NONLINEAR ANALYSIS AND COMPARISON OF OPEN GROUND STORIED STRUCTURE RETROFITTED BY SHEARWALL AND CROSS BRACING - A CASE STUDY

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Abstract : The building with open ground storey has become a common feature in multi-storey construction to facilitate the parking requirements. This sudden reduction in stiffness causes higher stress to be concentrated at the ground story columns leading to its failure. The present analytical study deals with existing building located in Zone V (Guwahati), points out various provisions to soft storey which can reduce the damage during earthquake. The modeling of the whole building is carried out using the computer program ETABS. This study deals with provisions of some retrofitting measures in two ways. Firstly by providing shear wall which increase the load carrying capacity and secondly by providing bracing which increases the stiffness of load carrying members. The behavior of open ground storied building is compared in terms of various seismic responses such as storey displacement, base shear, story drifts etc.
Index terms- Soft Storey, Time History Analysis, Pushover Analysis, Shear Wall, Cross Bracing, Case Study etc.

I.INTRODUCTION-

The severe damage can be seen on the structure due to irregularity of structures. Due to modern era of construction the buildings without open ground storey is unavoidable because there is shortage of area for parking so we have to provide some special measures on the structure to mitigate the effect of soft storey on the structure . It is very necessary to conduct an in-depth study on the nonlinear behavior of the structure so that it gives the proper response of the structure during earthquakes. In the present case study, a seven storied residential building was taken up. The buildings is situated at Guwahati, India which lies in the most seismically active zone of the country. Each floor, apart from the ground floor had four independent 3BHK flats with a box type shear wall at one end, serving the purpose of lift shaft and dog-legged stairs on the other end. This study discussed the behavior of existing structure and retrofitted structure in nonlinear analysis using ETABS software so that we can conclude the provision of shear wall or cross bracing on that locality is suitable or not.

Fig 1-Plan of the Building in AutoCAD.

Seven story regular reinforced concrete building is considered located in Sarojini Park Guwahati. The total beam length in (x) transverse direction are 30m and beams in (z) longitudinal direction are 18.8 m . Figure 4.1 shows the plan of the seven story building having 4apartments of 3 BHK . The plan dimensions are shown below. Story height of each building is assumed 3m.The height of open ground storey kept as 3.5m. The structure is drafted in auto cad and imported to ETABS. The other specifications of building are shown in the table below.

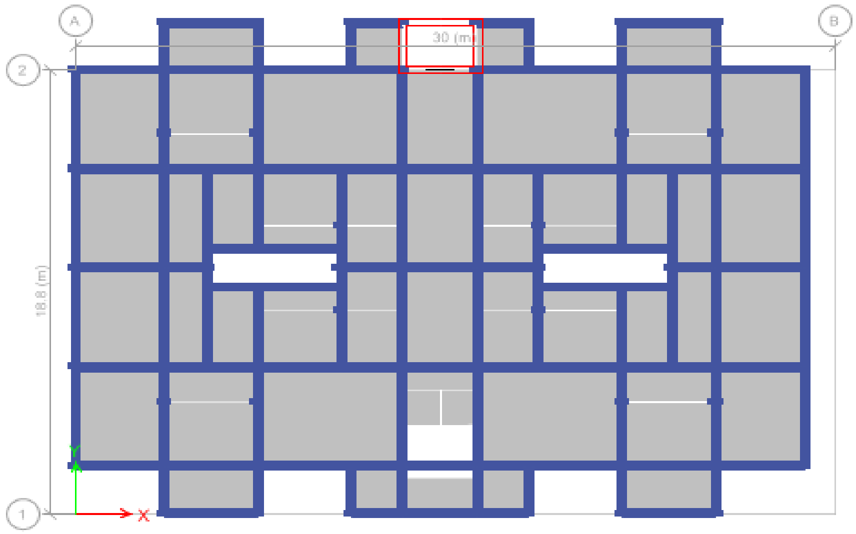


Fig 2- Plan of building imported in ETABS

II. MODELLING AND ANALYSIS-

The building considered in this study has following specifications-

Table 1 – Member Properties of building

S.No.	Description	Specifications
1.	Building Frame System	OMRF
2.	Ground Storey height	3.5m
3.	Typical Storey height	3.0m
4.	Type of soil	Medium (II)
5.	Support Condition	Fixed
6.	Grade of concrete	M30
7.	Grade of steel	Fe 415
8.	Live Load	3.5 kN/m2
9.	Floor Finish	1 kN/m2
10.	Infill Panel	Brick Masonry
11.	Importance factor	1
12.	Response Reduction Factor	3
13.	Column Size	600mm x 300mm
14.	Beam size	500mm x 350mm
15.	Slab Thickness	120mm
16. 0	Stair Slab Thickness	100mm
17.	Thickness of brick wall	230mm

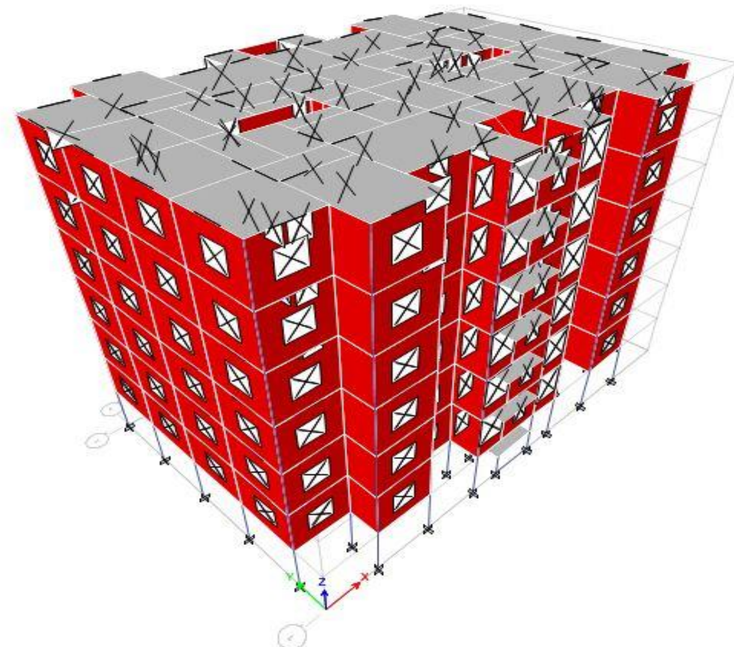


Fig 3- 3D view of Base Model (Model I)

The M30 concrete is used to provide shear wall for retrofitting in Model II. The shear wall was drawn from the quick draw option through which the walls can be drawn from bottom to top floor in one go.

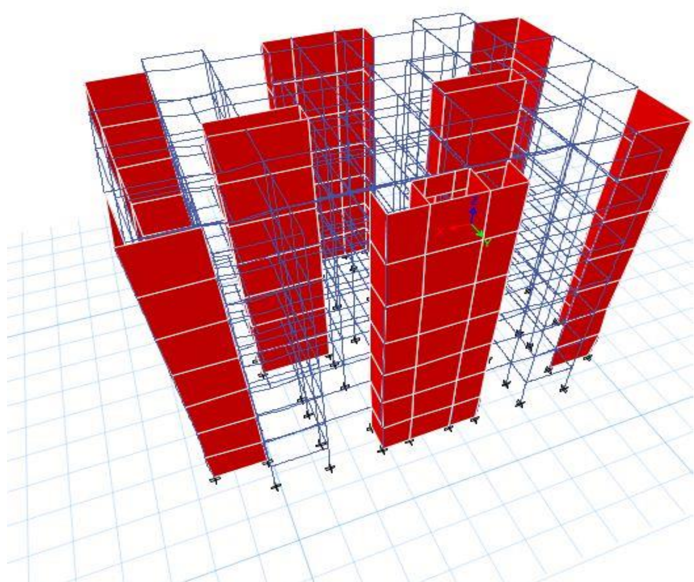


Fig 4- 3D view of shear wall retrofitted model (Model II)

The original OGS structure was retrofitted using cross steel bracings. These braces were added to the ground floor at pre-determined locations as shown below Among the many possible alternatives, the most feasible section was found using the 'Auto Select' feature of ETABS and finally ISHB 150 was used for the braces, which were pinned to the existing beam column joints.

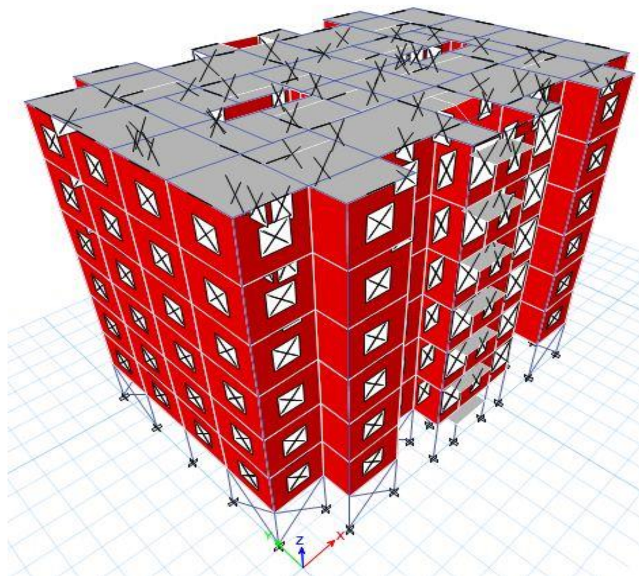


Fig 5- 3D view of cross bracing model (Model III)

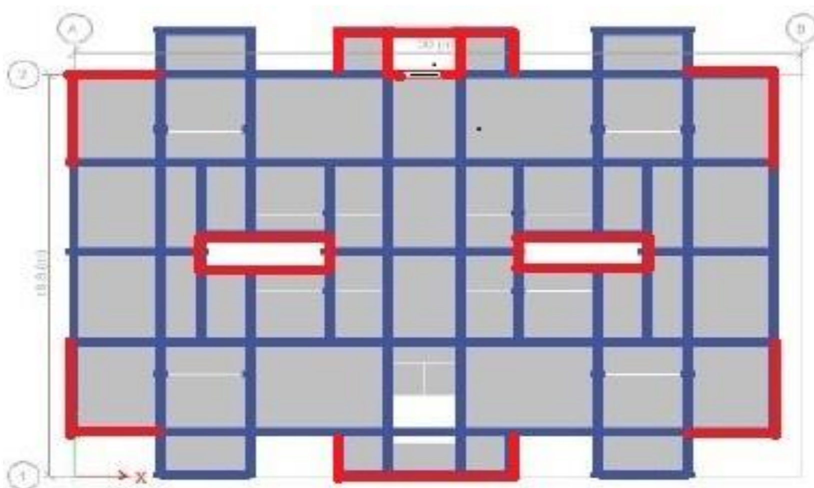


Fig 6- location of shear wall in Model II

The red lines showing the position of shear wall in the plan.

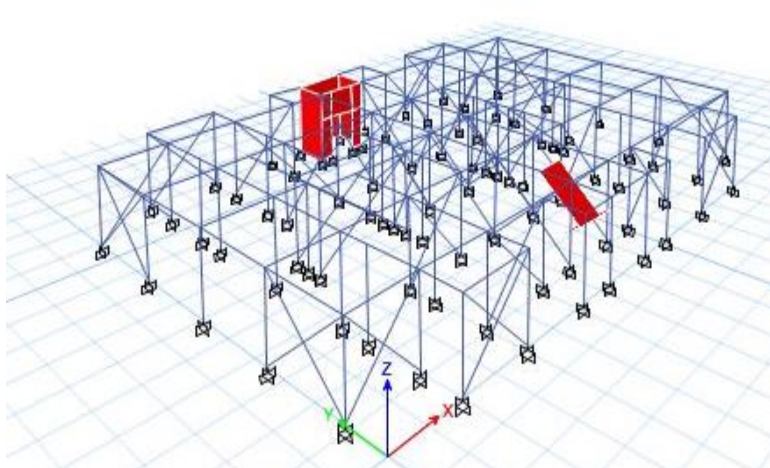


Fig 7- location of cross bracing in Model III.

2.1TIME HISTORY ANALYSIS-

Time history analysis is a step by step procedure where the loading and response history are evaluated at successive time increments. During each step the response is evaluated from the initial condition existing at the beginning of the step (displacements and velocities and the loading history in the interval). In this method, the non linear behavior may be easily considered by changing the structural properties. (stiffness k) from one step to another. Therefore this method is very effective to determine the non linear response. However, in linear time history analysis, the structural properties are assumed to remain constant and a linear behavior of structure is assumed during the entire loading history.
The following five ground motion records, which, have been considered for the time history analysis are discussed below:
1.1999 Chi Chi Taiwan
2. 1995 Kobe Japan
3. 1940 El Centro
4. 1989 Loma Prieta
5. 1994 Northridge USA

Table 2- Considered earthquakes for NTHA

S.No	Earthquake	Country	Date	Station	Hypocenter Distance
1	Chi Chi	Taiwan	25 Sept, 1999	Tcu080	10.2 Km
2	Kobe	Japan	16 Jan, 1995	KJMA	1.0 Km
3	El Centro	USA	19 May, 1940	USGS Stn. 0117	12.2 km
4	Loma Prieta	USA	18 Oct, 1989	CSMIP Stn. 1667	65.2 Km
5	North Ridge	USA	17 Jan, 1994	CSMIP Stn. 24514	9.9 Km

Table 3- Scaling of Ground Motions (Target PGA of Zone V = 0.36 g)

S.No.	Earthquake	PGA (cm/s2)	Target PGA (cm/s2)	Scale Factor
1.	Chi Chi	527.23	353.16	0.669
2.	Kobe	805.45	353.16	0.438
3.	El Centro	341.61	353.16	1.033
4.	Loma Prieta	281.40	353.16	1.255
5.	North Ridge	826.80	353.16	0.427

Table 4- Spectral Matching Details as per 'SeismoMatch 2016

SNo.	Earthquake	Average Misfit	Maximum Misfit	Maximum Acceleration
1.	Chi Chi	5.1 %	23.9 %	0.973 g
2.	El Centro	4.3 %	29.2 %	1.128 g
3.	Kobe	4.4 %	28.1 %	0.963 g
4.	Loma Prieta	6.5 %	21.0 %	1.084 g
5.	Northridge	3.0 %	22.8 %	1.110 g

From the data given above, the earthquake records were matched with response spectrum taking modal time period as 0.32 sec.

2.2 PUSHOVER ANALYSIS-

Pushover analysis is a static, nonlinear procedure in which the magnitude of the lateral loads is incrementally increased, maintaining a predefined distribution pattern along the height of the building. Pushover analysis can determine the behavior of a building, including the ultimate load and the maximum inelastic deflection

An idealized load-deformation curve is shown in Fig (8). It is a piece-wise linear curve defined by five points. Point 'A' corresponds to the unloaded condition. Point 'B' corresponds to the onset of yielding. Point 'C' corresponds to the ultimate strength. Point 'D' corresponds to the residual strength. For the computational stability, it is recommended to specify non-zero residual strength. In absence of the modeling of the descending branch of a load-deformation curve, the residual strength can be assumed to be 20% of the yield strength.Point 'E' corresponds to the maximum deformation capacity with the residual strength.

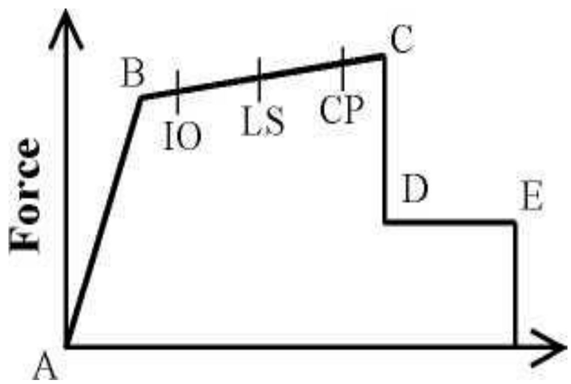
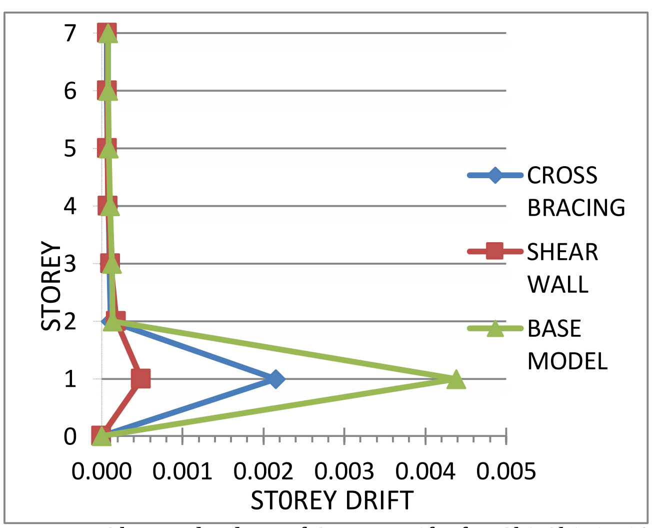


Fig 8- Idealized Load-Deformation Curve (11)

III.RESULTS AND DISCUSSIONS-

3.1 STOREY DRIFT-

A graph is plotted taking floor levels as ordinate and story drifts as abscissa for different models to compare storey drifts.



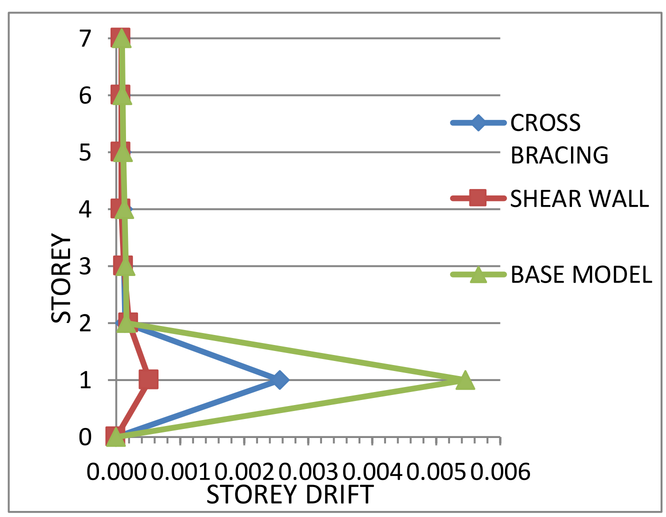
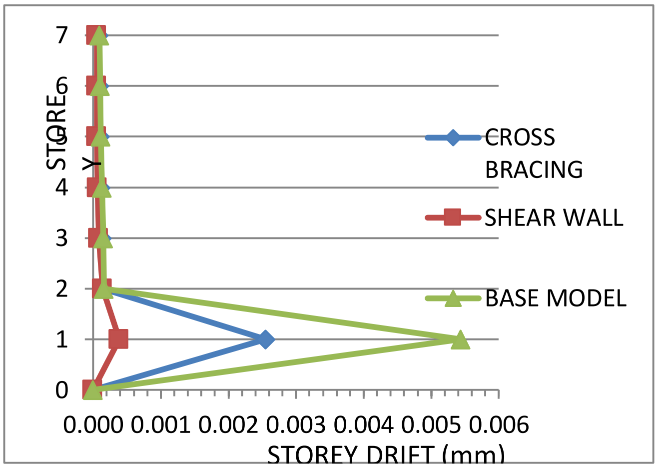


Fig 9-

Observed values of Storey Drifts for Chi ChiFig 10 - Observed values of Storey Drifts for Kobe



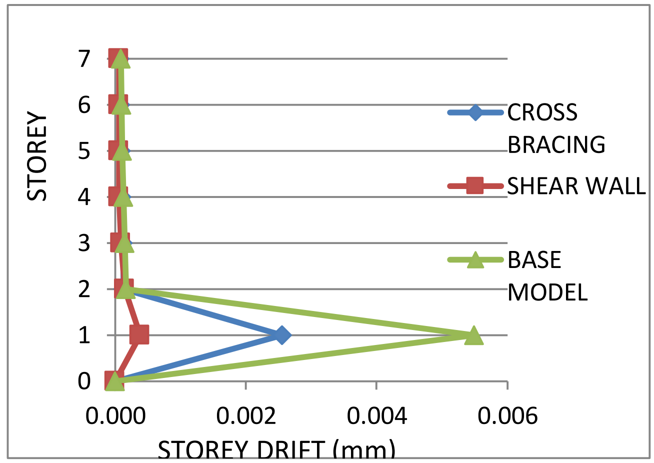


Fig 11- Observed values of Storey Drifts for El Centro.

Fig 12 - Observed values of Storey Drift for Loma Prieta

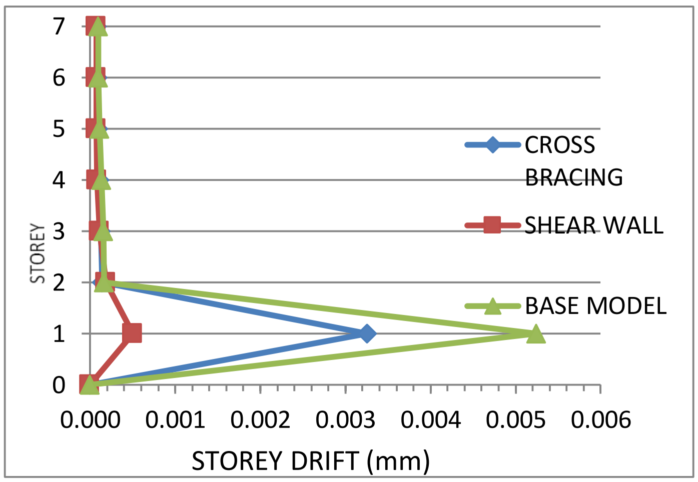


Fig 13 - Observed values of Storey Drifts for North Ridge

From the above profiles it is observed that storey drift in Model I is higher than other two models and it is lesser in Model II. The abrupt change of slope of drift in first storey can be seen in graphs. That means the ductility demand for Model I is largest (12). However the storey drift curve become smoother in Model II that means large stiffness and less ductility demand(12).

3.2 STOREY DISPLACEMENTS-

A graph is plotted taking floor levels as ordinate and story displacements as abscissa for different models to compare storey displacements.

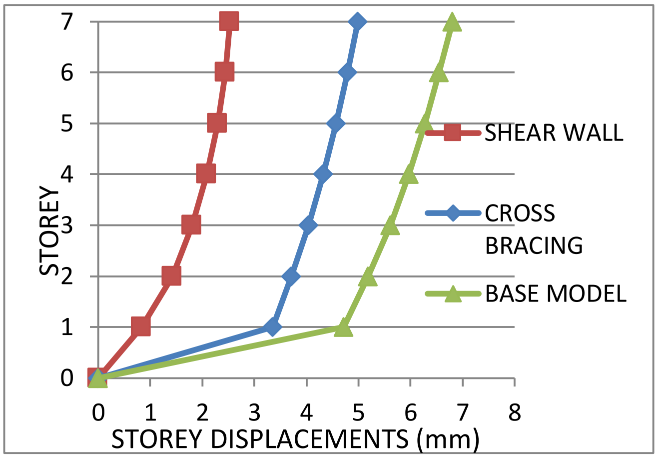


Fig 14- Observed values of Storey Displacements for Chi Chi

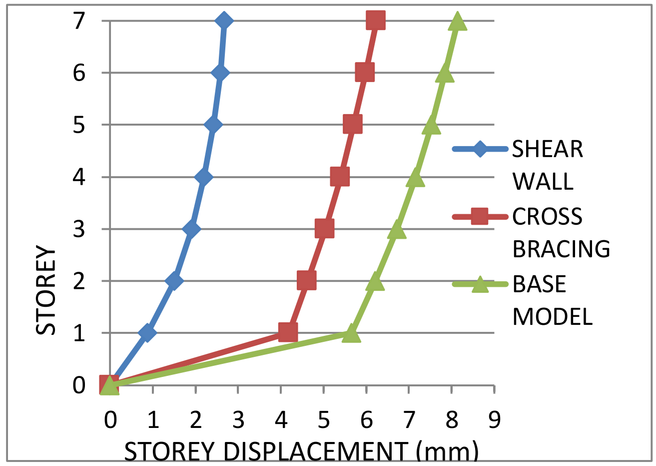


Fig 15- Observed values of Storey Displacements for Kobe

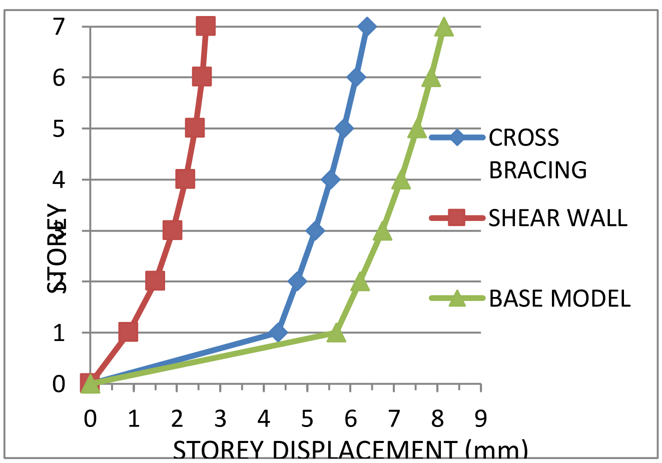


Fig 16- Observed values of Storey Displacements for El Centro

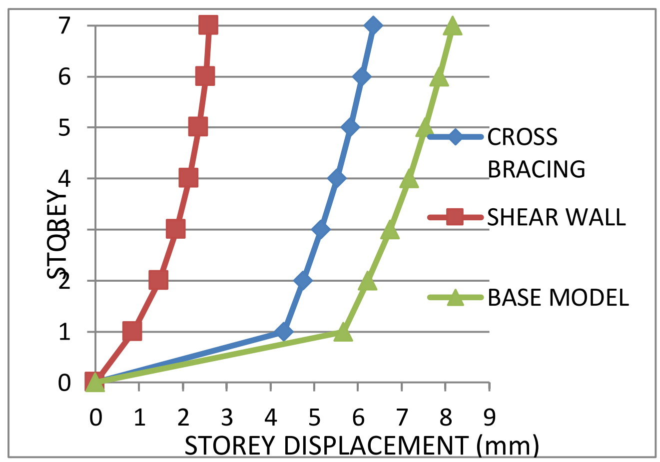


Fig 17- Observed values of Storey Displacements for LomaPreita

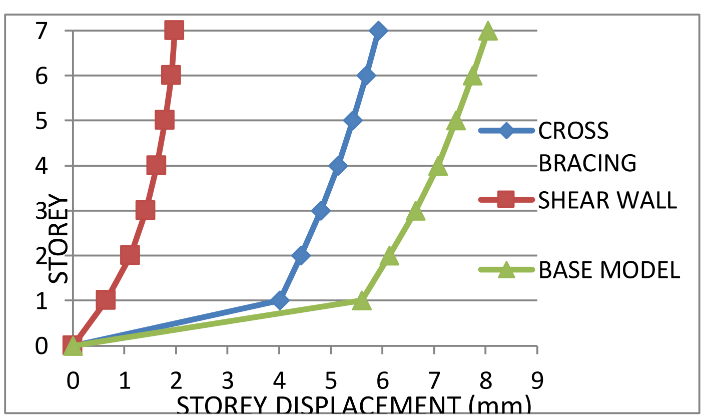


Fig 18- Observed values of Storey Displacements for North Ridge

From the above graphs it is clearly shown that the large storey displacement in case of soft storey in Model I. On the other hand if shear walls are used in the entire storey (Model II) the displacement is very small as compare to other two models. If we use shear wall in the structure then it reduces 75% displacement whereas if the cross bracings are used in the soft storey of base model then it will reduce 26% displacement.

3.3 TIME PERIOD-

A graph is plotted taking modes as Y axis and time period in X axis for all the models shown in figure below-

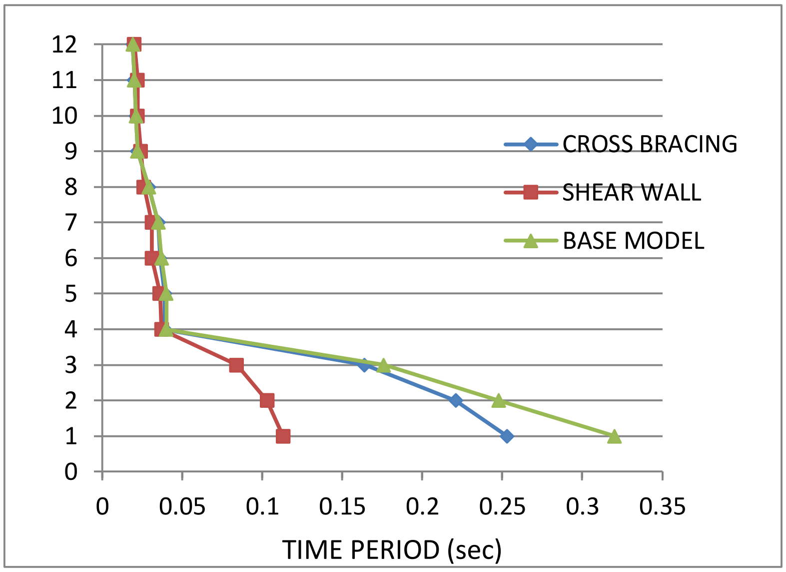


Fig 19- Comparison of time period for different modes in zone V

It is observed that the time period of vibrations for all the three models it is considerably reduced for models II and III as compared to model I. The model II having shear wall reduces time period in large extent as compare to model I and III which is base model and retrofitted with cross bracing respectively.

3.4 BASE SHEAR-

The base shear of different models are mentioned below-

Table 5- Observed base shear for different models.

EARTHQUAKES	BASE MODEL (KN)	CROSS BRACED MODEL (KN)	SHEAR WALL MODEL (KN)
Chi Chi	33679.8723	34043.7666	53318.8695
Kobe	40733.5333	41976.6685	56428.338
Loma Prieta	40416.8928	45461.8157	54986.9339
North Ridge	40386.7033	39459.3208	41646.0861
El Centro	40684.9721	44008.9444	54986.9339

Shear induced at the base of building during earthquake is called base shear which depends on the seismic mass and stiffness of building. Variation in base shear is as shown in table 3(a) and 3(b). It is observed that due to consideration of infill base shear has increased. Among all the different models, the building having shear wall i.e. model II has maximum base shear. Higher the base shear higher is the rigidity of the frame and more is the rigidity lesser is the displacement which can be seen in displacement graphs.(1)

3.5 PERFORMANCE POINTS-

Table 6- Performance points of different models.

Model	A – IO	IO - LS	LS – CP	CP - C	C - D	D - E	>E	TOTAL
Base Model	5204	12	5	15	0	0	0	5236
Cross Braced Model	5215	2	19	0	0	0	0	5236
Shear Wall Model	4564	0	0	0	0	0	0	4564

The plastic hinges may be applied to the beams, columns and bracings to study the nonlinear behavior as they show the structural conditions at different stages. Hinges will attain a collapsible condition after passing through some intermediate stages i.e. immediate occupancy (IO) and life safety (LS) levels. The formation of maximum number of hinges in the early stage is not good for the structure as it signifies the early reaching of collapse of the structure. From Table , it is clear that the number of hinge formation in retrofitted building by shear wall is less compared to the base model and retrofitted bycross bracing, thereby making it safer.

3.6 CAPACITY SPECTRUM CURVE-

In the graph shown below the retrofitted model with shear wall will have a higher performance level owing to the lower spectral displacement.

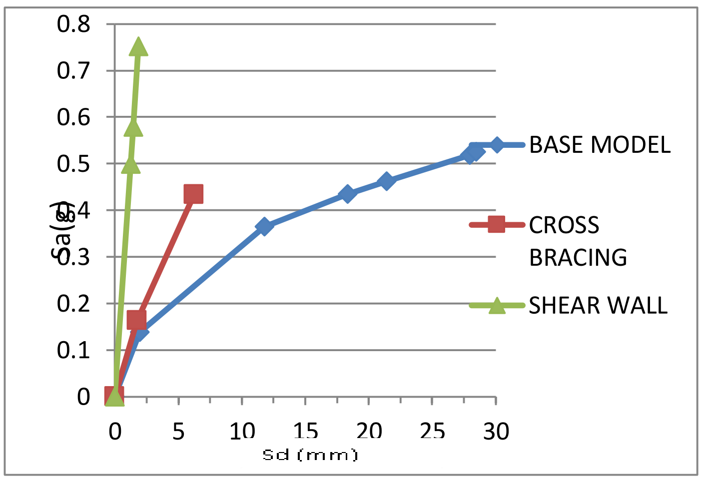
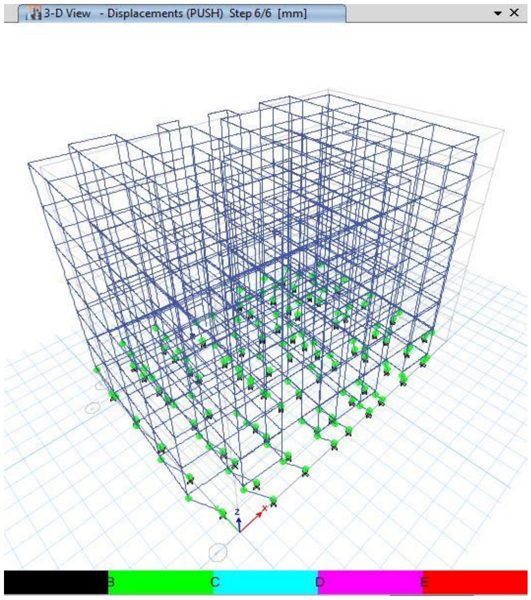


Fig 20 - Capacity Spectrum

This performance level can be found by overlapping the capacity spectrum with the Sa vs. Sd curve of target spectrum where Sa stands for spectral acceleration and Sd stands for spectral displacement.The ability of a structure to undergo inelastic deformation beyond the initial yield deformation is termed as ductility displacement. The ductility displacement demand of a given earthquake load is obtained from the pushover curve. The more the ductility displacement the more ductile is the structure. It can be clearly seen that the retrofitted building with shear wall has lesser ductility displacement.



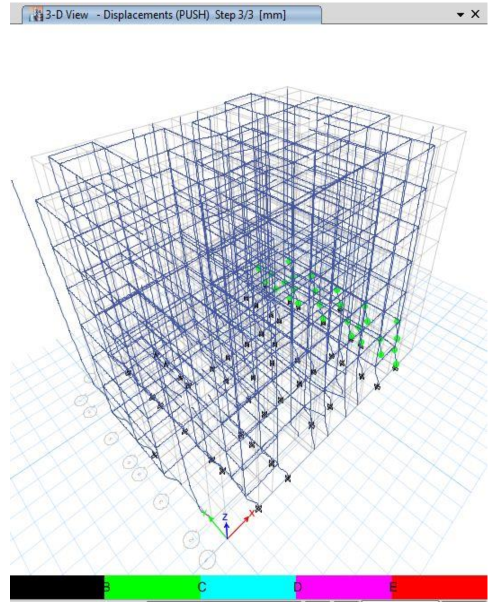


Fig 21- Hinge failure pattern for base model Fig 22- Hinge failure pattern for model retrofitted by shear wall

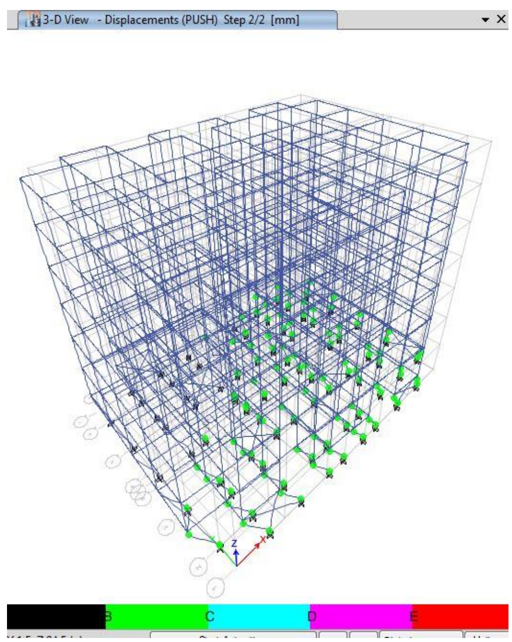


Fig23- Hinge failure pattern for model retrofitted by cross bracing

IV. CONCLUSION

The nonlinear behavior of the structure taken as case study of Zone V (Guwahati) had been analyzed for Time History as well as Pushover Analysis. It was subjected to a suite of six different earthquakes which were scaled as per the target spectrum of Zone-V and the performance of the structure was evaluated. The storey drift, storey displacement, base shear, time period, performance points and capacity spectrum have been observed and evaluated for base model and retrofitted with shear wall and cross bracings (both in different models). The behavior of retrofitted structure with shear wall may be significantly different from what has been observed for base model and cross bracing retrofitted structure. Synthesis of the observed seismic response has led down to the following conclusions-

1. Storey drift is reduced in base model due to introduction of shear wall as compared to cross bracing in great extent.
2. Storey displacement is reduced by 75 to 80% in model II and 23 to 26% in model III as compared to model I.
3. The time period of vibrations for all the three models was analyzed. It is considerably reduced for models II and model III as compared to model I.

4. Base Shear of models were analyzed and it is clearly shown that the base shear of the structure heavily increases and makes the structure more stable against seismic action by using shear wall for retrofitting of the structure.
5. The pushover analysis highlights the performance points in different models. It is shown that the performance of base model is poor as compare to other two models. After retrofitting the base model with shear wall the hinges are not formed beyond immediate occupancy level which makes structure safer.
6. In capacity spectrum curve model II shows less ductility demand under higher acceleration.

A financial feasibility study was also carried out, taking in to consideration the cost-benefit ratio, and it can be concluded that shear wall is an effective technique of retrofitting the structure against lateral loadings.

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