

# *Seismic Performance Enhancement of Geometrically Irregular Buildings Using Shear Walls*

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**Abstract**—In the new global economic year people are suffering from the scarcity of land for construction of house as a result of this the number of multistorey buildings are increasing day by day. As the high rise buildings were mostly affected by seismic forces the construction of these high raised buildings needs greater care. Pushover analysis is a non linear static analysis in which the seismic performance of the building can be found out.

In this paper a ten storey building having same plan area as 1,600 sq. meter with different shapes in plan was considered. Three different plan of the building modelled were square shape, H shape and T shape. The result after performing the pushover analysis was compared for performance curve, capacity curve, performance level etc. Then the H shape and T shape buildings were redesigned by providing shear wall. Thus the improved performance of the building were compared for pushover curve, capacity curve, performance level.

The result obtained from the pushover curve plots nature of the building. The Capacity curve shows the Performance point of the building under the load applied. The storey drift curve shows the Performance level of the building. Thus the building with geometric irregularity are provided with shear wall to carry more seismic loads. Shear walls provide large strength and stiffness to buildings in the direction of their orientation and thus increases resistance of the building to twisting. Shear walls in buildings must be symmetrically located in plan to reduce ill-effects of twist in buildings

**Keywords**—Building; performance point; plastic hinge; pushover analysis; seismic performance

## I. INTRODUCTION

The increase in the number of population in India leads to the increase in the number of multi-storey buildings. The buildings in urban area are more damaged during earthquake compared to that of rural area as the number of high-rise building in urban area are more than that of rural area and these high-rise buildings are mostly affected to seismic forces. To built structures in seismically more

venerable area engineering tools need to be sharpened. The pushover analysis in SAP2000 is a powerful tool to check the seismic performance of multi-storey building by evaluating the damage to structural and non structural elements caused by ground shaking. To know the behavior of the building under the earthquake the load versus deformation curve of the building is required.

The result obtained from pushover analysis gives the graphical representation of base shear versus roof displacement and the capacity curve of the building. The actual performance of the building may be varying from the calculated linear analysis. The non linear static analysis used by structural engineers is generally the pushover analysis described in FEMA-356 (Federal Emergency Management Agency-356) [4] and ATC 40 (Applied Technology Council document 40) [1]. The buildings with geometrical irregularity with and without shear wall is compared.

## PUSHOVER ANALYSIS OF STRUCTURES

### A. Pushover analysis

Pushover analysis is a non linear static 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. Pushover analysis consists of a sequential elastic analyses, superimposed to approximate force displacement curve of the overall structure. The two dimensional or three dimensional model which consist of the bilinear or tri-linear load-deformation diagrams of all the lateral force resisting elements are created first, then the gravity loads are applied. Then a lateral load pattern which is predefined is distributed along the height of the building. These lateral forces are increased until some members yield. [11]

The structural model is changed for the reduced stiffness of the yielded members and then the lateral forces are increased again until the additional members yield. The process is continued until the top of building reaches a controlled displacement or a certain level of deformation or as the structure becomes unstable. The result obtained gives the roof displacement with base shear thus the global capacity curve is obtained as shown in Figure.1. [5]

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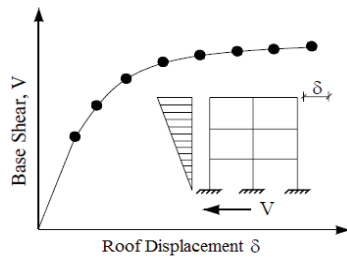


Figure 1 Pushover Curve of a Structure <sup>[2]</sup>

### B. Performance based earthquake engineering

Performance based earthquake engineering is very important in the field of civil engineering. It implies the structural design, construction of structure, monitoring the function and maintenance of engineered structures in which the performance under seismic loads responds to the diverse needs and objectives of society and users. It is based on the premise that performance can be predicted and evaluated, together with the client, life-cycle considerations rather than construction cost of the buildings alone.

Performance based earthquake engineering consist of complex scientific perception and analytical modeling which is involved in seismic hazard estimation and evaluation. A computational scheme involves steps like delineation of seismic source zones, their characterization, selection of an appropriate ground motion acceleration, attenuation relation and a predictive model of the earthquake hazards. The above steps are specific for particular regions. The standardization of the structural model is highly essential so that a reasonably comparable estimate of earthquake hazard can be made worldwide, which can be used across the regional boundaries.

## II. SEISMIC PERFORMANCE

The buildings performance under earthquake is measured by the state of damage. The state of damage is measured in terms of base shear versus roof displacement. The gravity push is carried out using force control method. It is followed by lateral push with displacement control.

The frame used in the pushover analysis is based on the type or grade of the material, defining forces in structure, deformation criteria for the hinges used in the pushover analysis. Pushover analysis gives an insight into the maximum base shear whether the structure is capable of resisting the seismic loads.

Buildings performance level is the combination of the performance levels of the structural and the nonstructural components. The performance level of the building gives the limiting damage condition which may be considered satisfactory for a given building with specific ground acceleration. The performances levels as per FEMA, ATC 40 are shown in Figure 2 Each particular point in the graph gives an idea about the performance of the building under pushover analysis.

**Immediate occupancy IO:** Damage is relatively limited; the structure can retains a significant portion of its original stiffness and most if not all of its strength.

**Life safety level LS:** Substantial damage has occurred to the structure, and it may have lost a significant amount of its original stiffness. However, a substantial margin remains for additional lateral deformation before collapse would occur.

**Collapse prevention CP:** At this level the building has experienced extreme damage, if laterally deformed beyond this point; the structure can experience instability and collapse. <sup>[11]</sup>

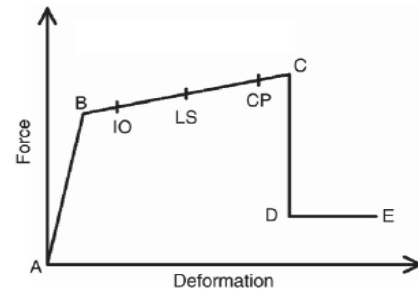


Figure 2 Force deformation curve <sup>[2]</sup>

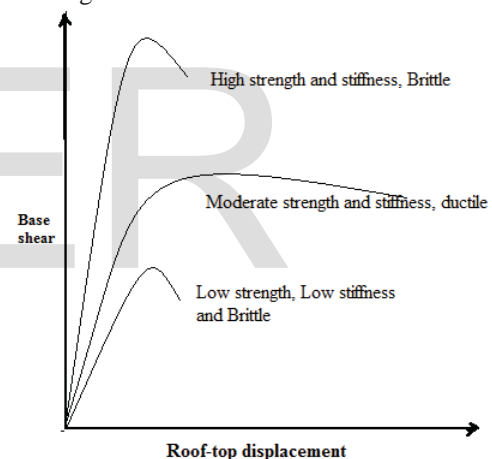


Figure 3 Roof displacement Vs acceleration

The roof displacement graph obtaining as shown in Figure 3 which describes the nature of the building whether the building has high strength, moderate strength or low strength and the behavior of the building whether brittle or ductile

Capacity-Spectrum Method of ATC-40 <sup>[1]</sup>, begins first with the generation of a force-deformation relationship for the structure. Then the results are plotted in Acceleration-Displacement Response Spectrum (ADRS) format as shown in Figure 4. This format is a simple conversion of the base shear versus roof displacement relationship using the dynamic properties of the system, and the result is termed as the capacity spectrum of the structure. The seismic ground motion specified for present study is also converted to Acceleration-Displacement Response Spectrum (ADRS) format, and the result is termed an Elastic Demand spectrum of the structure.

The elastic demand spectrum is modified to get inelastic demand spectrum by a procedure of effective damping to present the inelastic structural behavior under a specific ground motion. The damping includes the inherent damping in the structure and equivalent viscous damping taking into account for the energy dissipation of the hysteretic behavior of

the structure. The intersection of capacity spectrum and inelastic demand spectrum shown in Figure 4 is named as performance point, [5] Table 1 presents deformation limits for various performance levels. Maximum total drift is defined as the inter-story drift at the performance point displacement. Maximum inelastic drift is defined as the portion of the maximum total drift beyond the effective yield point. For Structural Stability, the maximum total drift in story  $i$  at the performance point should not exceed the quantity  $0.33(V_i/P_i)$  where  $V_i$  is the calculated lateral shear force in story  $i$  and  $P_i$  is the total gravity load (dead plus likely live load) at story  $i$ . The performance level of the building is shown in Table 1, [1].

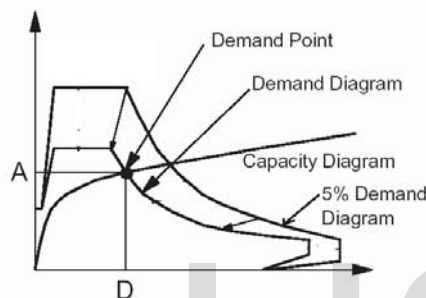


Figure 4 Capacity Curve

Table 1. Performance Level

	Performance level			
Inter storey Drift limit	Immediate occupancy	Damage control	Life safety	Structural stability
Maximum total drift	0.01	0.01-0.02	0.02	$0.33(V_i/P_i)$
Maximum inelastic drift	0.005	0.005-0.015	No limit	No limit

### III. CASE STUDY OF THE BUILDING

The present study is to evaluate the behavior of G+9 floor reinforced concrete structure subjected to earthquake force. The building is located in zone 3. The building is analyzed by non linear static analysis or pushover analysis.

#### A. Building Description

The building described here is a ten story reinforced buildings for residential use. The building has a plan area of 1,600 sq. meter. Different shapes for plan are selected like Square shape building, H shape building, T shape building etc according to IS 1893(Part 1) :2000 [9]. The floor height of the building is 3 meter. The Column size is 700mm X 220mm, and Beam size is 550mm X 220 mm. The material used are M 20 concrete, Fe 415 steel and the building is assumed to be located in zone III, soil type 2. The building is designed according to Indian Standard codes IS 456:2000 [10]. The loads considered are applied in X and Y directions. Figure 5 shows building with Square shape building, Figure 6 shows building with H shape and Figure 7 shows a building with T shape. The same building with shear wall provided are shown in figure 7 shows H shape building with shear wall and T shape building with shear wall. Shear wall are provided to increase the seismic

performance of the building. Shear walls are modelled by Mid-Pier Frame with plastic hinges defined according to FEMA 356. Mid-Pier is modelled as a frame element with the shear wall cross sectional parameters. Thickness of the rectangular rigid beam section can be considered the same as the wall itself. The plastic P-M-M hinge is defined according FEMA 356 with the given rebar distribution. The axial force level is considered for a combination of dead and live loads.

#### B. Modeling of the building

The structure considered here is a reinforced concrete framed structure which is capable of taking the stress produced by the lateral forces. For irregular building the geometry is changed by providing re-entrant corners, as per the IS 1893:2002 ( part-1) [9]. The beam and column is modeled as nonlinear framed element with lumped plasticity by defining plastic hinges to both beam and column ends. The analysis is done using SAP2000.

#### C. Comparison of the building

First the seismic performance of Square shape building, H shape building and T shape building are compared and from the result the building with geometric irregularity have less seismic performance the building with H shape and T shape are provided with shear wall and the improvement in seismic performance of the building is find out by comparing each building with and without shear wall.

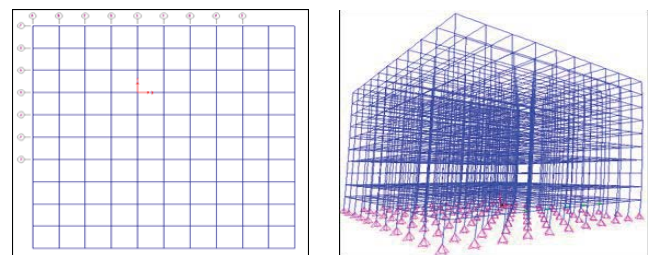


Figure 5 Square shape building

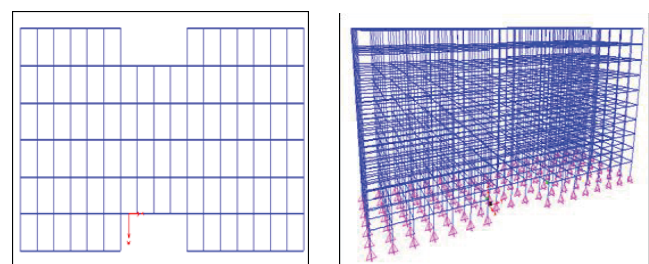


Figure 6 H shape building

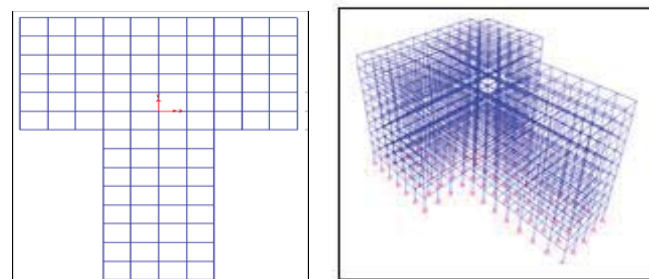


Figure 7 T shape building

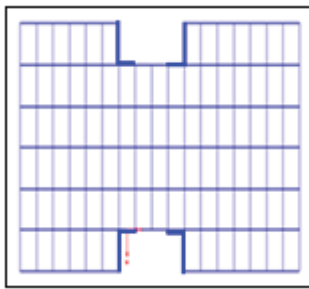


Figure 8 H shape building

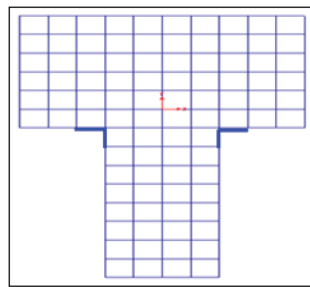


Figure 9 H shape building

#### IV. RESULT

After performing the pushover analysis the pushover curve for the building obtained was plotted in figure 10. The curve is initially linear but starts to deviate from linearity as the beams and columns undergo inelastic action. When the building is pushed into the inelastic range, the curve become linear again but with a smaller slope. thus the building has moderate strength and stiffness and is ductile in nature. All the three buildings perform in a similar way to pushover analysis.

The performance level of the three Square shape, H shape and T shape buildings are shown in Figure 11. From the figure we can infer that the storey drift of square shape and T shape building is within 0.01 to 0.02 thus the performance level of the building is between Life safety and Immediate occupancy which means moderately light damage has occurred to the structure, thus it may lose a significant amount of its original stiffness. However, a substantial margin remains for additional lateral deformation before collapse would occur.

Plastic hinge formation for the buildings has been obtained at different levels. The plastic hinge formation first take place at beam ends then moves to the lower floor columns propagates to the upper storey then to the intermediate columns thus the damage is moderate and is under control. But the performance of H shape building is above 0.02 so the performance level is above immediate occupancy. The performance point of H shaped building is between life safety and collapse prevention level thus the damage is severe, building is near collapse and the structure face extensive damages.

By providing shear wall the performance point and performance of the building has been improve. Figure 12 shows the performance of H shape building after shear wall is provided the base shear value of H shape building is increased while shear wall is provided. The performance of T shape building has also improved by providing shear wall. Table 3 shows the performance points of H shape and T shape buildings with and without shear wall.

From the Figure 14 we can see that while providing shear wall the performance level of the building is between 0.01 and 0.02 thus the performance level of the building has improved and the damage to the building is less and are under control.

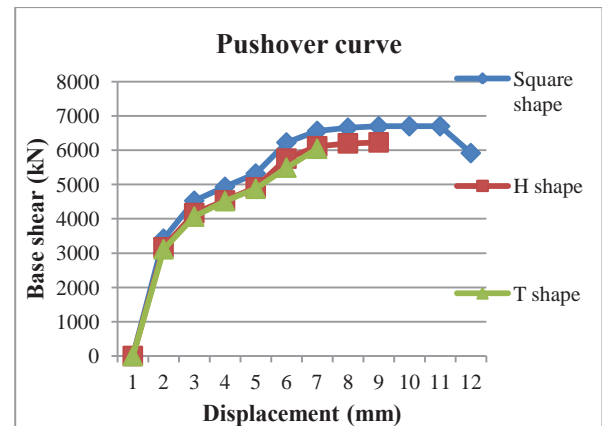


Figure 10 Pushover curve

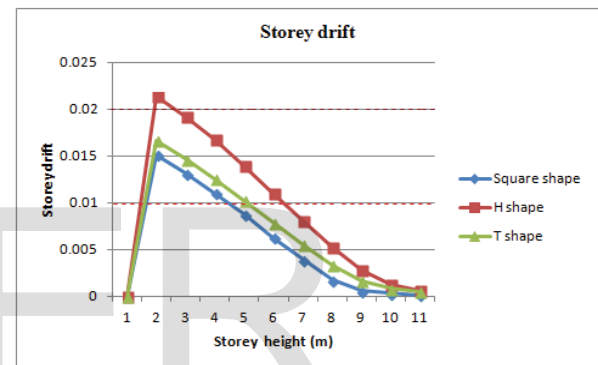


Figure 11 Performance level

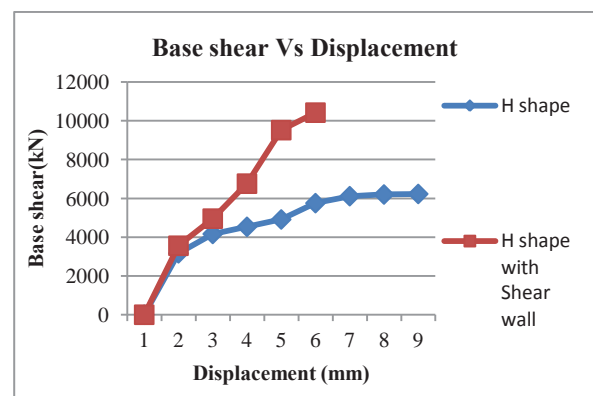


Figure 12 Pushover curve for H shape building

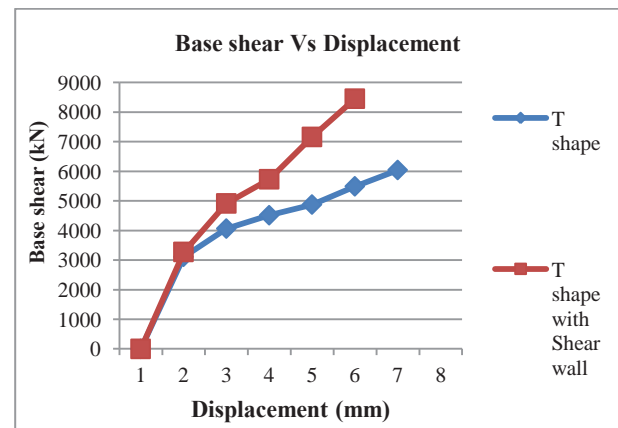


Figure 13 Pushover curve for T shape building



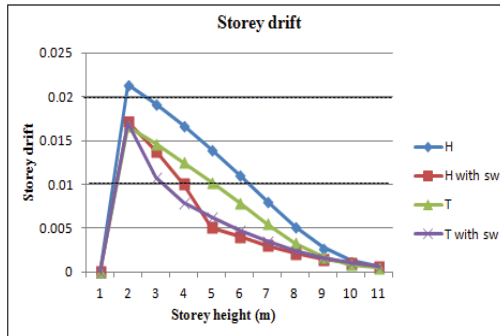


Figure 14 Performance level of H and T shape building

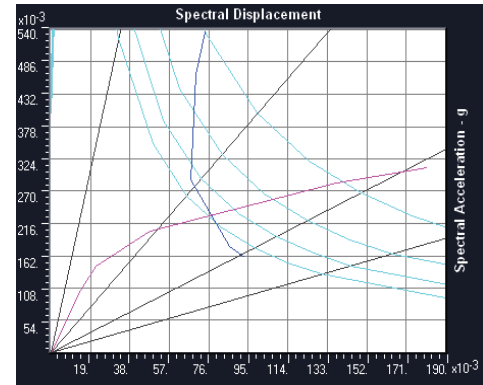


Figure 18 capacity curve of H shape building with shear wall

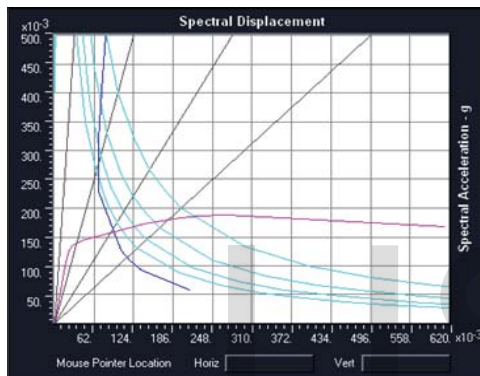


Figure 15 capacity curve of Square shape building

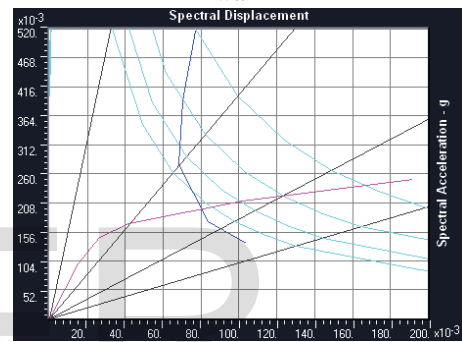


Figure 19 capacity curve of T shape building with shear wall

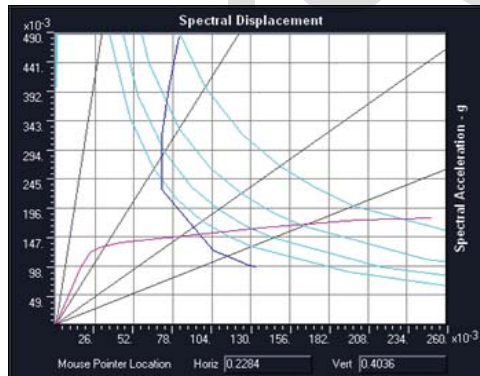


Figure 16 capacity curve of H shape building without shear wall

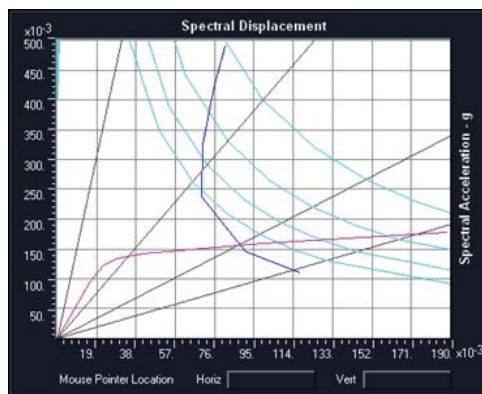


Fig.17: capacity curve of T shape building without shear wall

Table 2 Performance point

Performance Point					
Square Shape		H Shape		T Shape	
$V_{BP}$	$\delta_{roof}$	$V_{BP}$	$\delta_{roof}$	$V_{BP}$	$\delta_{roof}$
5685.566	0.099	5304.923	0.102	5350.996	0.100

Table 3 Performance point

Performance Point		
Model No.	$V_{BP}$	$\delta_{roof}$
H shape plan without shear wall	5304.923	0.102
H shape plan with shear wall	7532.823	0.121
T shape plan without shear wall	5350.996	0.100
T shape plan with shear wall	6575.770	0.062

The performance point which is the intersection of the demand curve and capacity curve of the buildings is shown above Figure 15 shows the capacity curve of square shape building, Figure 16 shows the capacity curve of H shape building without shear wall, Figure 17 shows the capacity curve of T shape building without shear wall, Figure 18 shows the capacity curve of H shape building with shear wall and Figure 19 shows the capacity curve of T shape building with shear wall.

Table 4 shows the hinge state details of square shape building, the Performance point of the building is between step 5 and 6 and the value is more similar to step 5. In step 5 all the hinge was formed between immediate occupancy and life safety and 93.5 percent was seen to be within immediate occupancy. Table 5 shows the hinge state details of an H

shape building. Performance point of the building is between step 4 and 5 and the value is more similar to step 5.

In step 5 all the hinge is formed between immediate occupancy and life safety and 85.4 percent is within immediate occupancy and Table 6 shows the hinge state details of the T shape building. Performance point of the building is between step 4 and 5 and the value is more similar to step 5. In step 5 all the hinge is formed between immediate occupancy and life safety and 89.5 percent hinge is within immediate occupancy. Table 7 shows the hinge states of H shape building with shear wall, performance point of the building is between step 3 and 4 and the value is more similar to step 3. In step 3 all the hinge is formed between immediate occupancy and life safety and 98 percent is within immediate.

Table 8 shows the building with T shape building with shear wall, Performance point of the building is between step 3 and 4 and the value is more similar to step 4. In step 4 all the hinge is formed between immediate occupancy and life safety and 99.2 percent is within immediate occupancy.

Table 4 Hinge state details of square shape building

Hinge state details								
A to B	B to IO	IO to LS	LS to CP	CP to C	C to D	D to E	Beyond E	Total hinge
6818	0	0	0	0	0	0	0	6818
6813	5	0	0	0	0	0	0	6818
6602	216	0	0	0	0	0	0	6818
6401	417	0	0	0	0	0	0	6818
6163	655	0	0	0	0	0	0	6818
5737	641	440	0	0	0	0	0	6818
5278	275	825	429	0	11	0	0	6818
5174	324	663	334	0	323	0	0	6818
5132	366	660	222	0	438	0	0	6818

Table 5 Hinge state details of H shape building

Hinge state details								
A to B	B to IO	IO to LS	LS to CP	CP to C	C to D	D to E	Beyond E	Total hinge
6660	0	0	0	0	0	0	0	6660
6658	2	0	0	0	0	0	0	6660
6411	249	0	0	0	0	0	0	6660
6198	462	0	0	0	0	0	0	6660
5894	716	50	0	0	0	0	0	6660
5270	423	967	0	0	0	0	0	6660
5161	275	816	232	0	176	0	0	6660
5069	367	613	278	0	333	0	0	6660
5030	406	612	204	0	408	0	0	6660

Table 6 Hinge state details of T shape building

Hinge state details								
A to B	B to IO	IO to LS	LS to CP	CP to C	C to D	D to E	Beyond E	Total hinge
6660	0	0	0	0	0	0	0	6660
6658	2	0	0	0	0	0	0	6660
6411	249	0	0	0	0	0	0	6660
6198	462	0	0	0	0	0	0	6660
5894	716	50	0	0	0	0	0	6660
5270	423	967	0	0	0	0	0	6660
5161	275	816	232	0	176	0	0	6660
5069	367	613	278	0	333	0	0	6660
5030	406	612	204	0	408	0	0	6660

Table 7 Hinge state details of H shape building with shear wall

Hinge state details								
A to B	B to IO	IO to LS	LS to CP	CP to C	C to D	D to E	After E	Total hinge
6660	0	0	0	0	0	0	0	6660
6657	3	0	0	0	0	0	0	6660
6463	197	0	0	0	0	0	0	6660
5906	627	127	0	0	0	0	0	6660
5166	636	799	59	0	0	0	0	6660
5033	561	847	142	0	77	0	0	6660

Table 8 Hinge state details of T shape building with shear wall

Hinge state details								
A to B	B to IO	IO to LS	LS to CP	CP to C	C to D	D to E	Beyond E	Total hinge
6500	0	0	0	0	0	0	0	6500
6497	3	0	0	0	0	0	0	6500
6156	344	0	0	0	0	0	0	6500
5800	649	51	0	0	0	0	0	6500
5208	630	662	0	0	0	0	0	6500
4899	466	805	247	0	83	0	0	6500

## V. CONCLUSION

From the above comparison it was concluded that,

1. The plan configurations of structure have significant impact on the seismic response of structure, in terms of displacement and Base shear. Shear walls provide large strength and stiffness to buildings in the direction of their orientation.
2. The pushover analysis is an effective tool to assess the seismic performance of the building.

3. Shear walls reduces lateral sway of the building and thereby reduces damage to structure and its contents.
4. The performance point of the buildings can be improved by providing shear wall.
5. The performance level of the building was between life safety and immediate occupancy thus the building face moderate damage and the damages occurred were repairable in nature.

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