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Seismic performance of flat slab shear-wall-core building

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Abstract

Flat slab configurations are favored by both architects and clients because of their aesthetic appeal and economic advantages. Though this form of reinforced concrete construction gives several advantages over framed structures, they also present some disadvantages as brittle punching failure and large lateral deformations. In order to enhance performance of this configuration, designers embed shear-wall-core in flat slab building as lateral load resisting element. In current study, performance of 8, 12 and 16 storey flat slab buildings with out and with 2 and 4 shear-wall-cores have been studied for different levels of seismic hazards as classified in IS-1893-2002. Observed parameters of nonlinear static analysis, namely performance points, inter-storey drift ratios and hinge formation indicate that with the introduction of shear-wall-core in flat slab building, its behavior improves significantly under seismic loading. A pilot study on applicability of different expressions of Eurocode-8 for predicating fundamental time period of flat slab shear-wall-core building indicates that time period obtained by modal analysis (in SAP2000) is less as compared to that obtained by Eurocode-8. It is also interesting to note that in flat slab shear-wall-core building, the contribution of columns in lateral load sharing increases with increase in nonlinearity of this building system.

Keywords: shear-wall-core, seismic performance, flat slab, flat plate, push over analysis

1. Introduction

Flat slab systems, in which columns directly support floor slab without beams, has been adopted for many recent building constructions. Since flat slab system does not have beams, it gives many advantages such as providing a lower storey height, better lightening and ventilation, easy arrangement of pipes and wires under slab, more clear space, architectural flexibility and easier formwork. The behavior and design of flat slabs structures for gravity loads is well established but their seismic behavior is generally a matter of concern due to its vulnerability to seismic loading (Somaprasad R. H. *et al.*, 1994) [21]. Flat slab is susceptible to progressive brittle punching shear failure under seismic loading (Robertson *et al.*, 2006) [16]. In order to strengthen the flat slab buildings various majors have been suggested in literatures like use of drop panels, shear walls, shear-wall-cores etc. Designers mostly utilize duct of lifts, service ducts or space of open to air duct, for fitting lateral load resisting elements in buildings. So a study has been carried out to assess the performance of such composite arrangement of 8, 12 and 16 storey flat slab shear-wall-core buildings without and with 2 or 4 shear-wall-core using nonlinear static (pushover) analysis.

2. Building Description

Flat slab buildings used as case study models have 5 bays in both X and Y directions with total plan dimension of 25 m x 25 m. Each bay is 5 m x 5 m in plan with a storey height of 3 m. Flat slab buildings with 8, 12 and 16 storeys, situated in zone IV and on medium soil (IS-1893-I-2002) [10] have been considered for analysis. Superimposed dead load of 2 kN/m^2, equivalent wall load of 2.9 kN/m^2 and live load of 3 kN/m^2 have been considered in the study. In each flat slab building following three configurations have been considered as shown in fig. 1, fig. 2 and fig. 3.

1. Without SWC (fig. 1)
2. With 2 SWC having core area of 1.25 % of the building plan area (fig. 2)
3. With 4 SWC having core area of 2.2 % of the building plan area**.** (fig. 3)

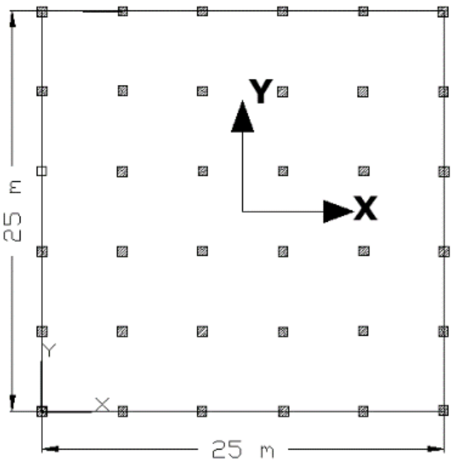

Fig 1: Building plan layout without shear-wall-core

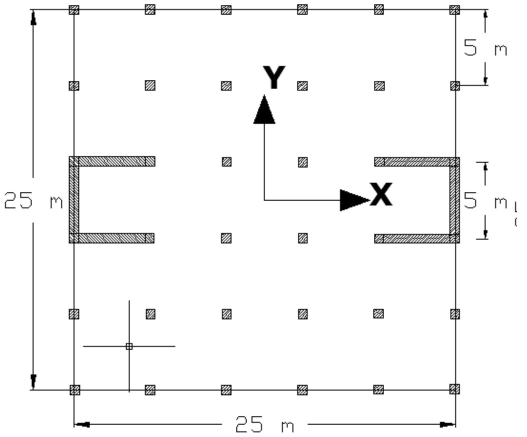

Fig 2: Building plan layout with 2 shear-wall-core

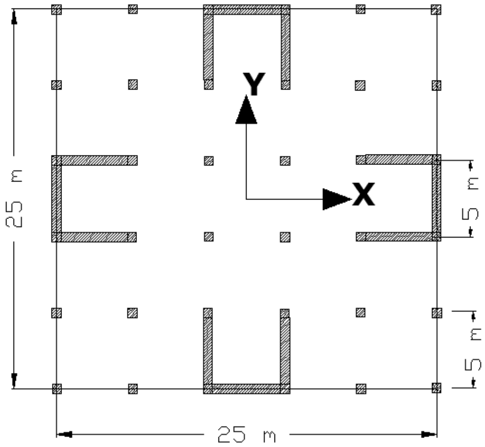

Fig 3: Building plan layout with 4 shear-wall-core

Flat slab has been designed for gravity loads using Equivalent Frame Method (Hwang *et al.*, 2000) [7] whereas Columns and shear-wall-core have been designed for design basis earthquake of zone IV as per the guidelines of IS 456:2000 & IS 13920-1993.

In each building configuration, slab thickness of 200 mm has been considered uniformly. At ground storey square columns with size of 400, 500, and 600 mm has been used in 8, 12 and 16 storey flat slab building respectively, which further reduces to minimum of 400 mm as one move to higher storey levels. Uniform thickness of 260 mm and 230 mm has been considered for SWC in building with 2 and 4 SWC respectively. All considered dimensions of each component are based on the linear static analysis.

3. Modelling of Flat Slab System

3.1 Flat Slab and Column

Modelling of each component is very important in order to get true simulation of respective prototype component. For flat slab modelling various methods are available in literatures (Hwang *et al.*, 2000)[7]. Out of all available methods equivalent frame approach observed to be most suitable for nonlinear analysis and hence it has been adopted in present study. Fig 4 shows line idealized model of equivalent frame.

The load transfer system in the ‘equivalent frame’ involves three distinct interconnected elements. (Hwang *et al.*, 2000) [7]

1. The slab-beam member (along span l1)
2. The columns (or walls); and
3. The torsional members, transverse to the frame (along span l2) and along the column lines.

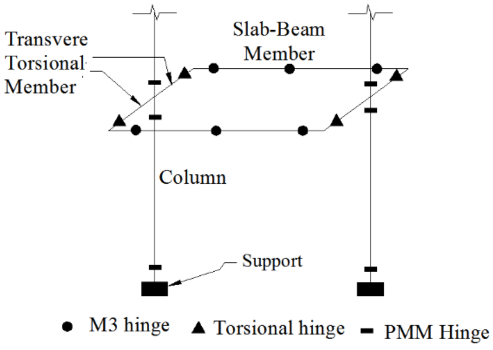

Fig 4: Idealized Model of equivalent frame with location of different type of hinges

Total slab is divided into number of strips which are represented as slab-beam member in model. For calculating the width of individual strip equation 1 and 2 has been used (Hwang *et al.*, 2000).

$$b = 2C_1 + \frac{l_1}{3} \text{ (for interior slab frame)} \qquad (1)$$

$$b = C_1 + \frac{l_1}{6} \text{ (for exterior frame)} \qquad (2)$$

The torsional member represents slab-column connection in model, for that explicit transverse torsional member method (Cano *et al.*, 1988) [3] has been used. The stiffness of torsional members and of columns are calculated using Eq:3 [CSA Standard A23.3, 94] and Eq: 4 respectively. Stiffness factor K_{ab} used for calculating column stiffness (Eq: 5) of individual column depends on the variation of the second moment of area along the span, are available in tabular form for common geometric and loading configurations in various design handbooks. [Concrete Design handbook, 1985 and SP: 24, 1983)

$$K_t = \frac{9E_{cs}C}{l_2(1-\frac{C_2}{l_2})^3} \quad ;$$

$$C = \sum(1-0.63\frac{x}{y})\frac{x^3y}{3} \qquad (3)$$

$$\frac{1}{K_{ec}} = \frac{1}{\sum K_c} + \frac{1}{K_t} \qquad (4)$$

$$K_c = \left(\frac{K_{ab} E_c I_c}{L_c} \right) \quad (5)$$

Dimensions of the transverse torsional member have been calculated by equating the torsional stiffness of member from Eq. 3 with the torsional stiffness of the rectangular section given by Eq.-6.

$$K_t = \frac{GJ}{L} \quad (6)$$

It has been recognized by many researchers that gross section properties overestimate the actual stiffness. The effect of cracking in the slab causes significant reduction in the section properties. Cano *et al*. (1988) [3] recommended to use lower bound estimate of slab stiffness, equal to 1/3 of the gross section properties**.**

3.2 Shear-Wall-Core

"Wide column approach" and the continuum approach are widely used for modelling of shear wall core for elastic/inelastic analysis. (Rutenberg *et al*., 1986; Reynouard *et al*., 2001; Beyer K. *et al*., 2008 and Kwan A., 1991 and 1993) In the wide column method, core is divided into number of components and for each component an equivalent column, having similar geometrical properties has been inserted at centre of mass of respective component. To retain core integrity individual equivalent column has been connect with each other by rigid links. Within the frame work of wide column analogy, (Xenidis H. *et al* (2000))[23] various arrangements were compared in addition to above, like single equivalent column for whole core at its "mass centre" or at "shear centre". It was concluded that arrangement having equivalent column at centre of mass of each components gives best simulation. With simplicity this approach has also some issues for linear as well as nonlinear analysis which needs concern. There are problems like parasitic bending moment and apparent shear deformation. Many researchers (Stafford S. *et al*., 1986 and Kwan A., 1991 and 1993) [22] suggest some remedial measure like to increase shear modulus (G) of vertical element and additional braces to vertical element and links. Although such measures results into better performance but yet they does not give problem free simulation. (Rutenberg *et al*., 1986) [17].

Beyer K *et al* (2008) [2] use the same modeling approach of wide column analogy for nonlinear range of study of core. One more literature (Reynouard *et al*., 2001) [15] comprised both an experimental as well as numerical modelling of SWC for nonlinear range of analysis, in which validation of result was done on basis of finite element code CASTEM 2000

Due to problem of parasitic bending moment and apparent shear deformation in wide-column analogy, finite element approach has been used to model of shear-wall-core in this study. Many researchers (Miao Z W *et al*., 2006 and Ile N. *et al*., 2005) [14] also use finite element approach to model shear wall and shear wall cores. In present study shear-wall-core has been modelled by nonlinear shell elements (SAP Manual, 2000) [19] in SAP2000 software package. This nonlinear shell element consists of many layers of different thickness and different material models of concrete and rebar. These material models are assigned to the layers so that structural performance of shear wall can be directly connected with the constitutive laws of concrete and reinforcement respectively.

4. Pushover Analysis Using Sap2000

To check the performance of flat slab building a nonlinear static (pushover) analysis has been performed using SAP2000 software. It is an approximate analysis method in which the structure is subjected to monotonically increasing lateral forces with an invariant height wise distribution, until a target displacement is reached.

A three dimensional model of each flat slab structure has been created to undertake the non-linear analysis. Slab-beam and columns have been modeled as nonlinear frame elements with lumped plasticity. SAP2000 V14.2.2 provides default-hinge properties and recommends M_3 hinge for slab-beam elements and P-M_1-M_2 hinges for columns, which are based on Table 6-7 and Table 6-8 of FEMA [6] 356-2000**.** In slab-beam elements, the plastic hinge properties are assigned as M_3 hinges at 3 locations (start, center and end) of beam, whereas P-M_1-M_2 hinges has been assigned at 2 locations (start and end) of column elements. Nonlinear behavior of slab column connection has been assigned to transverse torsional member as per Table 6-14 of FEMA 356-2000, which depend on gravity shear ratio (V_g/V_0). Fig 2 shows location and type of hinges assigned to respective components. In addition, for frame elements, the stiffness modifiers have been used to account for the effect of cracking as per Table 6-5 of FEMA-356-2000.

SAP2000 provides homogenous or layered shell element having all six degrees of freedom at each of its nodes and the same has been employed to model the shear-wall-core. Based upon the numerical experimental, an aspect ratio of 1 to 1.5 has been considered for discretization.

4.1 Loading

For pushover analysis, total seismic base shear of building has been distributed among centroids of each floor level as per IS 1893-I-2002. Distributed load varies in parabolic form from zero at base to maximum at roof. The distribution of the force along the height is given by Eq. 7 and 8.

$$F_i = V_B Q_i \quad (7)$$

$$Q_i = \frac{W_i h_i^{\,2}}{\sum_{i=1}^{i=n} W_i h_i^2} \quad (8)$$

5. Response Under Nonlinear Static Analysis

Performance of 8, 12 and 16 storey flat slab building with and without shear-wall-cores (SWC) has been investigated, for different earthquake hazard levels, as per IS 13920-1993, namely DBE IV, DBE V and MCE IV. Performance includes an assessment of period of vibration, inter-storey drift, propagation of yielding in the structural elements and finally the hinge formation to enable the system to be classified at various performance indices of Immediate Occupancy (I.O.); Life Safety (L.S.); and Collapse Prevention (C.P.).

6. Results

Table 1, illustrates the time period for various flat slab building configuration considered in present study. Bare flat slab and 4 SWC system are symmetric in X and Y direction and hence their results are same in the respective directions. It is apparent that when shear-wall-core is introduced in flat slab building, the time period reduces which is understandable as the insertion of shear-wall-core increases the stiffness of flat slab structure in lateral direction. In addition, the same has been compared with values obtained by using Eurocode-8 expression. Time period of shear-wall-core building, calculated by Eurocode-8 is more than, that computed by SAP. The reason of such discrepancy can be credited to flange action of shear-wall-core.

Performance point of building for DBE IV, DBE V and MCE IV is calculated from demand-capacity curve and is plotted on base shear v/s top displacement plot. Maximum inter-storey drift and their corresponding floor level for different earthquake levels for 8, 12 and 16 storey flat slab buildings with the different configurations are presented in table 2. It may be concluded that for flat slab buildings without SWC, maximum inter-storey drift ratio is observed to occur near middle storey level, whereas in buildings with 4 SWC it occurs in intermediate storey between top and middle. This location of maximum inter-storey drift get further shifted to upper storey as number of SWC decreases from 4 to 2.

Figs. 5 to Fig. 7 depicts the pushover curve for 8, 12 and 16 storey bare flat slab building with various configurations. For pushover in Y Direction in 8 storey flat slab building with 2 SWC configuration, yielding starts at slab column joint on the 7th storey level and a top displacement of 20.19 mm is observed. By correlating Fig. 5 and Fig. 8 for 8 storey FS building with 2 SWC one can observe that building starts yielding at displacement of 26.2 mm. From fig. 5, fig. 6 and fig. 7 it is clear that building with bare flat slab failed at DBE IV level earthquake, while for buildings with SWC performance of structure is much better at different performance levels (Immediate occupancy (I.O.), Life Safety (L.S.) & Collapse Prevention (C.P.)) The buildings collapses when SWC drops its load. It has been noted that at collapse most of frame elements failed in L.S. performance region.

From the pushover curve it can also be observed that when flat slab system is designed for earthquake forces using linear analysis, they are ready for immediate occupancy (I.O.) for DBE IV earthquake. However for MCE earthquake of same zone the building crossed L.S. performance limit state in some cases (12 ST with 2 SWC and 16 ST with 2 SWC).

Study suggests that with progressive yielding of bars in shear-wall-core segment, the proportion of base shear getting propagated to columns increases. Table 3 summarizes the percentage of the base shear shared by the columns corresponding to three performances indices i.e. I.O, L.S. and C.P.

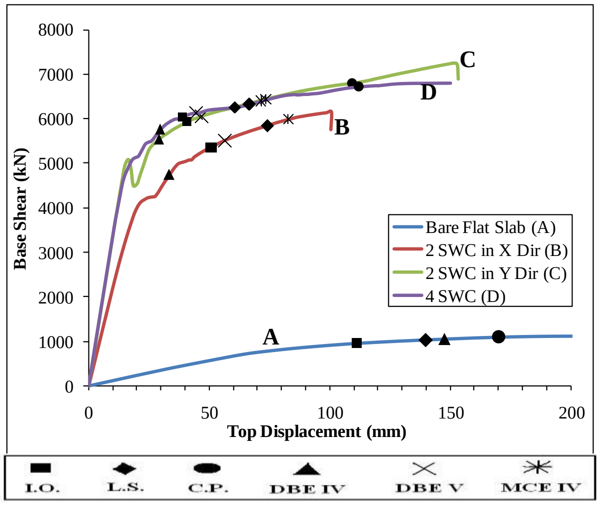

Fig 5: Pushover curves and performance point for 8 storey buildings

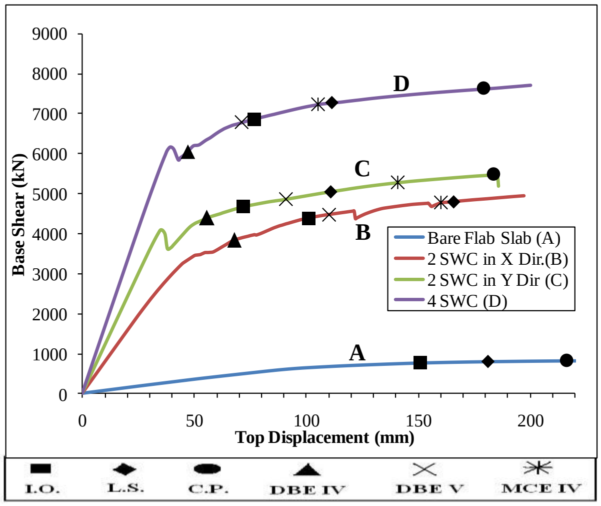

Fig 6: Pushover curves and performance point for 12 storey buildings

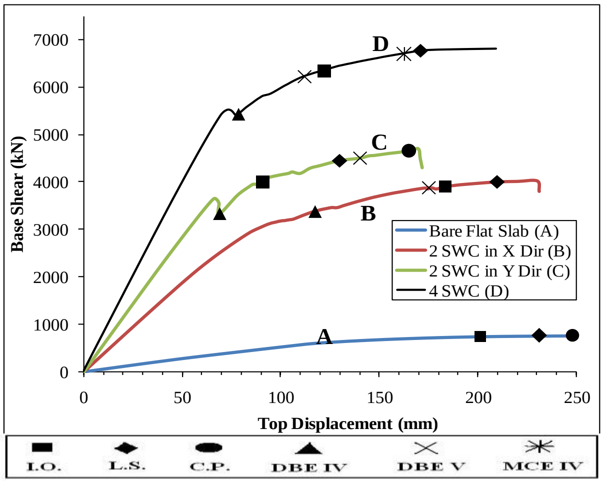

Fig 7: Pushover curves and performance point for 16 storey buildings

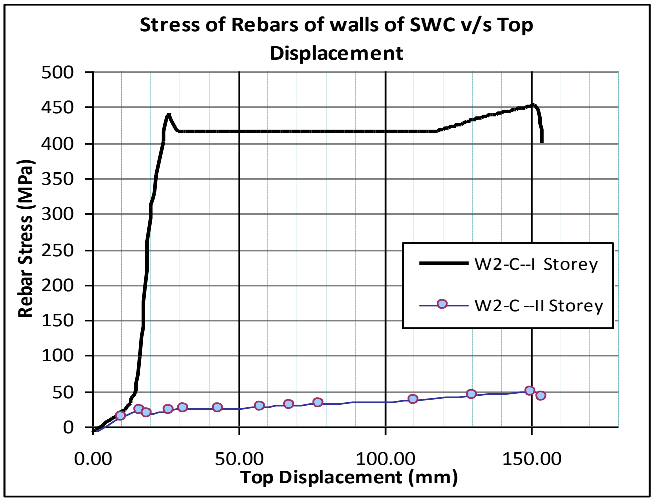

Fig 8: Stress plot of rebars in SWC for 8 storey flat slab building with 2 SWC for Y Direction of analysis

7. Conclusions

In the present paper, results of static nonlinear pushover analysis, has been discussed for each of 8, 12 and 16 storey flat slab building with three different configurations; namely building without shear-wall-core, with 2 SWC and with 4 SWC. In all the cases, building plan area is 25 m x 25 m. In case of 2 SWC & 4 SWC the area of shear-wall-cores is around 1.25 % and 2.2 % of building plan area respectively. The initial design of all the investigated buildings has been done complying with codal provisions of IS: 456-2000; IS: 1893-2002; and IS: 13920-1993 for seismic zone IV.

From this study following conclusions can be made:

1. Flat slab building behaves completely different in comparison to conventional framed building, due to its more lateral flexibility. By adding SWC, its lateral stiffness is enhanced significantly which significantly increases seismic performance of this dual system.
2. Top displacement of 8 storey flat slab building with SWC has been found to be 4 to 5 times lower than building without SWC. Thus, it can be concluded that SWC substantially increase the lateral stiffness of building
3. In models of FS building with SWC, nonlinearity first develops in the SWC which further proceed to slab-column connection. The Torsional hinge formed at slab column connection remains in immediate occupancy level for considered level of seismic hazard.
4. Performance of flat slab buildings with 2 SWC in X direction, having 4 in-plane walls in the load direction, comes in almost same range as of flat slab buildings with 4 SWC, which has 6 in-plane walls. The same is not true for response in Y direction.

8. Relevance of Paper for Civil Engineering Practice

Due to vulnerability of flat slab buildings for damages of seismic hazards, most of country’s building codes restrict the construction of flat slab building within seismically active areas. To cater the present day demand of flat slab buildings for big cities, structural designers embed shear-wall-core in it as lateral load resisting element. So the study presents seismic performance of such flat slab shear-wall-core buildings and can act as guide for designers.

9. Acknowledgment

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Table 1: Time period of different building configurations

MODELS	Analysis Direction	Time Period (second)					
		8 Storey		12 Storey		16 Storey	
		By SAP*	Euro Code 8 +	By SAP	Euro Code 8	By SAP	Euro Code 8
FS Building	In X and Y Dir.	2.78	0.813	4.19	1.102	5.33	1.36
FS with 2 SWC	In X Dir.	0.6	0.82	1.22	1.309	2.015	1.779
	In Y Dir.	0.5	0.99	0.99	1.525	1.651	2.016
FS With 4 SWC	In X and Y Dir.	0.48	0.674	0.84	1.057	1.38	1.419

* Time period obtained by modal analysis in SAP2000 V14.2.2 software

\+ Time period by Cl-4.3.3.2.1 of Eurocode-8 in which all shear walls of shear-wall-core has been considered

Table 2: Maximum Inter-storey drift with its location level at different performance points

Direction of Analysis	Drift (%)							
	X and Y		X		Y		X and Y	
Seismic Level	Max Value	Storey level	Max Value	Storey	Max Value	Storey level	Max Value	Storey level
8 ST Flat Slab Building								
	8 ST FS		8 ST FS 2 SWC				8 ST FS 4 SWC	
DBE IV	0.95	3rd	0.173	7th/8th	0.131	7th/6th	0.131	7th
DBE V	1.55	4th	0.279	7th	0.215	6th	0.21	7th
MCE IV	NA	NA	0.396	8th	0.332	6th	0.325	7th
Ultimate Load Condition	1.31	4th	0.469	8th	0.661	6th	0.525	6th/7th
12 ST Flat Slab Building								
	12 ST FS		12 ST FS 2 SWC				12 ST FS 4 SWC	
DBE IV	1.102	5th	0.235	11th	0.181	10th	0.157	10th

DBE V	NA	NA	0.353	11th	0.284	10th	0.227	10th
MCE IV	NA	NA	0.511	10th	0.428	10th	0.325	10th
Ultimate Load Condition	1.102	5th	0.623	10th	0.55	10th	0.598	9th/10th
16 ST Flat Slab Building								
	16 ST FS		**16 ST FS 2 SWC**				**16 ST FS 4 SWC**	
DBE IV	1.17	8th	0.3	13/14/15th	0.22	14th	0.21	13th/14th
DBE V	NA	NA	0.43	12 to 15th	0.33	13/14th	0.29	14th
MCE IV	NA	NA	NA	NA	NA	NA	0.386	13th/14th
Ultimate Load Condition	1.066	7th	0.5	13th	0.55	13th/14th	0.386	13th/14th

Table 3: Percentage of base shear shared by columns in different flat slab configurations

16 Storey			**12 Storey**		**8 Storey**	
2 Shear-Wall-Core						
S. No	**Level**	**% Share**	**Level**	**% Share**	**Level**	**% Share**
Push XX			**Push XX**		**Push XX**	
1	Elastic Range	**5.45**	**Elastic Range**	**3.2**	**Elastic Range**	**1.92**
2	IO	28.1	IO	15.34	IO	7.6
3	LS	33.5	LS	29.89	LS	15.25
4	Ultimate Load Condition	42.4	Ultimate Load	36.24	Ultimate Load	21.11
Push YY			**Push YY**		**Push YY**	
1	Elastic Range	7.6	Elastic Range	4.33	Elastic Range	2.2
2	IO	36.2	IO	27.1	IO	11.12
3	LS	47.6	LS	46.2	LS	18.6
4	C.P.	84.2	CP	78.9	CP	30.57
4 Shear-Wall-Core						
1	Elastic Range	2.7	Elastic Range	1.2	Elastic Range	1.79
2	IO	22.9	IO	8.4	IO	7.37
3	LS	41	LS	15.4	LS	14.12
4	CP	42.9	CP	27.5	CP	22.86

References

1. ACI-318. Building Code Requirement for Structural Concrete and Commentary, An ACI Standard, by ACI committee-318-2005.
2. Beyer K, Dazio A, Priestley MJN. Inelastic Wide-Column Models for U-Shaped Reinforced Concrete Walls, Journal of Earthquake Engineering, 2008; 12(S1):1-33.
3. Cano MT, Klingner RE. Comparison of Analysis Procedures for Two-Way Slabs. ACI Structural Journal. 1988; 85(6):597-608.
4. Concrete Design Handbook. Concrete Design Handbook, Canadian Portland cement Association, Canada, 1985.
5. CSA Standard A23.3-94. Design of Concrete Structure, Canadian Standards Association, Rexdale, Ontario, 1994.
6. FEMA-356. Prestandard and Commentary for the Seismic Rehabilitation of Buildings-2000, prepared by ASCE for the Federal Emergency Management Agency, Washington, 2000.
7. Hwang SJ, Moehle JP. Models for Laterally Loaded Slab-Column Frames. ACI Structural Journal. 2000; 97(39):345-353.
8. Ile N, Reynouard JM. Behaviour of U-shaped walls subjected to uniaxial and biaxial cyclic lateral loading. Journal of Earthquake Engineering. 2005; 9(1):67-94.
9. IS 13920. Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces, Code of Practice, Bureau of Indian Standards, New Delhi, 1993.
10. IS 1893-I. Criteria for Earthquake Resistant Design of Structures, Part 1 – General provisions and Buildings, Bureau of Indian Standards, New Delhi, 2002.
11. IS 456. Plain and Reinforced Concrete - Code of Practice, Bureau of Indian Standards, New Delhi, 2000.
12. Kwan A. Analysis of coupled wall/frame structures by frame method with shear deformation allowed, Proceedings of the Institution of Civil Engineers. 1991; 91(2):273-297.
13. Kwan A. Improved wide-column-frame analogy for shear/core wall analysis. Journal of Structural Engineering. ASCE 1993; 119(2):420-437.
14. Miao ZW, Lu XZ, Jiang JJ, Ye LP. Nonlinear FE model for RC shear walls based on multi-layer shell element and microplane constitutive model, computational methods in engineering and science, Aug 21-23,Tsinghua University Press & Springer-Verlag, China, 2006.
15. Reynouard J-M, Fardis MN. Shear wall structures, CAFEEL-ECOEST/ICONS Thematic Report No. 5, LNEC (Laborato´rio Nacional de Engenharia Civil), Lisboa, Portugal, 2001.
16. Robertson IN, Johnson G. Cyclic Lateral Loading of Nonductile Slab-Column Connections. ACI Structural Journal. 2006; 103(3):356-364.
17. Rutenberg A, Shtarkman M, Eisenberger M. Torsional analysis methods for perforated cores, Journal of Structure. Div., ASCE, 1986; 112(6):1207-1227.
18. Special Publication SP. Explanatory Handbook on Indian Standard Code of Practice for Plain and Reinforced Concrete (IS-456-1978), Bureau of Indian Standards, New Delhi, 24-(1983).
19. SAP. CSI Analysis Reference Manual, Berkeley, California, USA, 2000; 14(2):2.
20. Sharma J. Performance of flat slab shear-wall-core building under seismic loading, M.Tech. Thesis-2010,

IIT-Roorkee, India

21. Somaprasad R Hosahalli, Ahmet E Aktan. Seismic Vulnerability of flat slab-core buildings. Journal of Structural Engineering. ASCE, 1994; 120(2):339-359.
22. Stafford Smith B, Girgis A. Deficiencies in the wide column analogy for shear wall core analysis, Concrete International, 1986; 58-61.
23. Xenidis Hariton, Kostas Morfidis and Ioannis E. Avramidis. Modelling of Two Cell-Cores for Three Dimensional Analysis of Multi-Storey Buildings, The Structural Design of Tall Buildings, John Wiley & Sons Ltd., 2000; 9:343-363.