K., (2006) "Improved Strength Model for Interior Hat-Plate Column Connections Subject to Unbalanced Moment", ACI Structural Journal; pp 694-704.

[7] Park, R. & Gamble, W. L., "Reinforced Concrete Slabs", New York, pp 551-620.

[8] Pillai, S. U., & Menon, D., (2009) "Reinforced Concrete Design", India, pp 427-540.

[9] O'Moore, L., Dux, P. F. & Dao, V. N. T., (2005) "Punching shear of slab-column connection in flat-plate construction', International Congress."Global Construction: Ultimate Concrete Opportunities." University of Dundee, pp 183-190.

[10] Stein. T., Ghali. A. & Dilger, W. H., (2007) "Distinction between Punching and Flexural Failure Modes of Flat Plates", ACT Structural Journal. Vol. 104 No. 3. pp. 357-365. USA.

[11] Structural Analysis Program 2000 V 14.0, "CS1 product'"- An integrated solution for structural analysis and program.

[12] Subramanian, N., (2005) "Evaluation and enhancing the punching shear resistance of flat slabs using HSC", The Indian Concrete Journal, pp 31-37.

[13] Varghesc, P.C., (2009) "Advanced Reinforced Concrete Design". India, pp 158-247.

[14] Vijaya Narayan A.R., (2010) "Fragility Analysis and Safe Design Limits for RC and PT Flat Slabs subjected to Lateral drifts", A Master of Technology Thesis report, IIT Kanpur.