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Seismic Vulnerability Assessment of Irregular RCC Buildings by Considering the Effect of Shear Walls

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ABSTRACT
Seismic Vulnerability Atlas of India states that there are about 11 million houses vulnerable to earthquakes in Zone V and 50 million in Zone IV. There are around 80 million houses in general which are vulnerable to the seismic movement. Past tremor encounters have shown that structures with the rectangular arrangement or box type structures perform well than structures with sporadic molded plans.
In this paper, a study is done by comparing a 10 storied regular building and 3 different buildings of irregular plan configuration containing re-entrant corners with buildings strengthened with shear walls by performing linear and non-linear static and dynamic analyses.
The results obtained from all the 8 building models have been compared based on maximum story displacement, story drift, modal periods and performance levels. Seismic vulnerability of all 8 building models has been quantified from the results obtained after performing pushover analysis.
Keywords - Re-entrant corners, Irregular plan configuration, Shear walls, Response spectrum analysis (RSA), Modal Periods, Story Displacements, Story Drifts, Non-linear static analysis, Non-linear dynamic analysis, El Centro earthquake, Seismic Vulnerability Index, ETABS

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I. INTRODUCTION

In the present scenario, the dominant part of the structures has sporadic arrangements which can be either in plan or height or both. Any irregularity will lead to an abrupt change in strength or stiffness of the structure. Past earthquake experiences implicate that, buildings with irregularity are prone to earthquake damages. Therefore, it is essential to study the seismic response of the structure especially the irregular ones to reduce the damages in building as in future these buildings have the probability of being subjected to more devastating earthquakes. In such a case, it is necessary to understand the behaviour of the structures in order to make it possess sufficient seismic resistance.

The present investigation makes an endeavor to examine the impact of re-entrant corners likewise the impact of shear walls in a building plan on its seismic performance.

In order to assess the seismic performance of the considered irregularity, two analytical approaches are performed which includes both linear and nonlinear static and dynamic analyses.

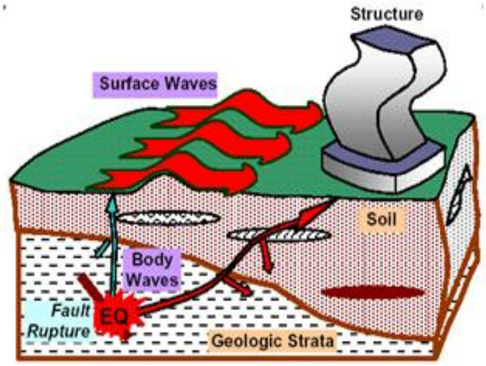


Fig-1 Arrival of Seismic Waves at the Local Site.

1.1. Structural Irregularities

Any structure is taken into account as irregular if there's a variation within the distribution of mass or stiffness or each. A regular structure has no such vital variation and hence, their seismic behavior is more predictable and favorable. However, in the case of irregular structure, they they undergo complex, unacceptable seismic behavior making the structural response troublesome to predict. Hence, there's a necessity for in depth study in understanding their response to seismic loading.

There are two types of structural irregularities, namely:
1. Vertical irregularity.
2. Plan irregularity.

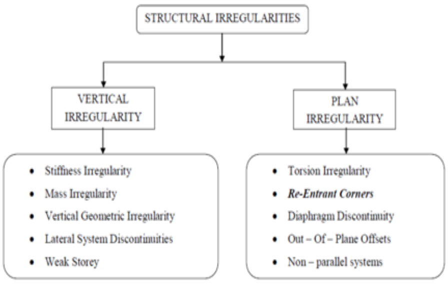


Fig-2 Flow chart representing various structural irregularities in a building

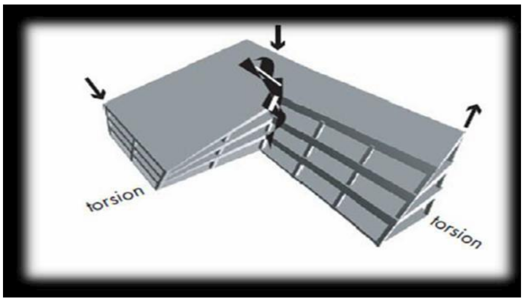
1.2. Re–Entrant Corners

Clause 7.1 Table 4 of IS 1893 (PART 1): 2002 defines re-entrant corner as a location in a structure where in the projection of the building component beyond that point exceeds 15% of its plan dimension in the given direction. When the building is subjected to ground motion inertial forces are mobilized. These forces travel along different paths known as ‘load paths’ through various structural components and finally being transferred to the soil through foundation.

In case of buildings with re-entrant corners, the shape of the plan is such that it necessitates indirect load paths which lead to local stress concentration at point where load path bends. Re-entrant corners in a building pose two major serious threats. Firstly, they cause differential motions in different wings of the building due to variation in rigidity leading to local stress concentration at the notch of the re-entrant corner. On the other hand, they induce significant torsion in the building as illustrated in Fig-3.

Previous earthquake experiences have revealed that buildings with re-entrant corners suffer significant seismic damages.

One such example has been shown in Fig-5,
which is North American school building in Alaska, Due to the local stress concentration at the notch, the upper story was completely destroyed.



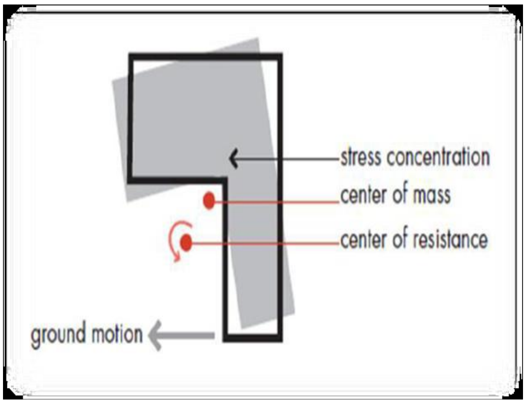


Fig -3 Structural action of re-entrant corner

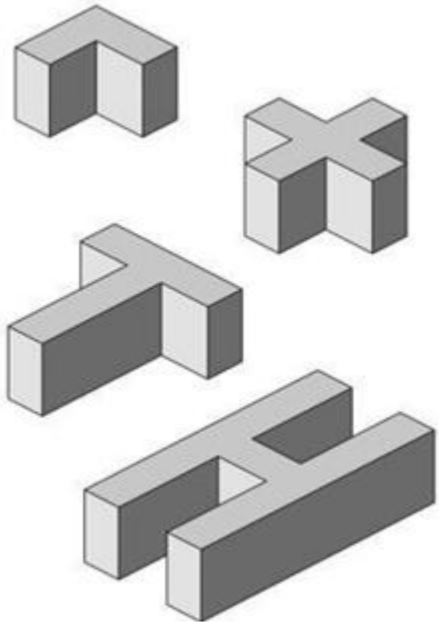


Fig -4 Plan shapes showing re-entrant corners

Fig-5 Damage to West Anchorage High School. Window wall fell inwards into the classrooms. Note sag in roof due to failure of reinforced concrete diaphragm during 1964 Earthquake.

1.3. Shear Walls

Reinforced concrete (RC) buildings often have perpendicular plate-like RC walls called Shear Walls (Fig-6) in addition to slabs, beams and columns. These walls generally start at substructure level and are incessant throughout the building height. Their thickness should be between 150mm to 400mm in high rise buildings. Shear walls are usually provided along both length and breadth of buildings (Fig-6). Shear walls are like vertically-oriented wide beams that carry seismic loads downwards to the foundation.

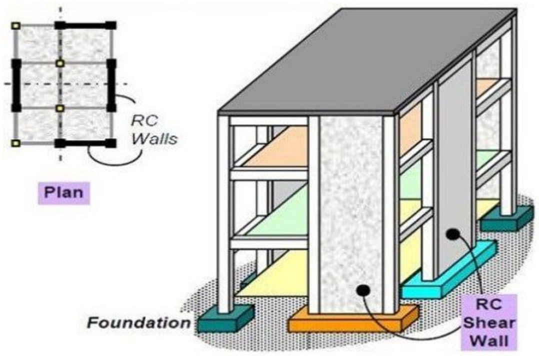


Fig-6 Reinforced concrete shear walls in building

Shear walls in high seismic regions require special detailing. However, in past earthquakes, even buildings with abundant amount of walls that were not specially detailed for seismic performance (but had enough well-distributed reinforcement) were saved from collapse. Shear walls are easy to construct, because reinforcement detailing of walls is relatively uncomplicated and therefore easily implemented at site. Shear walls are efficient, both in terms of construction price and effectiveness in minimizing earthquake damage in structural and non-structural elements (like glass windows and building contents).

II. LITERATURE REVIEW

Amin Alavi, Prof. P.Srinivasa Rao (2013) –In this study, eight different configurations of re-entrant corners with 5 stories have been considered. The irregularities chosen are in accordance with the code provisions of IS 1893. Also, accidental torsion in both X and Y direction has been considered. The results proved that building with severe irregularity is more vulnerable than those with less irregularity, especially in high seismic zones. And also the eccentricity between the center of mass and the center of resistance has a significant impact on the seismic response of structures even though, in the absence of the dual system.

Divyashree M, Gopi Siddappa (2014) –In this study L- shaped building of four-story height has been considered. Response spectrum analysis and pushover analysis has been performed for this model. In order to understand the performance, this model has been compared with a rectangular building. Also, the re-entrant corners have been strengthened using bracings and shear walls using various retrofitting technologies. The change in the behavior of the structure due to retrofitting has been studied. Results of analysis confirmed the enhancement in base shear carrying capacity and roof drifts capacity of the frames by the introduction of retrofitting methodologies.

T. Mahdi, V. Soltangharaie (2012) – The seismic behavior of three moment resisting frame of 5 stories, 7 stories and 10 stories has been considered in this examination. The plan of all 3 models contains re-entrant corners. Non-linear static analysis and linear and no linear dynamic analyses has been performed. The story drifts, displacement, and story shear of the models have been compared. The results of all the analyses have been compared and it was observed that non linear time history analysis has given genuinely precise outcomes when compared to pushover analysis as pushover analysis was not effective in capturing the seismic demands imposed by both a far-field and a near-fault ground motions and the nonlinear dynamic procedure produces results that are not quite same from those given by the nonlinear static and linear time history analyses.

Mehmed Causevic, Sasa Mitrovic (2010)– This paper gives an overview about the procedures that have been implemented in various codes such as Euro code 8 and FEMA 356. Non-linear dynamic time history analysis, improvised capacity spectrum method (CSM) and non linear static procedure have been described in this paper. These methods differ in accuracy, the complexity involved in carrying out the analysis, clarity about the theory behind it and transparency. Non-linear static analysis was developed to overcome the disadvantages of linear methods yet it provides a simple procedure. All the three methods make use of performance-based concepts laying more stress on damage control. These methods are illustrated by means of an eight-story RC framed building. The results of non-linear static and dynamic analysis have been compared. The top story displacement corresponding to dynamic analysis using real ground motion record gives about 145% of the target displacement obtained from the non-linear static procedure.

Putul Haldar and Yogendra Singh (2009) - In this paper more stress has been laid on capacity design. A set of code designed buildings have been considered and this concept has been validated with respect to various code provisions and the expected performance is estimated in both deterministic and probabilistic method. FEMA – 440 and HAZUS methodologies have been employed in estimating the seismic performance and vulnerability. It has been observed that SMRF buildings are more vulnerable when compared with OMRF due to higher allowable drift. It has also implied that the deterministic method of estimation is not sufficient as it does not provide complete insight into the seismic behavior of the structure.

Cinitha.A, P.K. Umesha, Nagesh R. Iyer (2012)– In this article, non-linear static analysis has been performed and the results from the analysis have been linked to the vulnerability of the structure using suitable formula. In this study, they have considered 2 building models of 4 stories and 6 stories. These models are varied as OMRF and SMRF to understand the importance of ductility in earthquake-resistant design and also to imply that ductile behavior is desirable in making the structure seismic resistant. More importance has been given in defining the hinges and plastic hinge length. Five typical cases corresponding to varying hinge length and properties have been discussed in this regard. Finally, the vulnerability of these building models has been computed using a formula which links the hinge performance in various members to a weight age factor associated with each hinge performance level. It has been shown that SMRF buildings are less vulnerable when compared to OMRF building in terms of the vulnerability index. Also, the story vulnerability index has been calculated to detect weak story if any in the structure.

FEMA 356-This book consists of standard procedures for rehabilitation of the buildings having suffered seismic damages. This provides a performance-based approach and a methodology for assigning the hinges in a structure. it also describes the hinge characteristics. It provides guidelines for the design of structural and non-structural components in the new and existing building.

ATC 40 -This document provides a sound methodology for seismic evaluation and retrofitting of the existing RC buildings. However, this is not intended for new building design yet has applicability. This is applicable to the overall structure including structural and non-structural components. It describes the seismic hazard levels, building performance levels and also the acceptability criteria. Damage occurred in a building is expressed in terms of inelastic deformation in the post-yield stage for various structural members. It provides a methodology to perform pushover analysis and also its theoretical background.

2.1. Summary

Irregular buildings are more vulnerable to earthquakes and have demonstrated poor performance in the previous earthquakes. The re-entrant corner is one such irregularity which causes stress concentration and torsion in the building. As per the guidelines of Indian code dynamic analysis has to be performed for irregular buildings. Response spectrum analysis is a powerful tool to understand the linear behavior of the structure. But the building needs to undergo non-linear analysis as well for a complete understanding of the seismic behavior. The non-linear dynamic analysis incorporates an actual environment under real earthquakes and provides results for every increment in time interval. Pushover analysis has to be performed to quantify the vulnerability of re-entrant corners

III. OBJECTIVES OF STUDY

Following are the main goals of this research:

1) To study the seismic performance of RC frames with re-entrant corners.

2) To investigate the effect of shear wall strengthening at the re-entrant corners in a building so that they do not pose a serious threat to the structure.

3) To compare the difference in the behavior of the models before and after strengthening in terms of capacity and performance.

4) To quantify and compare the Seismic Vulnerability Index of all the models.

IV. METHODOLOGY

4.1. Linear Static Analysis

This approach depends on the supposition that the entire of the seismic mass of the structure vibrates with a solitary time span. The structure is assumed to be in its fundamental mode of vibration. But this methodology provides satisfactory results only if the structure is low rise and there's no significant twisting on ground movement. As per the IS 1893: 2002, entire design seismic base shear is found by the multiplication of seismic weight of the building and the design horizontal acceleration spectrum value. This force is distributed horizontally in the proportion of mass and it should act at the vertical center of mass of the structure.

4.2. Linear Dynamic Analysis/Response Spectrum Analysis

Dynamic analysis is performed after the static analysis is finished. By default, the response-spectrum scale factor is I g / 2R, where g is acceleration due to gravity (9.81 m/sec2 for KN-m). After analysis, users should evaluate the base shear due to all modes, reported in the Response Spectrum Base Reaction Table. If the dynamic base shear reported is over 80% of the static base shear, no further action is required. However, if dynamic base shear is less than eightieth of the static base shear, then the scale factor should be adjusted such that the response-spectrum base shear matches 80% of the static base shear. In this case, the new scale factor would be (I g / R) * (0.80 * static base shear / response-spectrum base shear). Analysis should then be rerun with this scale factor specified in the response-spectrum.

4.3. Non-Linear Static Analysis

Non-linear static analysis is an improvement over linear static or dynamic analysis as it allows inelastic behavior of the structure. The method is simple to implemented and provide information on strength, deformation, and ductility of the structure as well as the distribution of demands. This permits the identification of critical member that is like to reach limits states during the earthquake, to which attention should be paid during the design and detailing process. But this technique relies on several assumptions that neglected the vibration of the loading patterns, the influence of higher modes of vibration and the effect of resonance. Despite of deficiencies, this method known as pushover analysis. It is the method of analysis by applying a specific pattern of direct lateral loads on the structure, starting from zero to a value corresponding to a specific displacement level, and identifying the possible weak points and failure patterns of a structure. The performance of the structure is evaluated and using the status of hinges at target displacement or performance point corresponding to a specified earthquake level (the given response spectrum). The performance is acceptable if the demand is less than capacity at all hinges.

4.4. Non-Linear Dynamic Analysis

This analysis utilises the available ground motion data in predicting the structural behavior to an actual earthquake. The time history record of the earthquake is loaded into the software while defining the time history function. The hinge assignment is similar to that of pushover analysis.

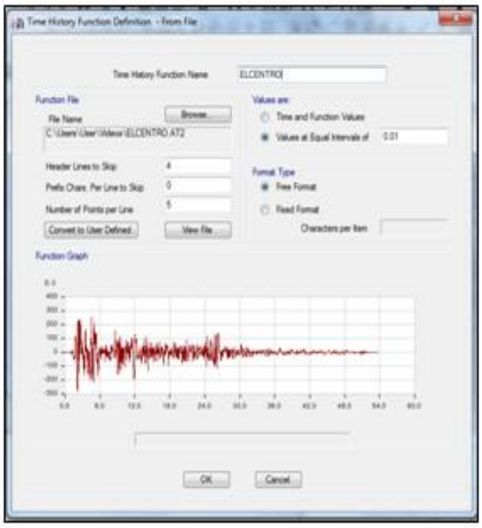


Fig-7 Accelerogram of El Centro earthquake

Fig-8 Geographical location of the El Centro epicentre

4.5. Vulnerability Index

Vulnerability index is an estimation of the damage caused to the structure after the structure has been pushed to its target displacement. In other words, this index is calculated after performing non linear static analysis. It is a linear combination of the various hinges formed in the member along with a weightage factor assigned to each hinge state as shown in formula. The hinge status of each individual member constituting the structure with respect to the prefixed objective displacement is taken into account in calculating the vulnerability index. These hinges are considered either at the performance point of the structure or at the point where the analysis will be terminated. However, in this study, the hinge status equivalent to the collapse prevention state of the structure has been considered.

$$VI = \frac{1.5|\sum_c^i Nc\ Xi + \sum_b^j Nb\ Xj}{\sum_c^i Nc + \sum_b^j Nb} \quad \text{.... (1)}$$

Where N_c = number of hinges formed in columns

N_b = number of hinges formed in beams

X_i = weightage factor for that corresponding hinge state in columns

X_j = weightage factor for that corresponding hinge state in beams.

TABLE -1: WEIGHTAGE FACTOR FOR VARIOUS PERFORMANCE RANGES OF HINGES

Serial no.	Performance range	Weightage factor
1	<B	0
2	B – IO	0.125
3	IO – LS	0.375
4	LS – CP	0.625
5	CP – C	0.875
6	C - D, D – E, >E	1

Where IO = immediate occupancy
LS = life safety
CP = collapse prevention C = collapse
E refers to points on the moment curvature curve beyond collapse

V. BUILDING MODEL CONFIGURATION

TABLE -2 BUILDING MODEL DESCRIPTIONS

Number of stories	10
Floor to floor height	3m
Slab thickness and type	150mm, membrane
Dead load	self weight of the slab + floor finish (inclusive of ceiling finish) = 3.75kN/m^2 + 1.25 kN/m^2 = 5 kN/m^2
LL	3kN/m^2
LL after applying reduction factor	3 X 0.25 = 0.75 kN/m^2
Floor finish	1.25 kN/m^2
LL on the roof	2kN/m^2
Seismic zone	V
Zone factor (Z)	0.36
Importance factor	1.5
Soil type	Medium (II)
Response reduction factor	5 (special moment resisting frame, SMRF)
Material used	M30 and HYSD500
Damping (ζ)	5%
Earthquake load	As per IS 1893 (PART 1) :2002
Beam dimension	300X600
Column dimension	700X700

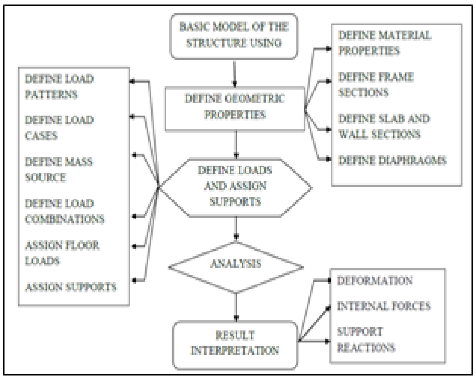


Fig-9 Flowchart of the steps involved in modeling using ETABS

In order to understand the seismic behavior of re-entrant corners, a total of eight building models with ground and nine storys were studied. They are as follows:

1. Control building – regular plan configuration of rectangular shape
2. Type A – irregular plan with re-entrant corner
3. Type B – one way asymmetrical building plan
4. Type C – two way asymmetrical building plan
5. Control Building$^{\#}$ (with Shear walls)
6. Type A$^{\#}$ Building (with Shear walls)

7. Type B# Building (with Shear walls)
8. Type C# Building (with Shear walls)

VI. BUILDING MODELS

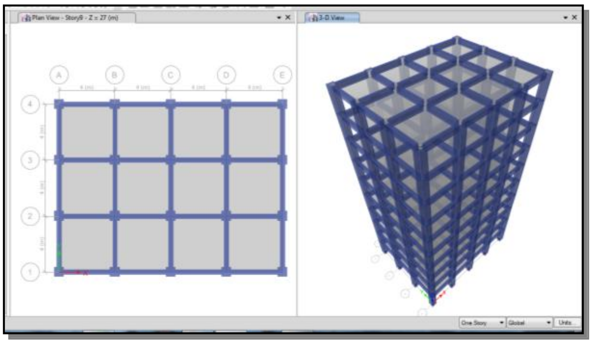


Fig-10 Control Building

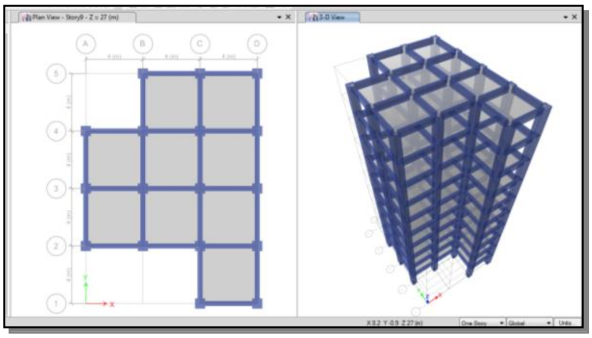


Fig-11 Type A Building

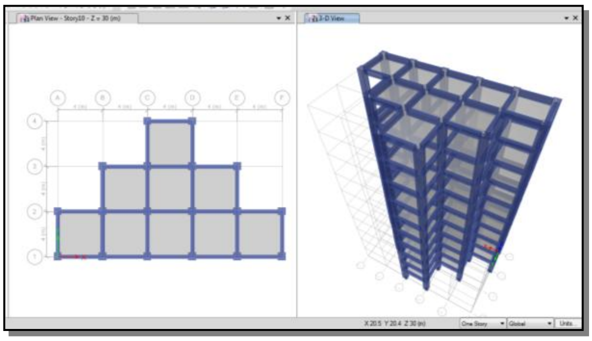


Fig-12 Type B Building

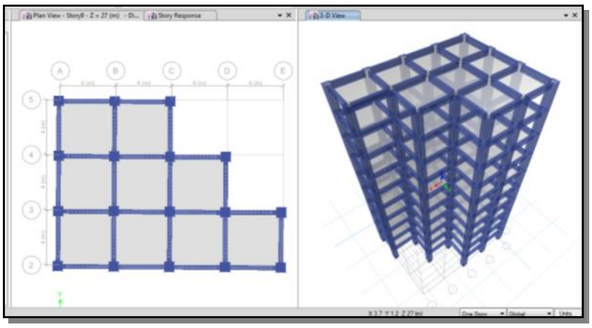


Fig-13 Type C Building

Three dimensional views of the building models strengthened with shear walls are shown below.
The performance of all 8 building models are compared.

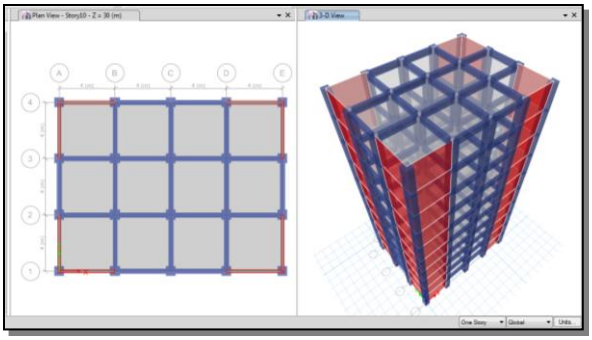


Fig-14 Control Building with shear walls

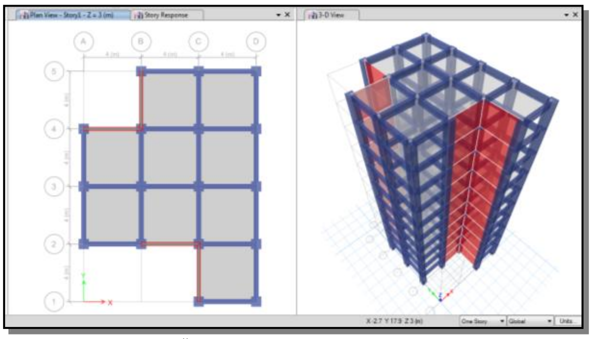


Fig-15 Type A# Building with shear walls

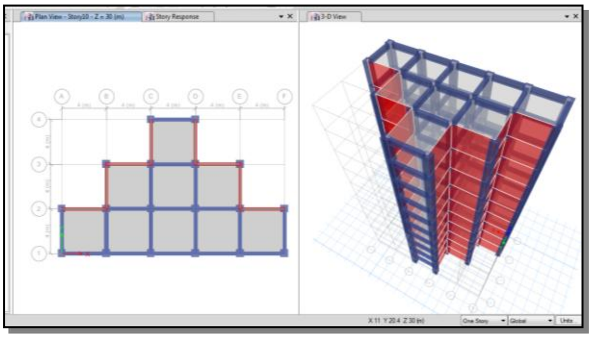


Fig-16 Type B# Building with shear walls

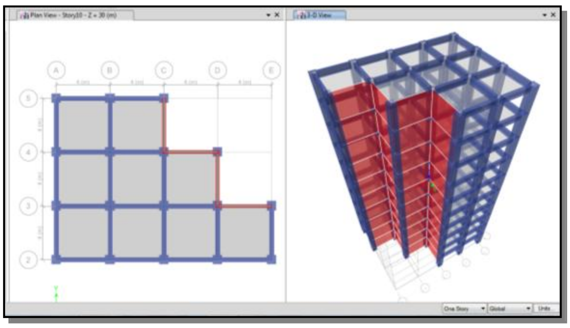


Fig-17 Type C# Building with shear walls

VII. RESULTS FROM LINEAR ANALYSIS

7.1.Modal periods

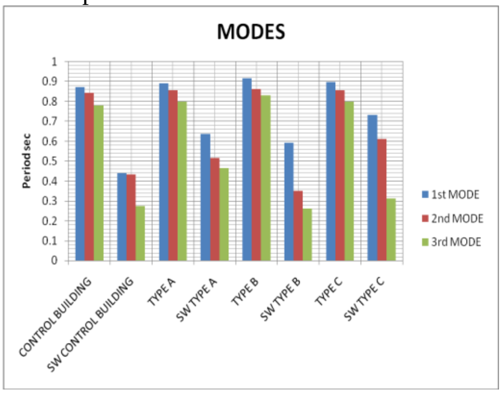


Fig-18 Modal Periods

Modal periods are characteristic of a building and no two buildings can have their natural period equal to each other unless they have their mass and stiffness also equal. Figure 18 represents the modal period of all the building models considered in this study. The number of modes considered in this analysis is twelve so that the modal participation factor is around 90% with reference to the code provisions of IS 1893: 2002. As evident from the graph, in the first mode type A building model has higher natural period than the remaining models. But this is not the case in the next consecutive modes. Control building has performed consistently in all the modes when compared to other models. Type A model has a relatively higher natural period in almost all the modes. Type B and type C also have higher modal periods and are consistent with type A. Hence with shearwall are considered, their modal periods is quite less than those without shearwalls.

7.2.Story Displacements

The analysis has been carried out for seismic zone V and medium soil. The story displacement of all the models has been compared. These graphs have been plotted and presented from fig.19 to 21.

Story displacement represents the movement of each story in the horizontal direction and this has been graphically shown along with the height of the building.

Also, a comparison has been made between models with and without shear walls to understand the impact of this lateral load resisting element on the displacement control.

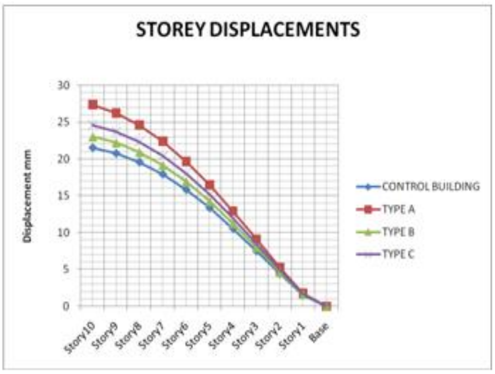


Fig-19 Story Displacements

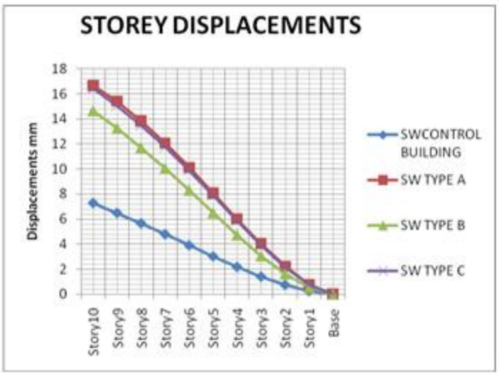


Fig-20 Story Displacements with Shearwalls

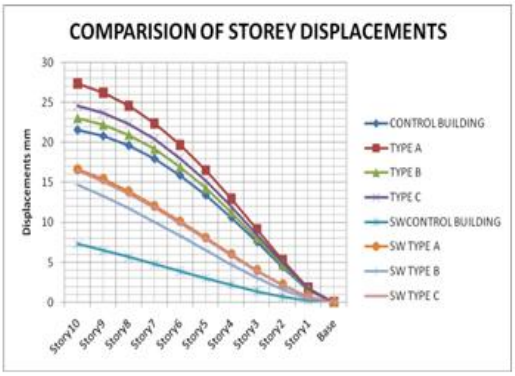


Fig-21 Comparision of Story Displacements

From Fig.21, the displacement undergone by the model type A is highest while the control building experiences lesser displacement. In fact, control building has undergone lesser displacement when compared to other types.

When the building models are strengthened with shearwalls, their displacements has been considerably reduced as shown in Fig 20 and 21.

7.3.Story Drift

Drift is the relative motion of each story with respect to its previous story. Drifts indicate the lateral movement of the building model. This parameter has been plotted for all the building models. Usually, buildings experience larger story drifts in the X direction as the applied seismic load is predominant in that direction. The story drifts in the Y direction is less due to higher stiffness. This is one of the parameters to understand the seismic behavior of the building. Also, it gives a better understanding about the vulnerability of re-entrant corners.

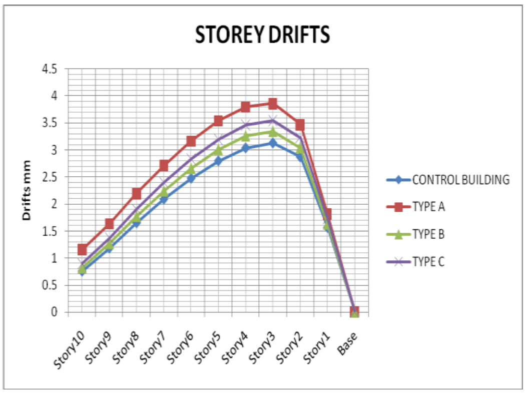


Fig-22 Story Drifts

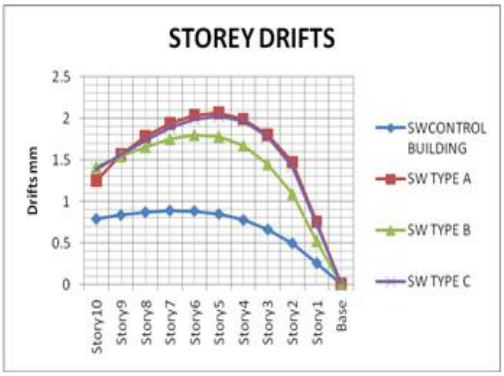


Fig-23 Story Drifts with Shearwalls

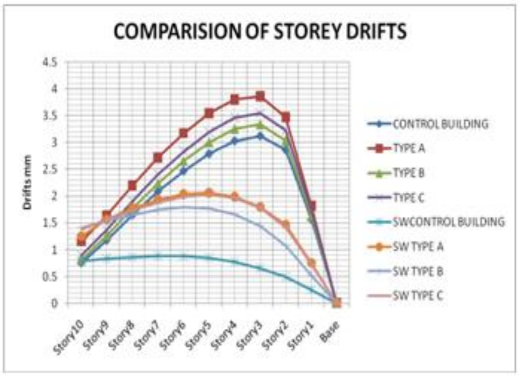


Fig-24 Comparision of Story Drifts

Type A configuration has undergone larger drifts while Control building has drifted the least as evident from the graph and suffers lesser drift than other models implying the fact that they are relatively safer and the most desirable configuration when subjected to seismic activity.

Control building with and without shearwall has shown consistent performance.

VIII. RESULTS FROM NON-LINEAR DYNAMIC ANALYSIS

8.1Base Shear Response

The variation of base shear with respect to the time of the building models when subjected to El Centro ground motion data have been presented in this section. Depending on the number of output steps and step size the range of output data available will be decided by the software. In this number of steps and step, size has been considered as 1000 and 0.01 respectively. As a result, the data is available up to first 10 seconds. The base shear response corresponding to building models with shear walls has larger variations and also the peak values are much higher than those without shearwalls.

In El Centro ground motion there are successive crests and troughs implying highly erratic nature of the earthquake.

TABLE -3 BASE SHEAR VS TIME

	BASE SHEAR (KN)	**TIME (secs)**
CONTROL BUILDING	850.24	3.8
CONTROL BUILDING# WSW	1784.97	5.1
TYPE A	850.24	3.8
TYPE A# WSW	1296.79	5.2
TYPE B	982.84	5.4
TYPE B# WSW	1182.18	2.6
TYPE C	852.36	5.4
TYPE C# WSW	914	2.6

From the above table, we can infer that the base shear response of the models with shearwalls is more for El Centro ground motion when compared to those without shearwalls. This is due to the higher peak acceleration of El Centro earthquake.

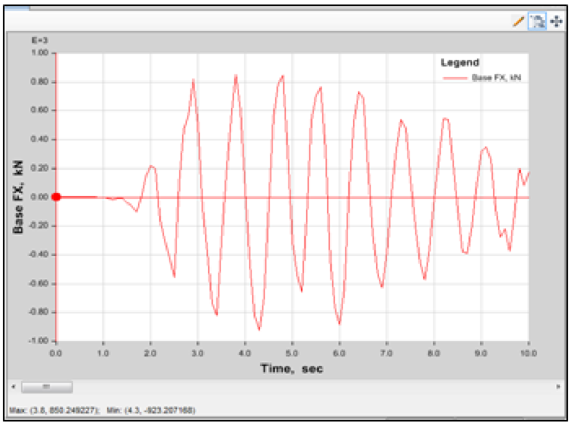


Fig-25 Control Building Base Shear vs Time 850.24KN, 3.8secs

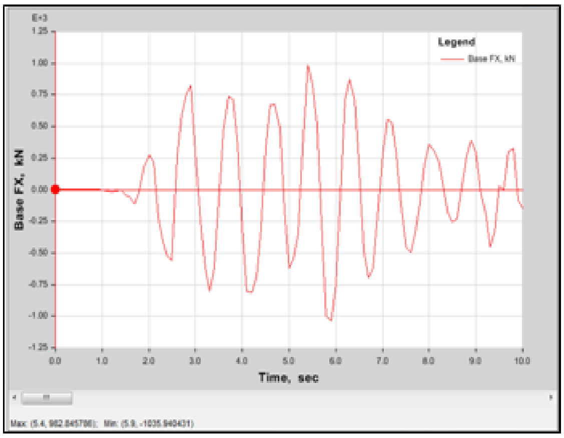


Fig-26 Control Building# with Shearwall Base Shear vs Time 1784.97KN at 5.1secs

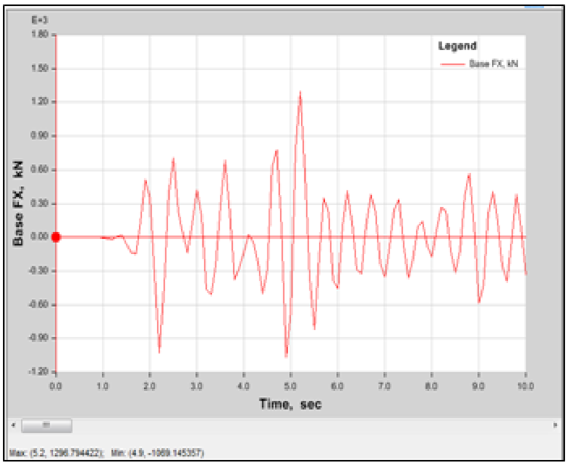


Fig-27 Type A Building Base Shear vs Time 850.24KN at 3.8secs

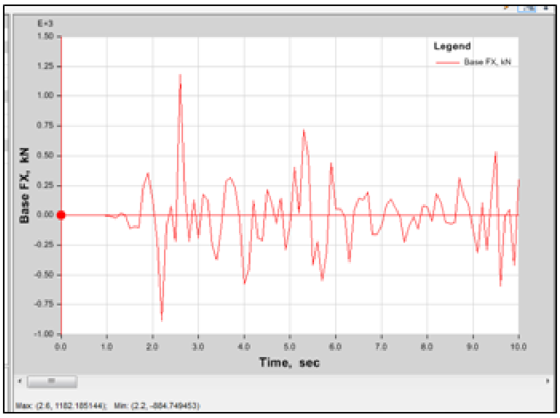


Fig-28 Type A# Building with Shearwalls Base Shear vs Time 1296.79KN at 5.2secs

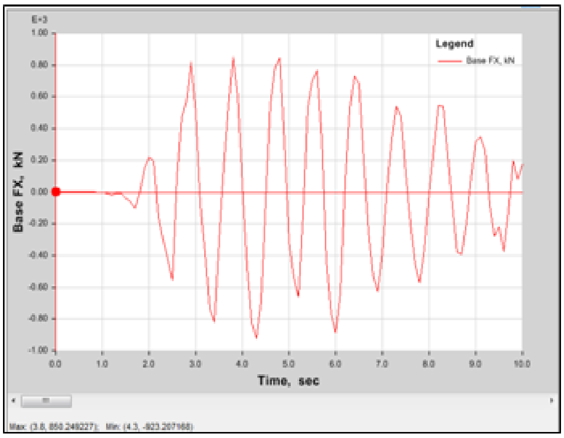


Fig-29 Type B Building Base Shear vs Time 982.84KN at 5.4secs

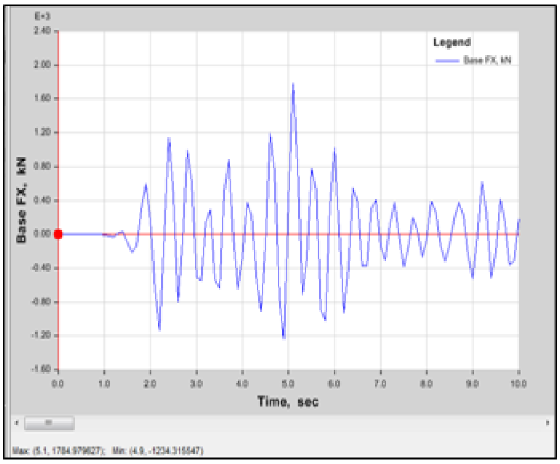


Fig-30 Type B# Building with Shearwalls Base Shear vs Time 1182.18KN at 2.6secs

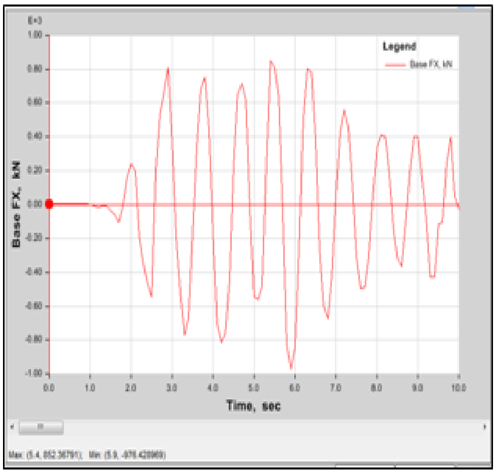


Fig-31 Type C Building Base Shear vs Time 852.36KN at 5.4secs

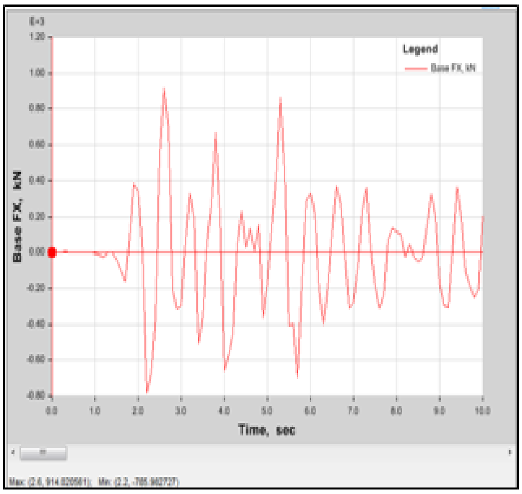


Fig-32 Type C# Building with Shearwalls Base Shear vs Time 914KN at 2.6secs

IX. RESULTS FROM NON LINEAR STATIC ANALYSIS

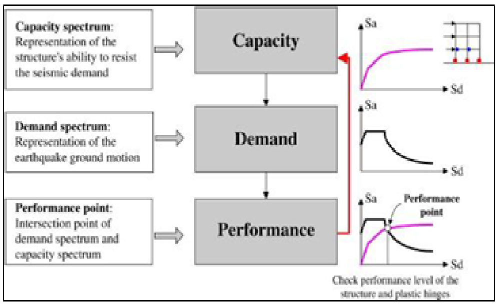


Fig-33 Determination of performance point

The intersection of the capacity spectrum and demand spectrum gives the performance point of the structure. Performance point is a measure of the seismic resistance of a structure. This combines the performance of both structural and non structural components in a building. It expresses the building performance in terms of damage states. Buildings are designed considering various parameters corresponding to this point.

However, in our study, the results are used for quantifying vulnerability.

There is an improvement in the performance of the structure when shear walls are provided. The spectral displacement of control building without shear wall is around 0.1m whereas that of the same model with shear wall is about 0.01 or less than that. This demonstrates the fact that shear walls do have an impact on the performance of the building and makes the structure more seismic resistant. Spectral values of acceleration and displacement are considered in defining the performance point of the structure.

Shear walls impart more structural stiffness to the structure. As they are lateral load resisting elements the performance of the structure has seen improvement in resisting the seismic load.

The plot of base shear against displacement is known as pushover curve. This shows the behavior of the building model beyond the yield point. The building has undergone significant displacement beyond the yield point. However, not much inelastic deformation has been observed after introducing a lateral load resisting system.

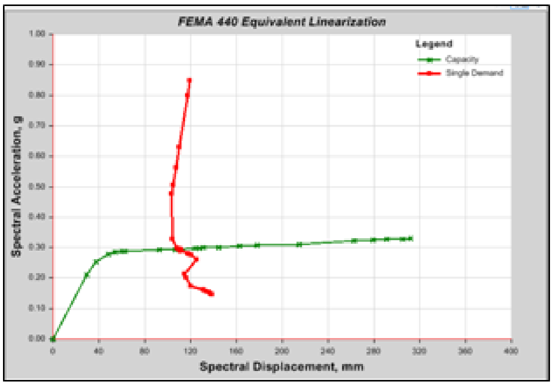


Fig-34 Capacity Curve for Control Building

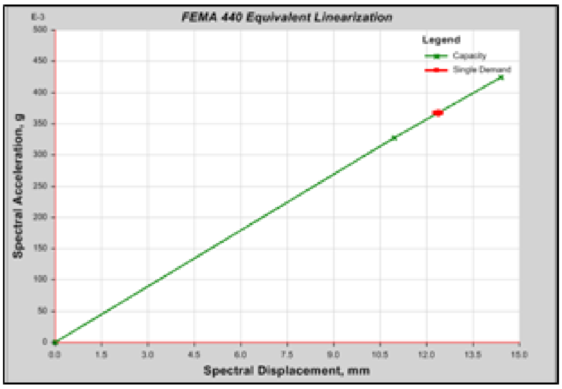


Fig-35 Capacity Curve for Control Building with Shearwalls

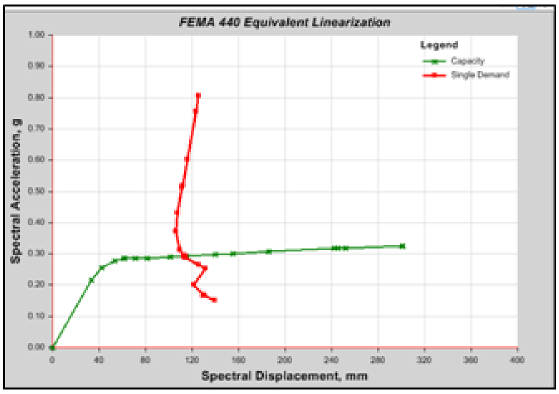


Fig-36 Capacity Curve for Type A Building

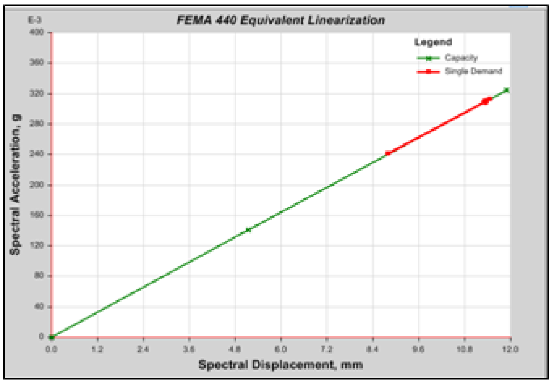


Fig-37 Capacity Curve for Type A Building with Shearwalls

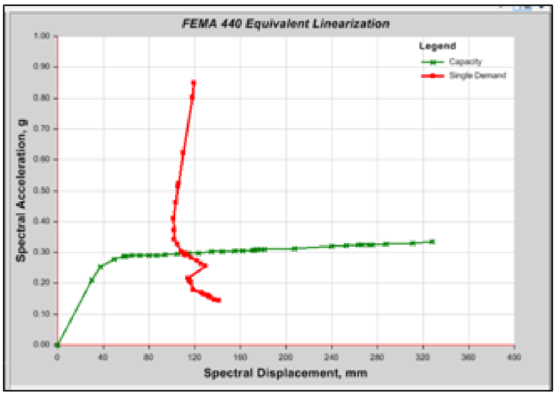


Fig-38 Capacity Curve for Type B Building

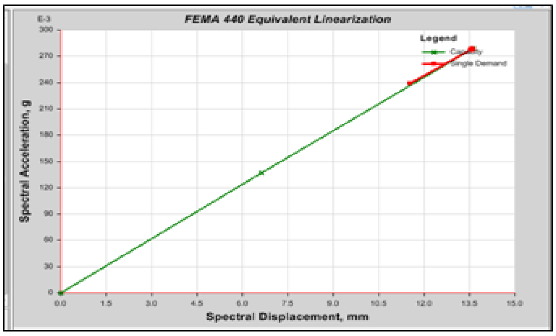


Fig-39 Capacity Curve for Type B Building with Shearwalls

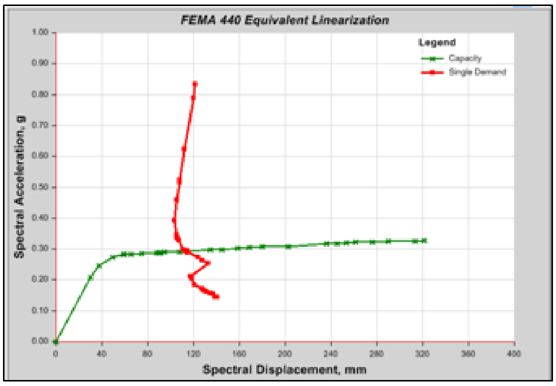


Fig-40 Capacity Curve for Type C Building

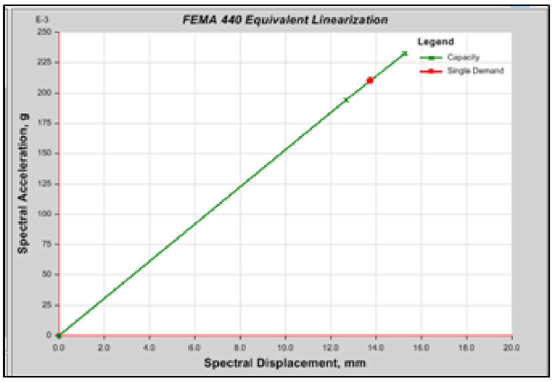


Fig-41 Capacity Curve for Type C Building with Shearwalls

TABLE -4 COMPARISON OF PERFORMANCE POINTS

MODEL TYPE	BASE SHEAR (KN)	DISPLACEMENT(mm)
CONTROL BUILDING	7363.08	132.95
CONTROL BUILDING# WITH SHEAR WALL	7794.48	18.01
TYPE A	6103.45	136.53
TYPE A# WITH SHEAR WALL	6457.45	20.29
TYPE B	6557.32	135.81
TYPE B# WITH SHEAR WALL	6937.64	10.59
TYPE C	6186.29	136.78
TYPE C# WITH SHEAR WALL	6545.1	27.56

Shear walls impart more structural stiffness to the structure. As they are lateral load resisting elements the performance of the structure has seen improvement in resisting the seismic load.

Hence from the above table, we can conclude that The inelastic deformation is minimized when shear walls are provided. This is due to the fact that shear walls impart more stiffness to the structure and makes the structure seismic resistant.

X. VULNERABILITY INDEX

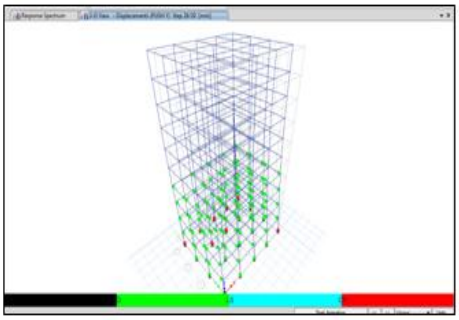


Fig-42 Damage Hinges in Control Building

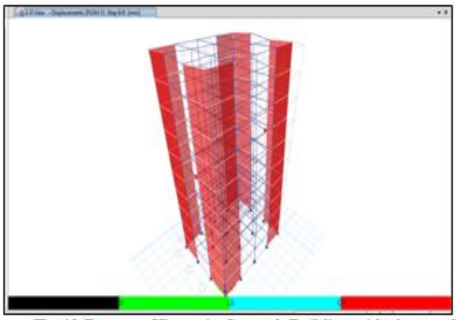


Fig-43 Damage Hinges in Control Building with shearwall

By making use of this color-coded display of hinges as shown in fig 42 and 43 the vulnerability is quantified by using Table 1 and equation 1 as explained in the beginning and the results are shown in Table 5

The vulnerability index implies that re-entrant building Type A without shear wall is more vulnerable than a regular building.

TABLE -5 COMPARISON OF VULNERABILITY INDEX

MODEL	WITH SHEAR WALL	WITHOUT SHEAR WALL
CONTROL BUILDING	0.16	0.24
TYPE A	0.19	0.27
TYPE B	0.1875	0.25
TYPE C	0.18	0.253

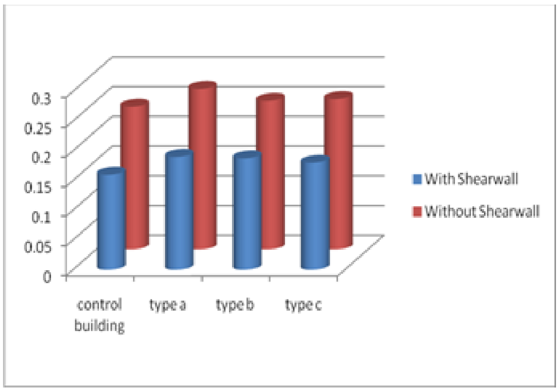


Fig-44 Comparison of Vulnerability Index

The vulnerability index of Building models without shear walls are quite higher when compared to other models with shear walls.

XI. CONCLUSIONS

The following conclusions were able to reach after a thorough analysis of the building models.

1. The modal periods of the control building with and without shear walls are less when compared to that with remaining models. Also, it can be concluded that building model with a lower time period is susceptible to minor earthquakes.
2. The story displacement and drift undergone by type A model is more than other types of models.
3. The drift and displacements are controlled when the lateral load resisting elements such as shear wall is provided.
4. The base shear response of the models with shear walls is more for El Centro ground motion when compared to those without shear walls. This is due to the higher peak acceleration of El Centro earthquake.
5. Among the chosen building models, the ones with shear walls provide better performance than the ones without shear walls.
6. The inelastic deformation is minimized when shear walls are provided. This is due to the fact that shear walls impart more stiffness to the structure and makes the structure seismic resistant.
7. The hinge status in various members corresponding to the fixed target displacement was studied. The hinges are moving towards the collapse stage in models which are not provided with shear walls.
8. The vulnerability index for all the models was calculated and it has been observed that type A model i.e., the two-way asymmetric building plan is the most vulnerable among all of them. And also, the installation of shear walls has best worked for this case.

Hence we can infer that re-entrant buildings are more seismically vulnerable than the buildings of regular plan configuration and strengthening with shear walls are effective in resisting structures against earthquakes.

XII. ACKNOWLEDGMENT

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I thank my grandparents who played a great role in my career and their love and support has been a major stabilizing force till this moment.

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Many people have contributed to my project dissertation, to my education, and to my life, and it is with great pleasure to take the opportunity to thank them. I apologize if I have forgotten anyone.

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