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Seismic Performance of Flat Slabs

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Abstract**—***Beam less slab type of structural systems are often not proposed in zone of high seismicity due to; lesser floor diaphragm rigidity, the vulnerability to punching shear under stress reversals, the 2nd order effects due to the increased inter-storey drifts and the successive punching failures of the lower floors due to the primary punching failures. This throws a challenge to structural engineers to explore the possibilities of making a beam less slab system safer, if not exonerate them from seismic vulnerability. Further, the degree of rigidity of any system makes it sensitive to acceleration, velocity and displacement depending on its proximity from the source of the ground motion, giving scope to ductile detailing, use of dampers and displacement based design*

Systems that are partially flexible and partially rigid are sensitive to velocity giving scope to the use of dampers. The flexible systems are sensitive to displacement making way for displacement based design. Some of the systems exhibit sensitivity for displacement, acceleration and velocity due to the narrowness in the time period range for velocity sensitive systems. The inter storey drifts were found to be higher in the intermediate storeys for tall structures thus giving higher second order effects like increased moments and punching shear stresses. However, the sensitivity of the system is to be investigated on a case to case basis. The factor by which the moments can be increased or decreased from the gravity loads can be arrived at by careful deliberation for stiffer systems. The flexible systems have to be carefully studied for the moments, for they show an eccentric behaviour.

Keywords*: Flat Slabs, Flat Plates, Punching Shear, Diaphragm rigidity, Shear wall.*

1. INTRODUCTION

In this research work, models were prepared with varying lateral stiffness; from flexible (columns) to stiffer (with shear walls). The lateral stiffness was provided in terms of columns only (flexible) and columns in combination with shear walls (stiffer). Shear walls were provided at the core, at the periphery and both at the core and the periphery. The effect of the providing panel drop and perimeter beam along with slab was also studied. The dimensions of the concrete elements were arrived through established codal provisions. The models were subjected to seismic forces; both response spectrum and strong ground motion along with the combination of the gravity loads. A free vibration analysis of the models was also studied for a better understanding of the system. The sensitivity of the system to acceleration, velocity and displacement was also studied for a given ground motion. The structural responses like natural periods, storey shear, moments, punching shear, and inter storey drifts were also studied.

2. NUMERICAL MODELING

The modeling of the structure is being done by Finite Element package. The beams and columns are modeled as the concrete frame elements. The slabs and the shear walls are modeled as the shell elements. The frame element consists of six degrees of freedom at a node which are three rotations and three displacements.

Shell Element: The shell is the combination of the membrane and the plate elements i.e. a shell can behave as plate and as well as membrane. The shell has six degrees of freedom at each node, by restraining the normal translation and bending rotations the shell acts as a membrane and when the in plane translations and the bending about the normal are restrained the shell acts as a plate element.

Beam element: The frame element internal forces are:P the axial force, V2 the shear force in the 1-2 plane, V3 the shear force in the 1-3 plane, T the axial torque (about the 1-axis), M2 the bending moment in the 1-3 plane (about the 2-axis), M3 the bending moment in the 1-2 plane (about the 3-axis)

Floor Constraints: The diaphragm constraints are used to restrain the deformation of the membranes by making the membrane rigid for in plane deformations and to ensure that all joints in plane move in the same pattern. The joint connectivity of the floor should be in the same plane. Plate constraints are also kind of constraints in which even the out of plane bending that is allowed in the diaphragm constraints. The joint connectivity shall be on any points in space.

2.1 Description of the Specimens

3D RC Flat Plates and Flat Slabs of (3×3) bays and (5×3) bays having Five and Ten Storeys are taken into consideration. The RC frames are designed as per Bureau of Indian Standards codes, IS 456-2000, "Plain and Reinforced Concrete-code of practice", IS 1893-2002 (Part 1), "Criteria for earthquake resistant design of structures" and detailed as per IS 13920-1993, the concrete is M40 and Tor steel are used for reinforcement. The RC frames comprises of columns, beams and slabs. Analysis of the frames was accomplished using ETABS 9.7 software. Dead load, imposed load, and earthquake load are considered for analysis.

Different types of Models considered for this analysis are; Flat Plates- FP 1- Flat Plate, FP 2- Flat Plate with Edge Beam, FP 3- Flat Plate with Shear Wall at Periphery, FP 4- Flat Plate with Shear Wall at Periphery adjacent sides-1, FP 5- Flat Plate with Shear Wall at Periphery adjacent sides-2, FP 6- Flat Plate with Shear Wall at Periphery Full Span, FP 7- Flat Plate with Shear Wall at Periphery with Edge Beam, FP 8- Flat Plate with Shear Wall at Core with Edge Beam, FP 8.1- Flat Plate with Shear Wall at Core and Periphery with Edge Beam, FP 9- Flat Plate with Shear Wall at Core L-Shaped with Edge Beam and FP 9.1- Flat Plate with Shear Wall at Core and Periphery L-Shaped with Edge Beam. Similarly, Flat Slabs were denoted as FSD.

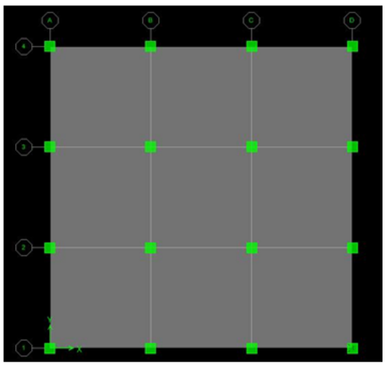

Fig. 1: FP1- Flat Plate

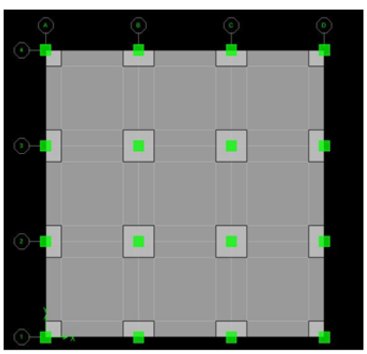

Fig. 2: FSD1- Flat Slab

3. METHODOLOGY

The Modeling of 3D RC frame with Flat Plates and Flat Slabs using IS 456-2000 considering dead load, live load and earthquake load. The numerical analysis was carried out for calculating the Dimensions of Columns, Thickness of Flat Plates and Flat Slabs, Panel Drop Thickness. Generation of response spectra and time history for seismic zone-V as per IS-1893:2002. The modal analysis of 3D RC frames is carried out to get the natural frequencies and mode shapes of the structure. The RC frame models are of Symmetrical 3 bay and Unsymmetrical 5x3 bay with five and ten storey for different configurations. The time history analysis is carried out for the entire zone V as per IS 1893-2002 to obtain joint displacement, velocity and acceleration.

4. RESULTS

4.1 Natural Time Period; Fundamental Natural Time Period as per IS 1893-2002, $T = 0.075H^{0.75}$ For 5 Storey Structure, T= 0.5716 secs and For 10 Storey Structure,T = 0.9613 secs.

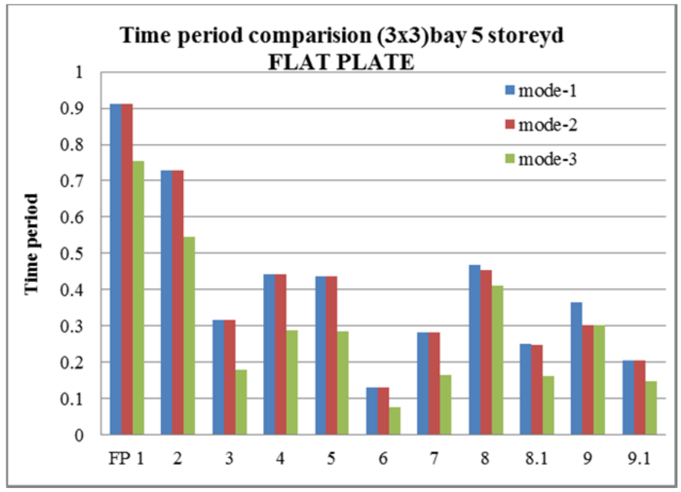

Fig. 3: Variation of Natural Time Period for (3x3) Bay 5-Storey Flat Plate systems.

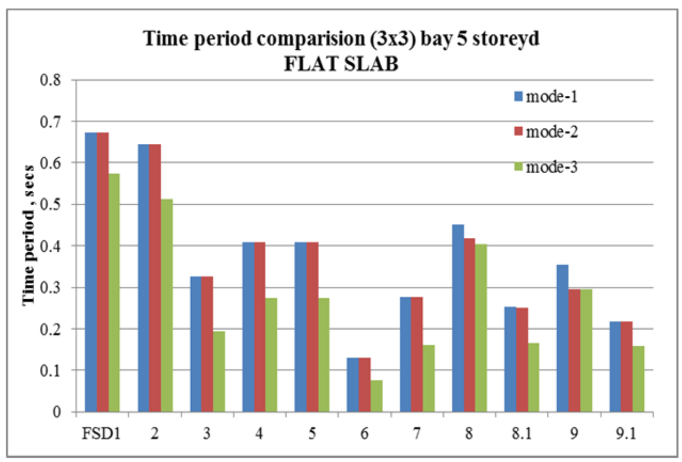

Fig. 4: Variation of Natural Time Period for (3x3) Bay 5-Storey Flat Slab systems.

Natural Time period of 5-Storey and 10-storey Flat Plate and Flat slab systems were compared.

The Torsional modes are predominant for systems with the shear walls at the Core i.e., Model FP8 & FP9 has a time period of T=0.469Secs and T=0.366Secs which is predominantly Torsional in nature as observed. It is a general practice to provide shear walls at the Core as explained above this proves to be catastrophic in nature for Flat Slab Systems as there is some order of Torsional eccentricity in all practical systems. Providing an Edge beam will reduce the Punching Shear at the Edges of the Slabs as framing action comes in to picture. Further, more the Edge beam adds to the mass of the system to reduce lateral forces i.e., (same Stiffness and higher masses FP1-0.912Secs and FP2- 0.728Secs). Providing Shear walls at the Periphery will increase the stiffness of the system and hence attract a larger lateral force as compared to the other systems. However the percentage of Shear walls at the Periphery should be based on an engineering judgment as the system tends to be highly rigid (as observed Time Period for FP3-0.381Secs, FP4-0.523Secs, FP5-0.523Secs and FP6-0.131Secs). With the increase in number of bays in one of the lateral directions, the addition of mass is more in proportion as compared to that proportional addition of stiffness (increased Columns). Therefore most of the system appears to be flexible as compared to systems with Symmetrical Bays (3x3 Bays). However a difference in behaviour comes in to picture with model FP1 i.e., In Flat Plates as the proportional increase in Stiffness has an edge over the proportional increase in Mass. The Second such exception is when the Shear walls are provided at the Core and has an Edge beam. The increase in dimension of systems and number of columns increases the torsional rigidity of system and hence a Stiffer resistance to torsion (Model FP8 of Unequal Bay System has a time period T= 0.312Secs pas compared to time period T=0.469Secs in a model with equal bays).

Height Effect; The Stiffness effect reduces drastically with a drastic increase in mass and height. Thus the Time Periods all though follow the same trends but for almost doubled values as observed in Table No.1, 2, 4 & 5. In a Flat Slab type of system, the diaphragm rigidity increases due to increase in slab thickness in the form of a Panel Drop. This in turn contributes to additional stiffness of the system in proportion to the increased mass (Flat Plate systems are flexible in comparison and framed systems are stiffer, Flat Slabs lie in between them. Therefore, the Time Period of the Flat Slab system appears to be lesser than those of a Flat Plate system as observed in Fig. 3 & 4.

4.2 Base shear

The Stiffer systems attract higher forces due to increased Stiffness and Mass also this is clearly visible in Model (FP 6-2667.87kN and FP 9.1-2714.48kN) as observed. Further, it may be noted that Base Shear for Static Load Case is higher as compared to the system subjected to Time History the reason being lesser build up in force over consecutive time steps. This might also change from Ground motion to Ground motion i.e., Ground motion with longer strong Ground motion period can result in higher force build up. The increase in Base Shear is proportional to the increase in the mass. Therefore the effect on Base Shear can be said as mass dependent phenomenon which is particular to this study. Further, it may be noted that there is a disproportional increase in mass as compare to stiffness for system with unequal bays of constant height (bays increased in one direction only and the other direction is still flexible) as observed in Graph No.9 and Graph No.13. Height Effect; although the increase in mass is high, due to the flexibility of the system the period accordingly is high. Therefore, the system attracts lesser horizontal forces and hence reduced Base Shear was compared. Due to reduced Time Periods and increased mass the horizontal co-efficient of forces increases and hence an increase in Base shear is observed.

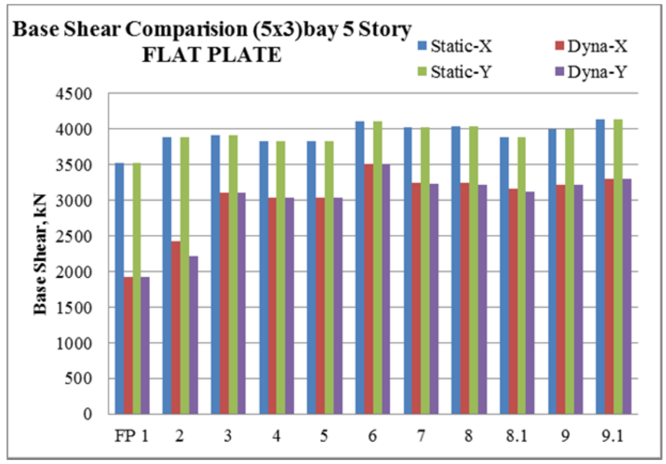

Fig. 5: Variation of Base Shear for 5x3 Bay 5-Storey Flat Plate systems

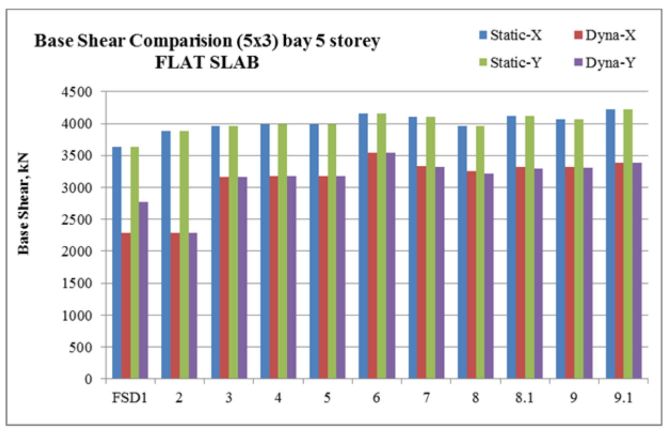

Fig. 6: Variation of Base Shear for 5x3 Bay 5-Storey Flat Slab systems

4.3 Span Moments and Support Moments:

Introduction of Rigidity into system in terms of Shear walls reduces the span moments and support moments in all load cases, this is due to the reason that the loads are supported at multiple points and hence a substantial proportion of load is transferred as axial compression in Shear walls and Columns. However, the flexible systems subjected to lateral loads such as (Models FP1 to FP5) exhibit a different behaviour. As when support moments and span moments are concerned (Models FP1 to FP5 are the system which needs to be subjected to dynamic analysis to arrive at actual forces for realistic behaviour of the system).

The Seismic Static case appears to give a higher value of Span moments for flexible systems. The increase in the support moment could be attributed to the increased rigidity of slab diaphragms. The Support moments shows a decreasing trend with increase of lateral rigidity of system due to loads transferred through multiple points (axial compression of Shear walls).

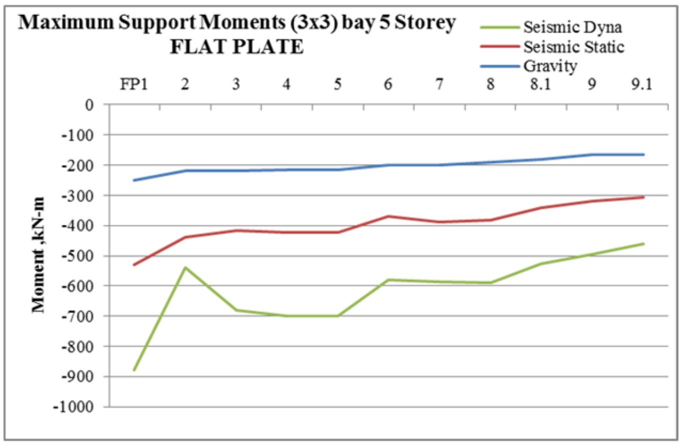

Fig. 7: Variation of Support Moments for 3x3 Bay 5-Storey Flat Plate systems.

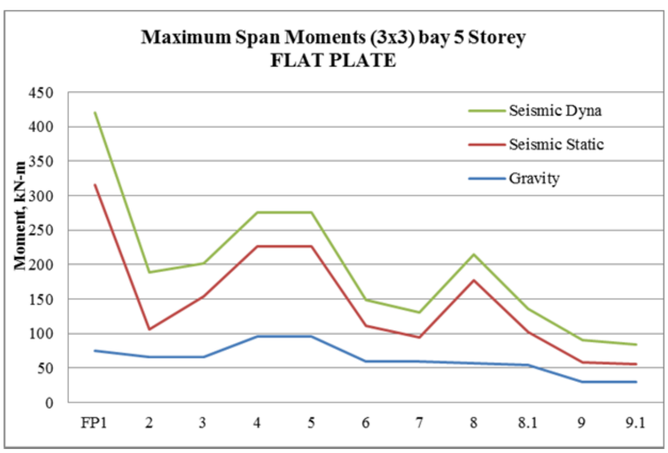

Fig.8 Variation of Span Moments for 3x3 Bay 5-Storey Flat Plate systems.

4.4 Punching shear

Punching Shear pattern at periphery is similar for all models except for extremely rigid (Model FP6) for both Seismic Static and Dynamic cases (this can be clearly visible from Fig.11). The Punching Shear shows a declining pattern from flexible to rigid systems (substantial proportion of load is transferred by axial compression). However, the gravity loads may govern for partially rigid systems (Model FP3, FP4 & FP7) and seismic loads govern for extremely flexible and highly rigid systems. (Remaining models). For Partially rigid systems based on careful observation a factor can be arrived to obtain punching shear value. Punching shear at the core shows a gradual decline pattern as substantial proportion of load is transferred by axial compression as seen in Fig.11. Further, Punching Shear pattern for partially flexible systems is governed by gravity load. For a highly rigid flexible system the punching shear pattern is governed by the seismic cases.

Height Effect; Similar trends of a 5-Storey system are followed except for the magnitude being higher for intermediate storeys (5th Storey) even for flexible and rigid systems (gravity governs).

Due to the increase in the Time Period, there is a reduction in the Punching Shear, Bending Moments, Displacements and Drifts. The Rigid systems appear to be more acceleration sensitive in case of tall buildings. Due to the absence of Shear walls at the periphery and the increase in depth of slab in terms of Panel Drops as observed in FSD1 & FSD2, the moments attracted by the panel drops at the periphery is of a higher order which is not the case in Flat Plate systems. However this magnitude of moments affects the punching shear values marginally less in flexible system without panel drops.

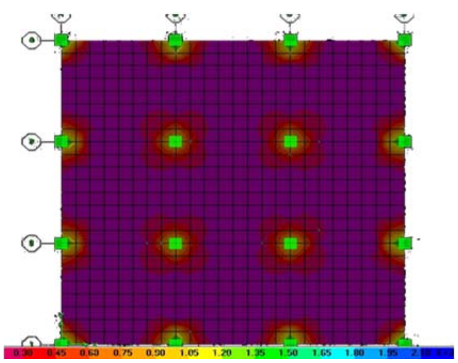

Fig. 9: Typical Punching Shear Contour for FP1-5 Storey.

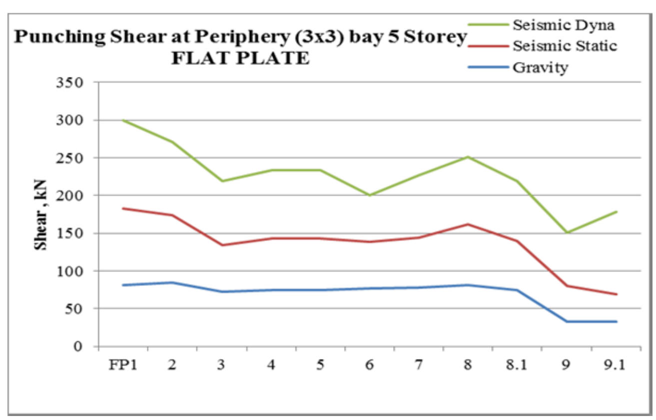

Fig. 10: Variation of Punching Shear Stress at the periphery for 3x3 Bay 5-Storey Flat Plate systems.

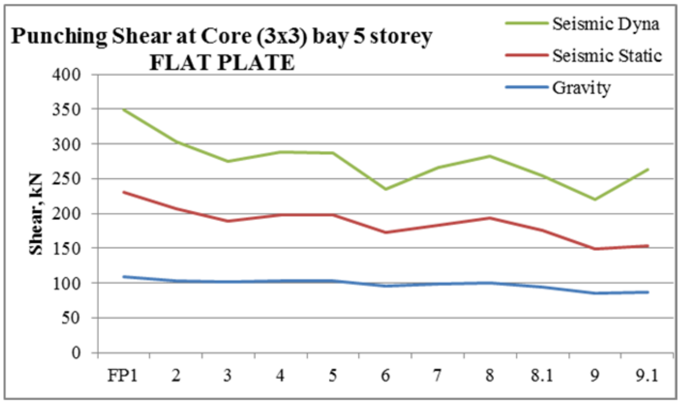

Fig. 11: Variation of Punching Shear Stress at the core for 3x3 Bay 5-Storey Flat Plate systems

4.5. Inter Storey Drift

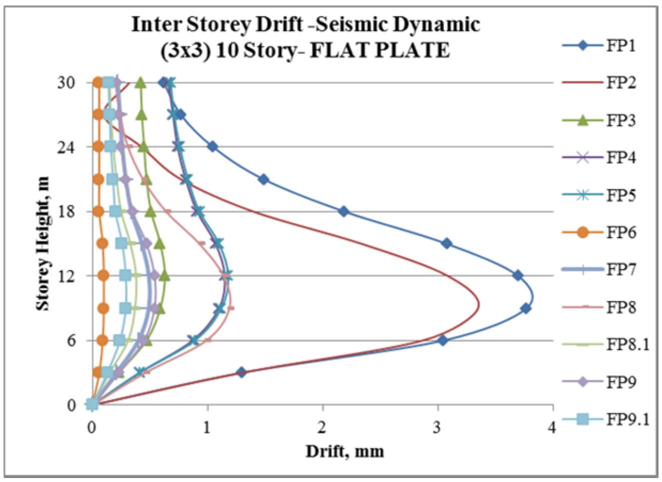

Fig.12: Variation of Inter Storey Drifts in Seismic Dynamic Case for 3x3 Bay 10-Storey Flat Plates.

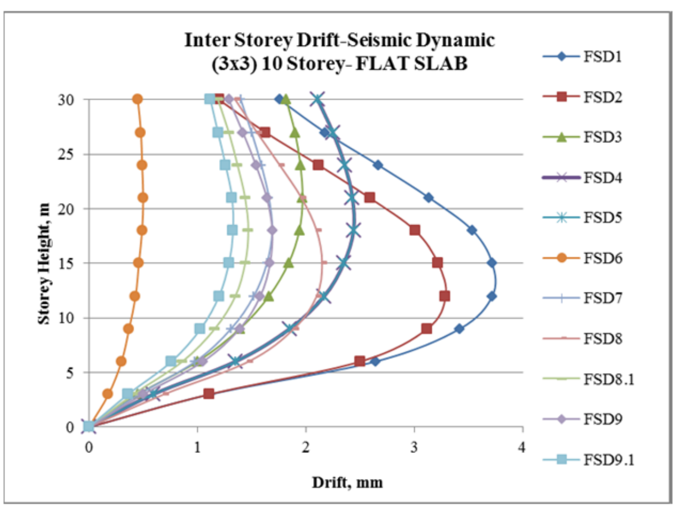

Fig. 13: Variation of Inter Storey Drifts in Seismic Dynamic Case for 3x3 Bay 10-Storey Flat Slabs.

The non- linearity involved in the inter storey drifts is found in the flexible systems without any Shear wall. has six degrees of freedom at each node, by restraining the normal translation and bending rotations the shell acts as a membrane and when the in plane translations and the bending about the normal are restrained the shell acts as a plate element.

5. CONCLUSIONS

Flat Slabs with Panel Drops do significantly contribute for the diaphragm rigidity in flexible systems. Introduction of Panel Drops may not be effective in systems with Shear Walls to achieve diaphragm rigidity. Providing a perimeter Beam enhances the diaphragm action of both the systems. It also enhances the Punching Shear and Bending Performance of Slabs through a framed action.

The Span moments follow a similar trend for stiffer system. However both span moment and support moment exhibit an abnormal behaviour for flexible systems in Seismic dynamic case. This makes a Time history analysis a necessity for flexible Flat plates and Flat Slab systems.

The Short structures (5-Storeys) are observed to be highly sensitive to acceleration. Therefore a stiffer system with ductile detailing may be preferred for near field ground motion. Thus Shear walls along with ductile detailing become an essential part of Flat Slab system subjected to near field ground motions. Providing a Shear wall at Core proves to be more detrimental in all aspects; acceleration, velocity and displacement for short structures.

The Displacement control is an important part of design for any structural system. A Beamless structural system with Columns only shall not be preferred in a Zone of high Seismicity as it shall result in excessive displacements and Inter storey drifts. Therefore Shear walls become an integral part of a design for displacement control.

Providing Shear walls in higher proportion makes the system acceleration sensitive which means ductile detailing should be a part of design. The systems with intermediate rigidity are found to be sensitive to velocity even in tall structures thus bringing a scope for external dampers.

For Near field motion the acceleration sensitive system should be adopted with ductile detailing and the Shear walls at the periphery accompanied by the Shear walls at the Core. For Far field motions displacement control becomes critical and hence system should be provided with Shear walls for displacement control and partially rigid systems with External Dampers can be explored to reduce the seismic response.

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