International Journal of Research in Engineering, Science and Management
Volume-1, Issue-6, June 2018
www.ijresm.com

Effect of Shear Wall with Flat Slab by Dynamic and Non-Linear Pushover Analysis

Karthik A. S[1], Vidya. V[2]

[1]*P. G. Student, Department of Civil Engineering, Global Academy of Technology, Bangalore, India*
[2]*Assistant Professor, Department of Civil Engineering, Global Academy of Technology, Bangalore, India*

***Abstract*—Flat slab is mostly used system to avoid the beam-column clogging, and it is very economical. Flat slabs directly transfer the loads to columns without beams. But flat slabs are not efficient in transfer the lateral loads. Punching shear strength around the column-slab connections always possess a problem. Earthquake disaster had always been one of the great natural calamities upon the mankind bringing in hardship to the people affected. Simplified approaches for the seismic evaluation of structures, which account for the inelastic behavior, generally use the results of static collapse analysis to define the global inelastic performance of the structure. Currently, for this purpose, the nonlinear static procedure (NSP) which is described in ATC-40 (Applied Technology Council, 1996) documents are used. A Regular RCC model along with Flat slab model with and without shear wall and perimeter beams are analyzed for the existing earthquake data using dynamic time history analysis and non-linear static method (Pushover). Key results are extracted like displacements, Base shear, acceleration, and time period. And pattern of hinge formations, performance points using pushover analysis. It was found that FSS with shear wall and perimeter beams offered certain resistance towards earthquake loads when compared with all other structural systems. From the pushover analysis results obtained it can be concluded that, flat slab structure with the provision of perimeter beams shows well performance in static non-linear case. Further with the introduction of shear wall in FSS additional control of displacements are observed, but the effect of perimeter beams is found to be less.**

Index Terms—flat slab, pushover analysis, time history analysis.

I. Introduction

Flat Slab construction is widely used in residential, office and industrial buildings. The main advantage of this construction is the faster construction compared to mushroom and ribbed slabs. Generally, slabs are supported by beams & these beams are supported by columns. Beam reduces available net clear ceiling height. Sometimes beams are avoided and slabs are directly supported by columns. This type of construction provides aesthetical appearance also. Those slabs which are directly supported by columns are called as flat slabs. Flat slab also referred as beamless slab, it is the directly connected by columns without beams. Due to the advantages of flat slabs over other reinforced concrete floor system engineers are mostly used in construction works. The main disadvantages of flat slab systems are; they are not suitable for supporting brittle (masonry) partitions, higher slab thickness, Chance for progressive collapse is more in flat slab due to the punching shear failure, in flat slabs the middle strip deflection may be critical. Flat slabs are not efficient in transferring the lateral loads, cutting stresses around the column and plate joints are always a problem. Shear punching is a type of failure of RC slabs subjected to high localized forces. When the shear strength exceeds the shear strength of the plank, the slab will be pushed down the column and will be called as punching of flat slab due to shear. This causes the column to break through the part of the surrounding slabs.

As a solution of seismic load resistance, time and cost-effective construction shear walls are most effective method. Seismic tremors had dependably been one of the considerable regular disasters trust on humankind since time age-old. Indian sub-continent been knowledgeable about the absolute most serious tremor on the planet. Streamlined methodologies for the earthquake assessment of structures, that represent inelastic conduct, by and large utilize the consequences of static collapse investigation to characterize worldwide inelastic behaviour of structure.

II. Literature Review

Lan N Robertson (1997) done analysis of flat slab structures subjected to combined lateral and gravity loads. This study reviews two structural analysis models and compares them to experimental test results. A two-beam analytical model more accurately predicts the test results with respect to slab moment distribution and lateral drift. Three-dimensional analysis done by ETABS computer program. These models assume a uniform slab effective width coefficient and constant cracking factor for an entire span. The analytical models were unable to reproduce the slab flexural moment distribution observed in test specimen at either 0.5 or 1.5 % drift levels.

Navyashree K (2014) introduced use of FS in multi- storey commercial building situated in high seismic zone. The proposed work compared the behavior of multistory commercial buildings having 2-way slabs with beams & with that of having conventional RC frame and flat slabs, then studied the effect of height of the building. Modeling and analysis are done by ETABS V. For the analysis and design total six models were considered. Three building heights (G+3, G+8, and G+ 12) were considered. Base shear of flat slab building less than RC building. Lateral displacement maximum obtained at terrace level. As storey level increases lateral displacement also increases. Lateral displacement higher in flat plate building. Time period higher for flat slab building compared to conventional building. As height increases storey drift drastically increases. Storey drifts more in flat slab building.

M K Devtale (2016) compared the seismic response between flat slab building and regular frame building. Seismic behavior of flat slab building has been carried out in the present study. Regular framed structure building and linear analysis of flat slab building has been carried out for this purpose. Analysis is carried out using SAP 2000 by the method of equivalent lateral force analysis. After the analysis it is concluded that regular frame building performed better than flat slab building with use of shear wall, the performance of flat slab building improves much more.

M. D. Rizwan (2016) has completed a comparative study of linear and nonlinear seismic response of RC structure in diff seismic zones of India. For the analysis soft soil, medium soil and hard soil were considered. Modelling and analysis carried out by using ETABS V 9.7.4. Equivalent static and push over methods are used to study the seismic behaviour. Base shear, displacement and storey drift were studied in both methods. After the analysis it is observed that the lateral deformation capacity is increasing, the symmetry of the structure decreasing. From bottom to middle storey, and from middle storey it gradually decreasing to top storey. In loose soil building shows less performance.

III. Modelling and Analysis

The modelling of the G+10 storey building is done using SAP 2000 software. This building is modelled with RCC structural elements. Here are the types of model shown for the easy assessment.

1. Model 1 – Regular building -RCC
2. Model 2 – Flat slab building
3. Model 3 – Flat slab building with perimeter beam.
4. Model 4 – Flat slab with shear wall.
5. Model 5 – Flat slab with shear wall and perimeter beam.

A. Defining Material Properties

The material property is an important aspect to be defined while modelling a structure. Both the steel and concrete are having some property, which has to be specified as listed below:

Young's modulus (Steel), Es = 2, 10,000 MPa
Young's modulus (concrete), EC = 27386 MPa
Compressive strength of concrete, Fck= 30 MPa
Yield stress for reinforcing steel, Fy = 500 MPa

B. Defining Frame Sections

The beam and column form the frame. The frame members have to be defined, as listed below in Fig. 1.

C. Defining Loads

The different types of loads are defined under this option, here we can define,

1. Dead load
2. Live Load
3. Super dead Load
4. Glazing Load

Further the load combinations are automatically generated in the SAP2000.

1) 1.5 (DL+LL)
2) 1.2 (DL+LL+EL)
3) 1.5 (DL+EL)
4) 0.9DL * 1.5EL

D. Dynamic Time History Analysis.

For the dynamic time history analysis BHUJ and ELCENTRO time history data was chosen and are defined in SAP 2000 as below.

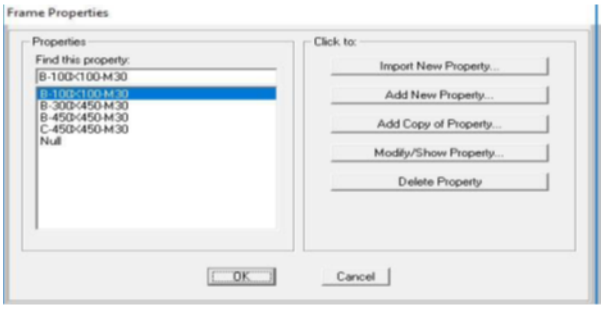

Fig. 1. Frame property

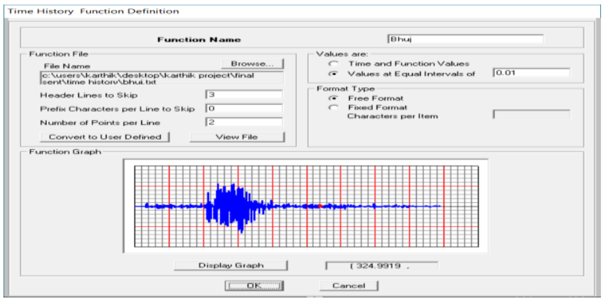

Fig. 2. BHUJ Time History data

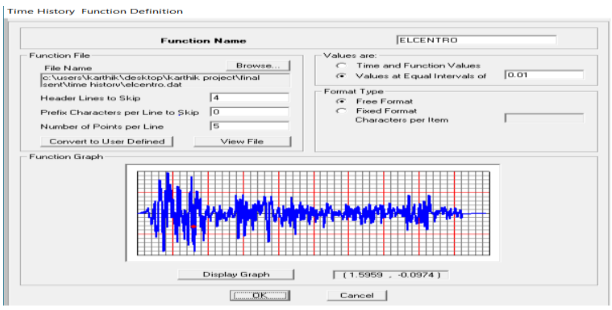

Fig. 3. EL CENTRO Time History data

International Journal of Research in Engineering, Science and Management
Volume-1, Issue-6, June 2018
www.ijresm.com

E. Building Information

TABLE I
DESIGN DATA FOR THE EXAMPLE BUILDINGS

Structure		RCC Structure.
No. of storey		G+10 Storey.
Storey height	First storey	3.0 m
	Upper storey	3.0 m
Type of building		Commercial
Foundation type		Fixed base
Assumed dead load intensities		
Roof finishes		1.50 KN/m^2
Floor finishes		1.50 KN/m^2
Live load intensities		
Roof		4.0 KN/m^2
Floor		4.0 KN/m^2

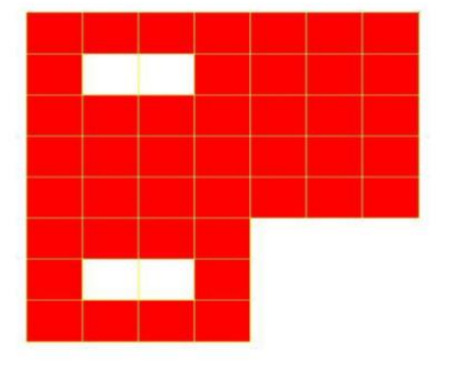

Fig. 4. EL CENTRO Time History data

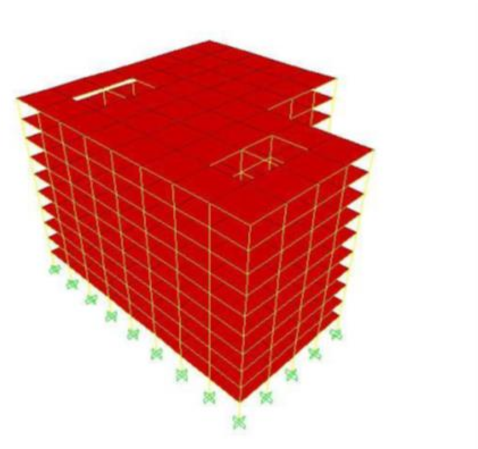

Fig. 5. 3D View

The standard models are prepared. The similar models are created based on the different type of shear wall and flat slab arrangement.

IV. RESULTS

Results from Time history analysis for ELCENTRO and BHUJ are extracted and important results like peak acceleration, displacements, and base force are presented in the form of response plots graphs.

A. Dynamic Time History Analysis: (ELCENTRO EQ)

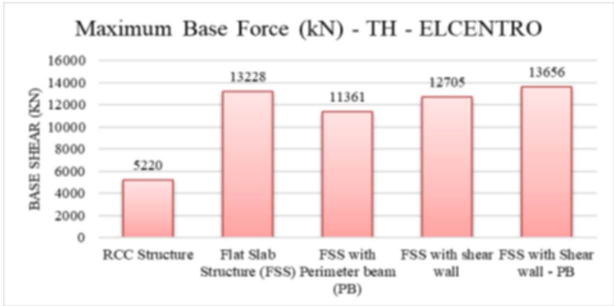

Fig. 6. Maximum base shear – X Dir.

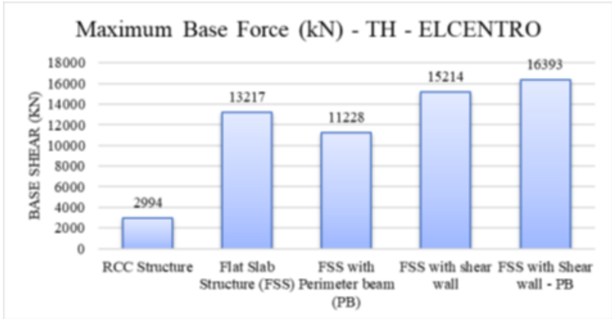

Fig. 7. Maximum base shear – Y Dir.

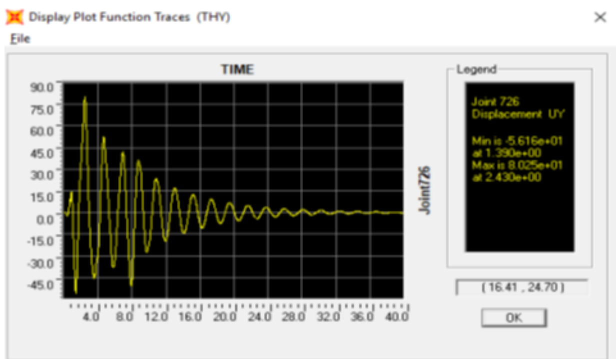

Fig. 8. Peak Displacement response – RCC – Y Dir.

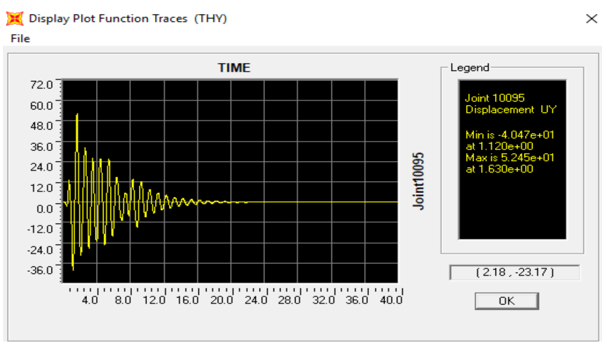

Fig. 9. Peak Displacement response – Flat Slab Structure (FSS) – Y Dir.

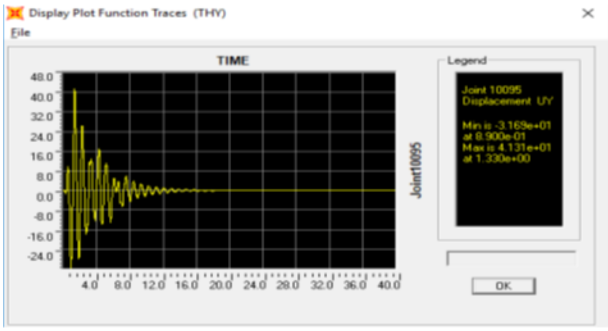

Fig. 10. Peak Displacement response – FSS with Perimeter beam (PB) – Y Dir.

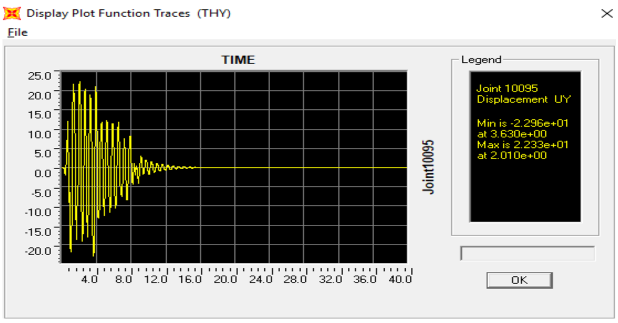

Fig. 11. Peak Displacement response – FSS with shear wall – Y Dir.

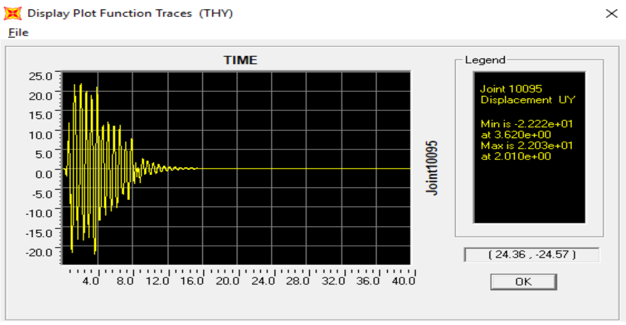

Fig. 12. Peak Displacement response – FSS with shear wall and PB – Y Dir.

The below Table-2, is the summary of the maximum base force, peak acceleration and peak displacements.

TABLE II
TIME HISTORY RESPONSE SUMMARY CHART – EL CENTRO

Models	Base Force (kN)		Peak Acceleration (m/s^2)		Peak Displacements (mm)	
	X - Dir	Y - Dir	X - Dir	Y - Dir	X - Dir	Y - Dir
RCC Structure	5220	2994	4.05	4.29	53.8	80.25
Flat Slab Structure (FSS)	13228	13217	6.20	6.17	52.8	52.45
FSS with Perimeter beam (PB)	11361	11228	4.72	4.88	41.7	41.31
Flat Slab with shear wall	12705	15214	6.63	6.79	12.0	22.96
FSS with Shear wall - PB	13656	16393	6.56	6.51	11.5	22.22

From Table-2, it can be observed that, the maximum base force is found to be flat slab with shear wall consisting of perimeter beams along both X and Y directions. FSS with shear wall and PB has base force 3.13% and 19.3% greater than that of flat slab structure.

Peak acceleration is found to be maximum in Flat slab with shear wall along both X and Y direction i.e., 6.63 N/mm^2 and 6.79 N/mm^2 respectively and it is found that, about 78% and 58% reduction in peak displacements in FSS with shear wall and perimeter beam.

B. Dynamic Time History Analysis: (BHUJ EQ)

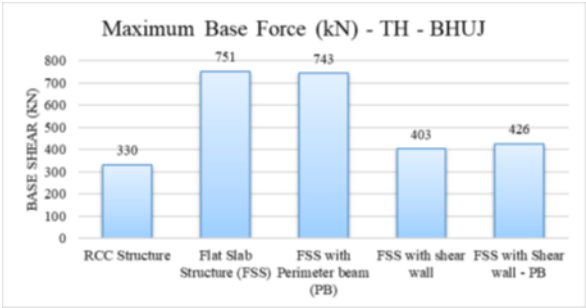

Fig. 13. Maximum base shear – X Dir.

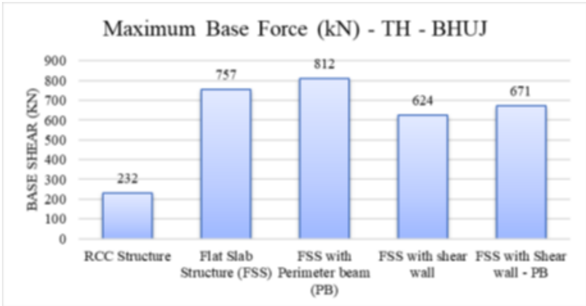

Fig. 14. Maximum base shear – Y Dir.

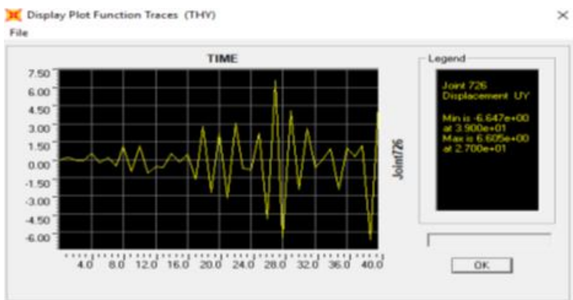

Fig. 15. Peak displacement response – RCC – Y Dir.

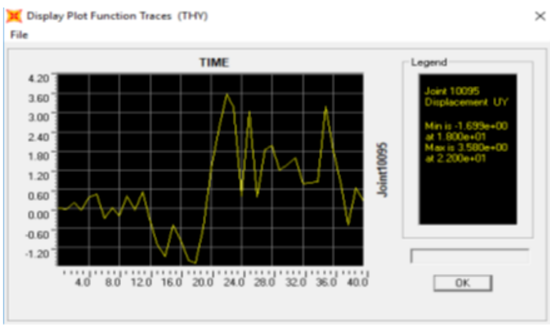

Fig. 16. Peak displacement response – Flat Slab Structure (FSS) – Y Dir.

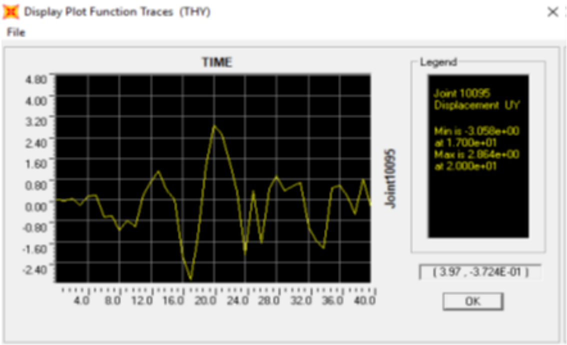

Fig. 17. Peak displacement response-FSS with Perimeter beam (PB) -Y Dir.

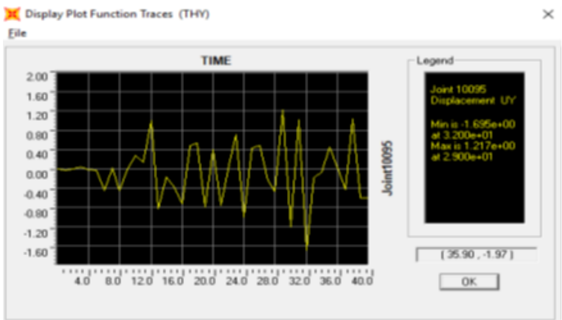

Fig. 18. Peak displacement response – FSS with shear wall– Y Dir.

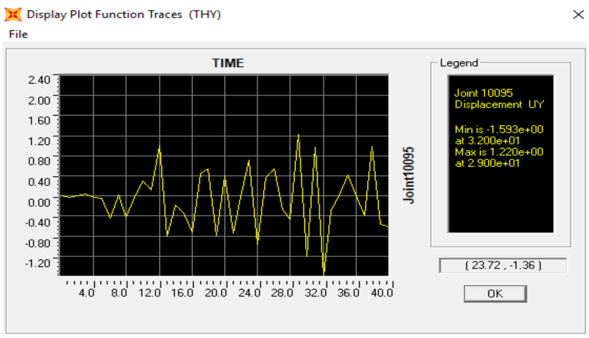

Fig. 19. Peak displacement response-FSS with shear wall and PB-Y Dir.

The below Table-3, is the summary of the maximum base force, peak acceleration and peak displacements.

TABLE III
TIME HISTORY RESPONSE SUMMARY CHART -BHUJ

Models	Base Force (kN)		Peak Acceleration (mm/s^2)		Peak Displacements (mm)	
	X - Dir	Y - Dir	X - Dir	Y - Dir	X - Dir	Y - Dir
RCC Structure	330	232	62.38	62.02	4.83	6.64
Flat Slab Structure (FSS)	751	757	208.1	208.4	3.65	3.58
FSS with Perimeter beam (PB)	743	812	211.0	195.1	2.99	3.05
Flat Slab with shear wall	403	624	168.9	300.5	0.30	1.69
FSS with Shear wall - PB	426	671	173	290.7	0.32	1.59

C. Performance Point

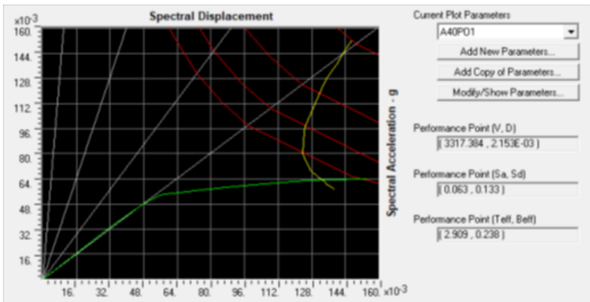

Fig. 20. Performance point-RCC-Y Dir.

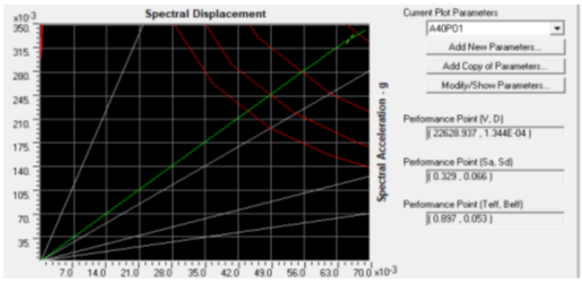

Fig. 21. Performance point-FSS-Y Dir.

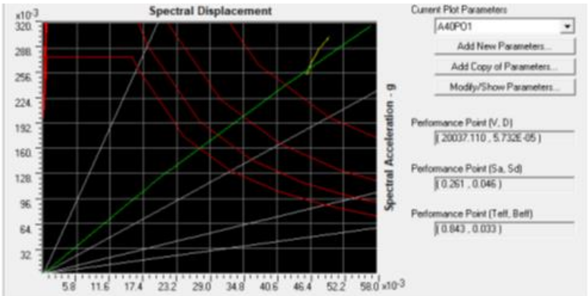

Fig. 22. Performance point-FSS-Y Dir.

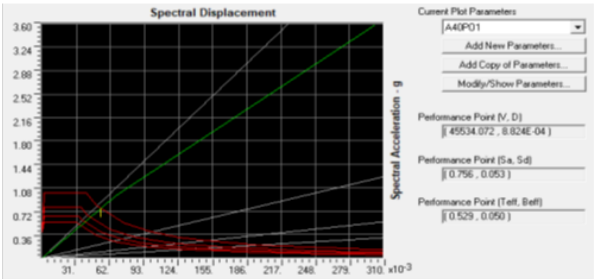

Fig. 23. Performance point-FSS-SW-Y Dir.

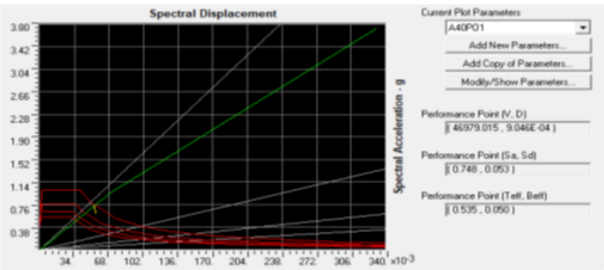

Fig. 24. Performance point-FSS-SW-PB-Y Dir.

TABLE IV
PERFORMANCE POINT SUMMARY RESULTS

Models	Base Force (KN) at Performance point		Time Period at Performance point		Displacements at performance point	
	X - Dir	Y - Dir	X - Dir	Y - Dir	X - Dir	Y - Dir
RCC Structure	3874	3317	2.33	2.90	105	133
Flat Slab Structure (FSS)	22618	22628	0.89	0.89	66	66
FSS with Perimeter beam (PB)	21417	20037	0.83	0.84	49	46
Flat Slab with shear wall	57175	45534	0.35	0.53	31	53
FSS with Shear wall - PB	59659	46979	0.36	0.53	32	53

From the pushover summary results, it can be observed that, base force is found to almost same for flat slab with shear wall with and without perimeter beam, also time period and displacements at performance point. Time period is found to be 60% less than that of FSS along X direction and displacement is about 51% less than that of FSS along X direction, in comparison with FSS with shear wall and perimeter beams.

D. Plastic Hinge Formation Results

The possible failure mode and its location that a structure would come under during earthquake has to be identified and analyzed in pushover analysis. The hinge location at performance point step for FSS with shear wall and perimeter beam is shown below.

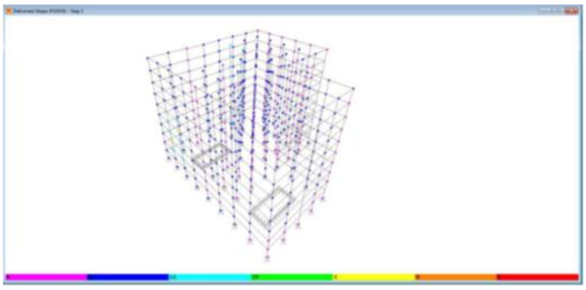

Fig. 25. Hinge formation for FSS with shear wall and perimeter beam in X direction

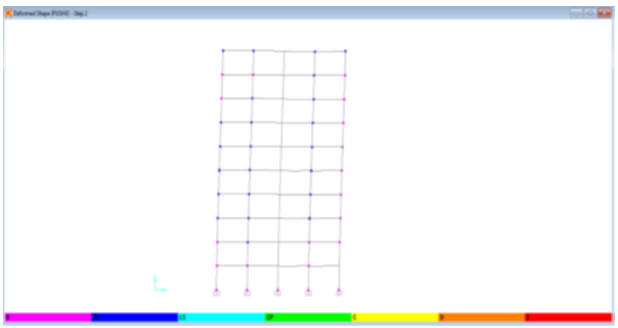

Fig. 26. Hinge formation for FSS with shear wall and perimeter beam in XZ plane

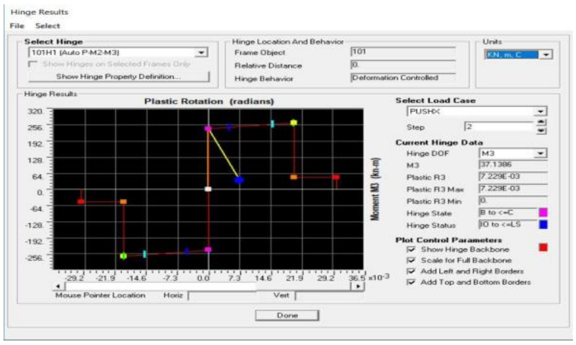

Fig. 27. Plastic Hinge formation for element 101 in FSS with shear wall and perimeter beam in X direction.

The Fig. 26 shows the formation of hinges at performance point with a base shear of 59659 KN for FSS with Shear wall & PB. Also, the Fig. 27 shows the plastic hinge formation for frame object 101. It can be seen that the hinge is formed with in immediate occupancy (IO) and life safety (LS) limit and hence it can be inferred that the members are safe within the prescribed limits.

V. CONCLUSION

From dynamic time history and pushover analysis following conclusions are made.

1) Form dynamic time history analysis it can be concluded that, there responses characteristics depends on the location of structure and intensity of the earth quake.
2) Peak acceleration is found to more to be more in case of FSS with shear walls this concludes that, flat slab structure with shear walls has more stiffness compare to conventional RCC and flat slab structure without shear walls.
3) From the peak displacement results it can be concluded that, the utilization of perimeter beams in flat slab structure with shear wall will provide additional stiffness hence better performance can be achieved in reducing the displacements during strong earthquake.
4) From the pushover analysis results it can be concluded that, shear wall with the provision of perimeter beams shows well performance in static non-linear case.
5) The formation of plastic hinge is well within IO & LS for FSS with shear wall and PB.
6) Hence form the present study, FSS with shear wall and perimeter beam is considered as the suitable structural system. A conclusion section is not required. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

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