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Nonlinear Static and Dynamic Seismic Analysis of High Rise Structure with and without Shear Wall

Dhanshree A. Bhoskar[1] **Prof. R. V. R. K. Prasad**[2]
[1]M. Tech Student [2]Professor
[1,2]Department of Civil Engineering
[1,2]KDKCE, Nagpur-441501, Maharashtra, India

Abstract— Growth in construction and limited land has given birth to high rise structure. Building that aren't earthquake safe are prone to damage. However, Nonlinear Seismic procedures are becoming an acceptable and approved for evaluating seismic behavior on existing or new structure. Nonlinear Static Procedure or Pushover analysis is considered to be sufficient in providing information on seismic demands urged by the design ground motion on the structural system and its component. Nonlinear Static Procedure is proposed by FEMA 356- Prestandard for seismic Rehabilitation of Existing Buildings, which is embraced by In this research work, models with same plan and different number of storey will be considered. Each model, one with shear wall and one without shear wall will be examined. The models will be analyzed using nonlinear static and dynamic analysis considering Zone III in software. Parameters like storey drift, base shear and lateral drift will be evaluated for models for comparative study. The analysis of model will be done according to International Standards as well as Indian Standards codes.

Keywords: Pushover Analysis, Time-History Analysis, High Rise Structures, Shear Wall

I. INTRODUCTION

The height of a building is relative and cannot be defined in absolute terms either in relation to height or the number of stories. But, from a structural engineer's point of view the tall building or multi-storied building can be defined as one that, by virtue of its height, is affected by lateral forces due to wind or earthquake or both to an extent that they play an important role in the structural design. Earthquakes have become a frequent event all over the world. It is very difficult to predict the intensity, location, and time of occurrence of earthquake. The design approach adopted in the Indian Code IS 1893(Part I): 2002 'Criteria for Earthquake Resistant Design Of Structures' is to ensure that structures posses at least a minimum strength to withstand minor earthquake occurring frequently, without damage; resist moderate earthquakes without significant structural damage though some non-structural damage may occur; and aims that structures withstand major earthquake without collapse.

II. METHOD OF ANALYSIS

Structures need to have suitable earthquake resistant features to safely resist large lateral forces that are imposed on them during frequent earthquakes. These lateral forces can produce the critical stresses in a structure, set up undesirable vibrations and, in addition, cause lateral sway of structure, which could reach a stage of discomfort to the occupants.

For a calculation of the seismic response, the linear state of stress is often used. In complex situation or by higher significance of the structure is suggested to use some non-linear method. These two methods of analysis are used and defined:

- Non-linear static (pushover) analysis,
- Non-linear time-history (dynamic) analysis

A. *Non-linear Static (Pushover) Analysis*

Pushover analysis is a nonlinear static analysis for a structure subjected to lateral loading. The gravity loads are applied, and then lateral loading is applied – first in X direction starting at the end of the gravity push, and next in Y-direction again starting at the end of the gravity push (Valles et al., 1996; CSI, 2000). The concept of plastic hinge is extremely important in the nonlinear analysis.

While a concrete element undergoes large deformations in the post-yield stage, it is assumed that all the deformation takes place at a point called "plastic hinge", which has approximately a length of the order of the effective depth (also called as plastic hinge length, ld). The rotation capacity θ of a plastic hinge is taken as $ld(\varphi u - \varphi y)$. A similar approach can be used for obtaining the rotation capacity of columns under axial force and bending moment in two directions. Similar plastic hinges with limit capacities on deformation can be defined for all six degrees of freedom, namely, axial force, transverse shear forces in X- and Y-directions, moments about Y- and Z-axes, and torsion (moment about X-axis). More details on evaluation of ductility, energy absorption, damage modelling, and detailing are available elsewhere (Lakshmanan, 2003a, 2005a). A typical response at a plastic hinge may be as shown in Figure (i). Here, Point A is the origin; B is the point of yielding; BC represents the strain-hardening region; C is the point corresponding to the maximum force; and DE is the post-failure capacity region. On the frame structure, the analyst identifies the possible locations for plastic hinge formation from his experience. Mathematically, nonlinear static analysis does not lead to a unique solution. Small changes in properties or sequence of loading can lead to large variations in the nonlinear response.

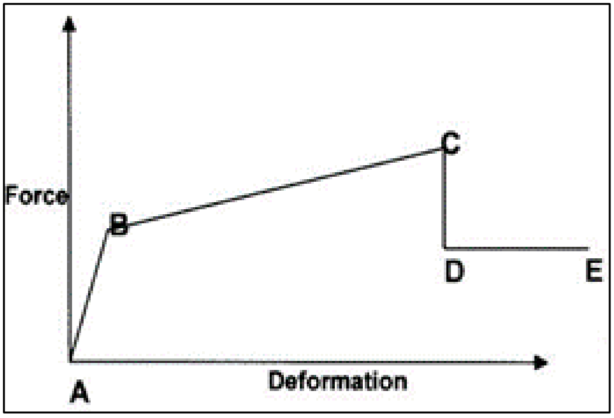

Fig. 2.1.1: Idealized force-deformation curve

B. Non-linear Time History (Dynamic) Analysis

Time History Analysis, in order to examine the exact nonlinear behavior of structures, nonlinear time history analysis has to be carried out. In this method, the structure is subjected to real ground motion records. This makes this analysis method quite different from all of the other approximate analysis methods as the inertial forces are directly determined from these ground motions and the responses of the building either in deformations or in forces are calculated as a function of time, considering the dynamic properties of the structure.

III. MODELING AND METHODOLOGY

The models which have been adopted for study are symmetric fifteen storey (G+15) and symmetric twenty storey (G+20) buildings.

A. Material Properties

- Seismic Grade of Concrete – M35
- Grade of Reinforcement – Fe500
- Poisson Ratio of Concrete – 0.2
- Poisson Ratio of Reinforcement – 0.3
- Density of Concrete – 25KN/m3
- Damping Factor – 0.05 (As per Clause 7.2.4 of IS 1893(Part 1):2016

B. Response Spectrum Analysis

- The slab thickness – 125 mm
- Beam cross sections – 0.60 m × 0.30 m
- Internal Column – 0.75 m × 0.75 m
- Corner Column – 0.85 m × 0.35 m
- Peripheral Column – 0.70 m × 0.40 m
- Storey Height – 3.0 m on all the stories.
- Shear Wall thickness = 250 mm

C. Time History Analysis

A Wall load = unit weight of brickwork x thickness of wall x height of wall.

- Unit weight of brickwork = 20KN/m^3
- Thickness of wall = 0.23m
- Wall load on all other levels = 20 x 0.23 x 3 = 13.8KN/m (wall height = 3m)

Live loads have been assigned as uniform area loads on the slab elements as per IS 1893(Part 1) 2016

- Live load on roof = 1.5 KN/m^2
- Live load on all other floors = 4.0 KN/m^2

D. Load Combination

- 1.2(DL+LL±(EQX±0.3EQY))
- 1.2(DL+LL±(EQY±0.3EQX))
- 1.5(DL±(EQX±0.3EQY))
- 1.5(DL±(EQY±0.3EQX)
- 0.9DL±1.5(EQX±0.3EQY)
- 0.9DL±1.5(EQY±0.3EQX)

Four models have been considered for the purpose of the study.

- Fifteen storey (G+15) building without shear walls.
- Fifteen storey (G+15) building with shear walls.
- Twenty storey (G+20)building without shear walls.
- Twenty storey (G+20) building with shear walls. The plan of the two buildings is as shown below.

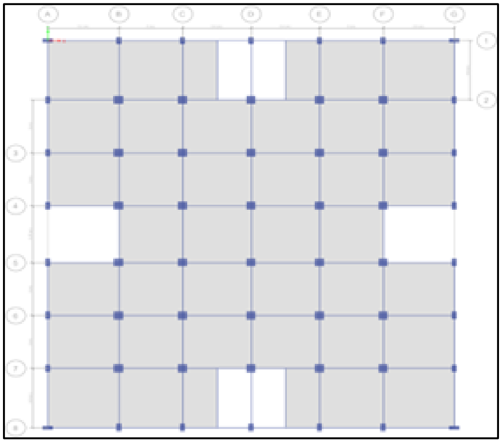

Fig. 3.3.1: Typical plan of building

IV. ANALYSIS OF THE STRUCTURE

Namely two types of analysis procedures have been carried out for determining the various structural parameters of the model. Here we are mainly concerned with the behavior of the structure under the effect of ground motion and dynamic excitations such as earthquakes and the displacement of the structure in the elastic range. The analyses carried out by Response spectrum and Linear Time History method.

Modal analysis is carried out for obtaining the natural frequencies, modal mass participation ratios and other modal parameters of the structure. where,

Z = 0.16 considering zone factor III
I = 1.5 considering commercial building.
R = 5.0 considering special RC moment resistant frame (SMRF)
S a /g = By software

For the static nonlinear analysis effect, response spectrum method is carried out using the spectra for medium soil as per IS 1893 (Part 1) 2016.

The spectral acceleration coefficient (Sa/g) values are calculated as follows.

For medium soil sites, $Sa/g = 1+15*T$ $\quad T \leq 0.10$
$=2.5 \quad 0.10 \leq T \leq 0.55$
$=1.36/T \quad 0.55 \leq T \leq 4.00$
$=0.34 \quad T > 4.00$

A. Modeling of Flexural Plastic Hinges

In the implementation of pushover analysis, the model must account for the nonlinear behaviour of the structural elements. In the present study, a point-plasticity approach is considered for modelling nonlinearity, wherein the plastic hinge is assumed to be concentrated at a specific point in the frame member under consideration.

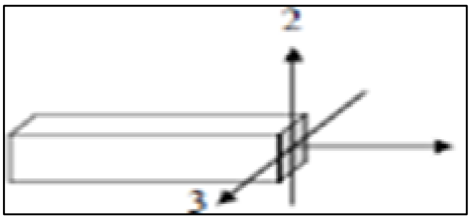

Fig. 4.1.1: The coordinate system used to define the flexural and shear hinges

Beam and column elements in this study were modeled with flexure (M3 for beams and P-M2-M3 for columns) hinges at possible plastic regions under lateral load (i.e., both ends of the beams and columns). Refer above figure for the local axis system considered.

B. Modeling of Time History Function

Time History analysis has been carried out using the Imperial Valley Earthquake record of May 18, 1940 also known as the El centro earthquake for obtaining the various floor responses. The record has 1559 data points with a sampling period of 0.02 seconds.

The peak ground acceleration is 0.319g. Newmark's direct integration method has been adopted and the mass and stiffness proportional coefficients have been calculated taking into account the frequency of the structure in two consecutive modes in the same direction.

The horizontal component of "EL-Centro" earthquake ground motion is chosen for time history analysis. The details of the ground motion like PGA and recording station is presented in graph .the ground motion are applied along the X direction. The linear Time History Analysis in ETABS 2016 was performed.

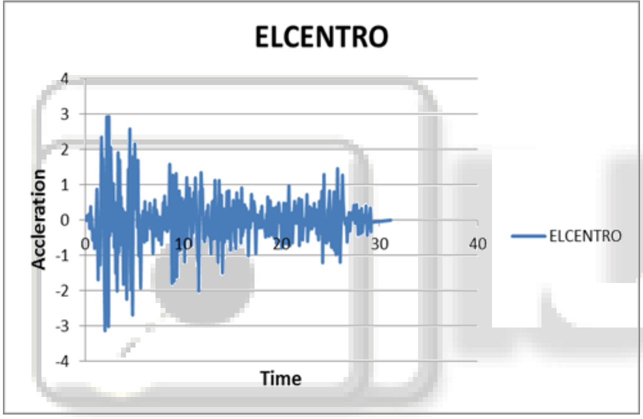

Fig. 4.2.1: Graph showing El-Centro ground motion data up to 30 sec

V. RESULTS AND DISCUSSION

After the 3-D model was defined and assigned with all the properties, the displacement controlled pushover analysis was performed.

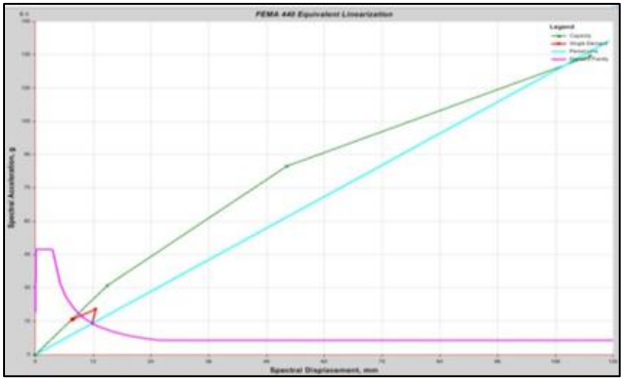

Fig. 5.1: Demand capacity versus spectrum capacity due to Push in x- dir – G+15 building

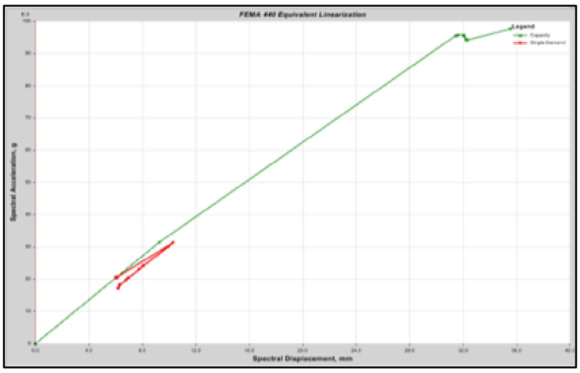

Fig. 5.2: Demand capacity versus spectrum capacity due to Push in x- dir – G+15 building with shear wall.

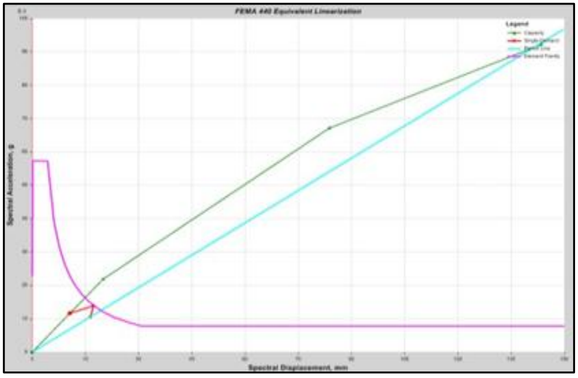

Fig. 5.3: Demand capacity versus spectrum capacity due to Push in X- direction – G+20 building.

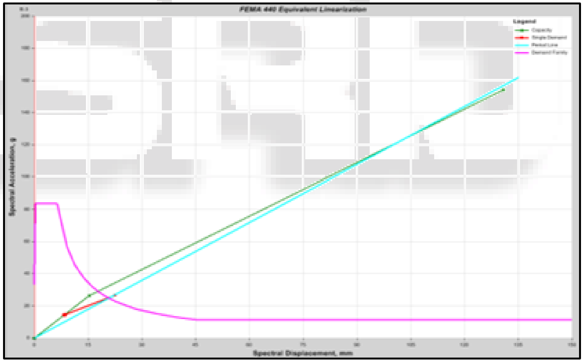

Fig. 5.4: Demand capacity versus spectrum capacity due to Push in X- direction – G+20 building with shear wall.

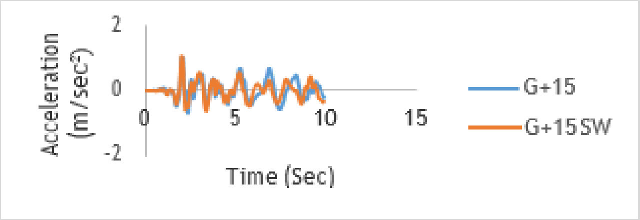

Fig. 5.5: Acceleration in m/sec² for G+15 building with and without shear wall.

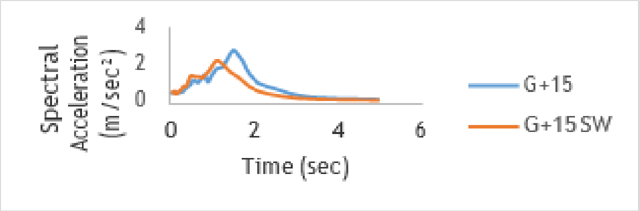

Fig. 5.6: Spectral Acceleration in m/sec² for G+15 building with and without shear wall.

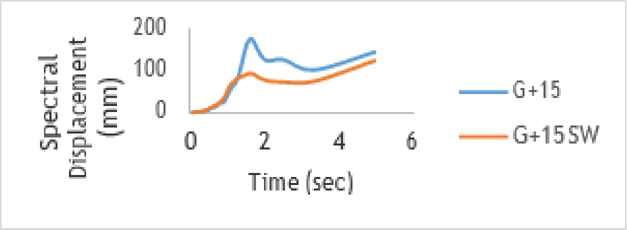

Fig. 5.7: Spectral displacement in mm for G+15 building with and without shear wall.

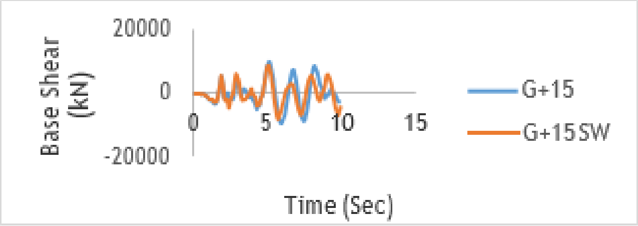

Fig. 5.8: Base shear in kN for G+15 building with and without shear wall.

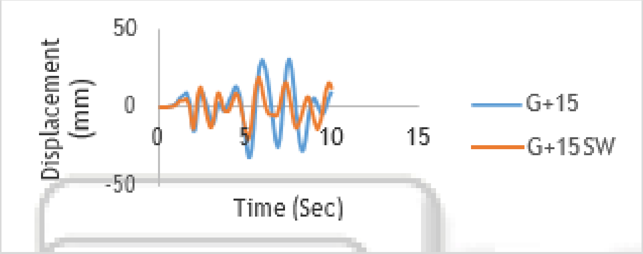

Fig. 5.9: Maximum lateral displacement in mm for G+15 building with and without shear wall.

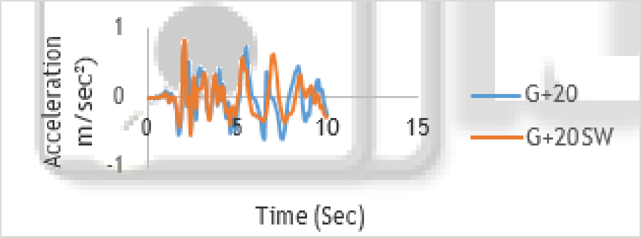

Fig. 5.10: Acceleration in m/sec² for G+20 building with and without shear wall.

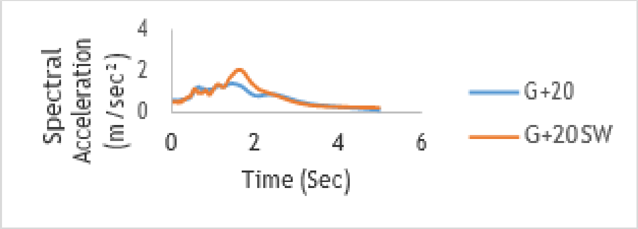

Fig. 5.11: Spectral Acceleration in m/sec² for G+20 building with and without shear wall.

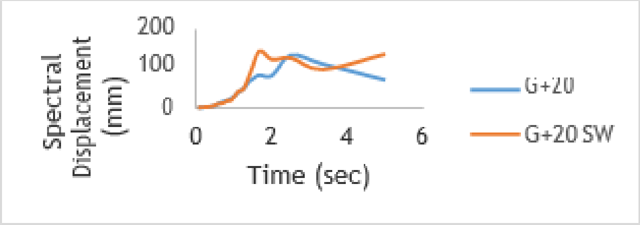

Fig. 5.12: Spectral displacement in mm for G+20 building with and without shear wall.

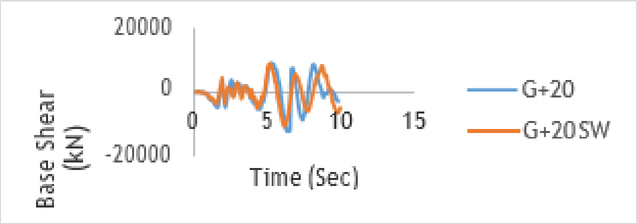

Fig. 5.13: Base shear in kN for G+20 building with and without shear wall.

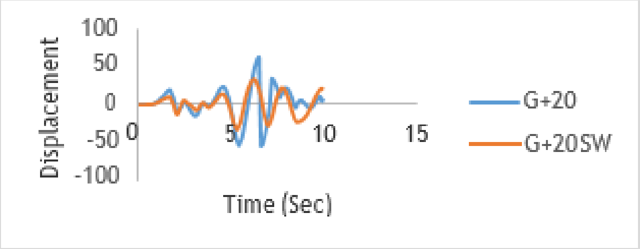

Fig. 5.14: Maximum lateral displacement in mm for G+20 building with and without shear wall.

VI. OBSERVATIONS

- From the Figure 5.1 it can be seen that the demand curve intersects the capacity curve (Sa = 0.015977g, Sd = 7.672mm) near an elastic response zone and it means that a safety margin is granted.
- From the Figure 5.2 it can be seen that the demand curve intersects the capacity curve (Sa = 0.020517g, Sd = 6.06mm) near an elastic response zone and it means that a safety margin is granted.
- From the Figure 5.3 it can be seen that the demand curve intersects the capacity curve (Sa = 0.011594g, Sd = 10.605mm) near an elastic response zone and it means that a safety margin is granted.
- From the Figure 5.4 it can be seen that the demand curve intersects the capacity curve (Sa = 0.014567g, Sd = 8.464mm) near an elastic response zone and it means that a safety margin is granted. Therefore, it can be concluded that the safety margin against collapse is high and the structural system has sufficient strength and displacement reserves.
- Fig. 5.5 shows plot of acceleration used for analysis in G+15 building with and without shear wall for El centro ground motions. It is shows that maximum acceleration value is 1m/sec² at 2.5sec for G+15 building. Also maximum acceleration is 1.0735m/sec² at 2 sec for G+15 building with shear wall.
- Fig. 5.6 shows plot of spectral acceleration for G+15 building with and without shear wall for El centro ground motions. It is shows that spectral acceleration is 2.768m/sec² at 1.54 sec for G+15 building. Also spectral acceleration is 2.237m/sec² at 1.11 sec for G+15 building with shear wall.
- Fig. 5.7 shows plot of maximum spectral displacement for G+15 building with and without shear wall for El centro ground motions. It is shows that maximum spectral lateral displacement is 174.33mm at 1.66 sec for G+15 building. Ground motion acceleration for this spectral lateral displacement is 0.03 m/sec². Also maximum spectral lateral displacement is 124.60mm at

5 sec for G+15 building with shear wall. Ground motion acceleration for this spectral lateral displacement is 0.01 m/sec².

- Fig. 5.8 shows plot of base shear output for G+15 building with and without shear wall for El centro ground motions. It is shows that maximum base shear is 9993.6243kN at 5.1 sec and minimum base shear is 9401kN at 6 sec for G+15 building. Also maximum base shear is 8753.168kN at 5.1 sec and minimum base shear is 7822kN at 5.7 sec for G+15 building with shear wall.
- Fig. 5.9 shows plot of maximum lateral displacement for G+15 building with and without shear wall for El centro ground motions. It is shows that maximum lateral displacement is 31.956mm at
- 5.2 sec for G+15 building. Also maximum lateral displacement is 20.0328mm at 5.2 sec for G+15 building with shear wall.
- Fig. 5.10 shows plot of acceleration used for analysis in G+20 building with and without shear wall for El centro ground motions. It is shows that maximum acceleration value is 0.776133m/sec² at 2.1sec for G+20 building. Also maximum acceleration is 0.83417m/sec² at 2.1 sec for G+20 building with shear wall.
- Fig. 5.11 shows plot of spectral acceleration for G+20 building with and without shear wall for El centro ground motions. It is shows that spectral acceleration is 1.38m/sec² at 1.4285 sec for G+20 building. Also spectral acceleration is 2.0537m/sec² at 1.66 sec for G+20 building with shear wall.
- Fig. 5.12 shows plot of maximum spectral displacement for G+20 building with and without shear wall for El centro ground motions. It is shows that maximum spectral lateral displacement is 132.6415mm at 2.5 sec for G+20 building. Ground motion acceleration for this spectral lateral displacement is 0.02 m/sec².Also maximum spectral lateral displacement is 142.61963mm at 1.666 sec for G+20 building with shear wall. Ground motion acceleration for this spectral lateral displacement is 0.01 m/sec²
- Fig. 5.13 shows plot of base shear output for G+20 building with and without shear wall for El centro ground motions. It is shows that maximum base shear is 9228.40kN at 5.2 sec and minimum base shear is 12199kN at 6.3 sec for G+20 building. Also maximum base shear is 8839.13kN at 5.1 sec and minimum base shear is 10606kN at 6.1 sec for G+20 building with shear wall.
- Fig. 5.14 shows plot of maximum lateral displacement for G+20 building with and without shear wall for El centro ground motions. It is shows that maximum lateral displacement is 61.2497mm at 6.5 sec for G+20 building. Also maximum lateral displacement is 33.0076mm at 6.2 sec for G+20 building with shear wall.

VII. CONCLUSION

Lateral displacement in building with shear wall is reduced to 30% as compared to building without shear wall by both methods in both directions.

Time period of building with shear wall is low than as that of building without shear wall.

Storey drift of building with shear wall is reduced to 60% as that of building without shear wall in both directions.

Axial force in columns of building with shear wall is reduced to 40% as that of building without shear wall.

Shear force and moments in columns of building with shear wall is reduced to 60% as that of building without shear wall.

The pushover analysis is simple way to study the static nonlinear behavior of buildings. The results obtained in terms of pushover demand, capacity spectrum and plastic hinge shows load carrying capacity of structures. As per weak beams and strong columns criteria, hinges are formed in beams first. The column hinges have limited damages.

Provision of shear wall results in a huge decrease in base shear and roof displacement. Base shear is reduced to about 30% and roof displacement is reduced to 60% using shear wall at corners.

The performance of reinforced concrete frames was investigated using the pushover analysis. As a result of the work that was completed in this study, the following conclusions were made:

- It is concluded that G+15 and G+20 building frame used for pushover analysis were seismically safe, because the demand curve intersects the capacity curve near the elastic range, the structure has a good resistance and high safety against collapse.
- Maximum roof displacement in with and without shear wall building were within target displacement. Also hinges were not formed in C-D limit (LS-CP) for all models for design roof displacement, so safety against collapse is granted.

As Time History Analysis is a realistic method used for seismic analysis, it provides a better check to the safety of structures analyzed and designed by the method specified in IS code.

Nonlinear time history analysis of building shows that building has capacity to displace 60% more safely than design displacement.

Seismic performance of building can be improved by providing shear wall.

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