Shear Wall And Steel Bracing System Seismic Interaction in High Rise Buildings

Dr. Rama Mohan Rao P[1], Nihal Kumar Choudhary[2]
[1]Associate Professor, Dept of Sr.(Centre for Disaster Mitigation and Management),
[2]Dept of in Structural Engineering
[1, 2] Vellore Institute of Technology,Vellore -632014.

Abstract- *ETABS software represent extended three-dimensional analysis of building systems. The main task of this software is the analysis (linear or nonlinear) and design of multi-story buildings. This paper checks the seismic vulnerability and structural deformation of a G+10 storied R.C. building model located in the urban areas of earthquake zone V using the finite element program (ETABS) and proposes the best and most economical retrofitting technique against seismic vulnerability. The present work inspects the combined behavior of shear wall and Steel bracing system, and also the influence of their position in high rise residential building (G+10) under seismic loading. Response Spectrum Analysis is done for each model with and without Shear Wall and combined Shear Wall and Steel Bracing.*

Keywords- Response Spectrum Analysis, seismic vulnerability, finite element program, Steel Bracing, shear wall, structural deformation, retrofitting.

I. INTRODUCTION

There is a great requirement of construction of high rise buildings due to expansion of the process of the formation and growth of cities and also due to the increase in population. Earthquakes have the ability for causing severe damages to tall structures. The Earthquake causes shivering ground motions at the base of the structure, and the structure rapidly reacts to these motions. Earthquake is a universal phenomenon which cannot be avoided and projected but the damage caused by an Earthquake can be reduced by enhancing the lateral force resistance of the structure through design and construction practices unlike from the older methods. The failure of the structure starts at the point of imperfections or weakness in the structure. These spots of imperfections are may be due to irregularity/discontinuity in geometry, stiffness and mass of the structure. Therefore in practical field our attempt should be to make regular kinds of structures. However there are many real life cases where due to certain limitations imposed by people on the construction of regular structures irregularity remains the only option to go for.

Usually reinforced concrete multi-storied buildings are very complicated to model and are modeled as two dimensional or three dimensional frame systems using finite beam elements. Since, the Earthquake forces are unplanned in nature and uncertain, the engineering tools need to be refined for analyzing the structures under the action of these forces.
Analyzing the structure for preceding earthquakes of different magnitudes and checking for multiple conditions at each level has become crucial and central these days. The main variables to be examined in the seismic analysis of structures are load carrying capacity, ductility, stiffness, damping and mass. The analysis can be divided into two main steps. First, a linear analysis is carried out with dimensioning of all the structural elements, checking the functionality of the structure after minor earthquakes, and then the action of structures during strong earthquakes has to be seen using non linear methods.

Seismic Retrofitting is the modification of existing structures to make them more resistant to seismic activity, ground motion, or soil failure due to earthquakes. In buildings this process includes restoring the weak connections, continuity ties, shear walls and the roof diaphragms.

Seismic Retrofitting of vulnerable structures is important for protecting the lives and properties of building occupants and to maintain the continuity of their work.

When a discussion about retrofitting methods is going on, it is important to tell about the various types of retrofitting techniques. There are two types of retrofitting techniques:

i. Global
ii. Local

Global Retrofitting Technique: To provide increased lateral stiffness and strength to the building as a whole. And to ensure that a total collapse of the building does not occur. Global retrofitting technique include- adding shear wall, adding infill wall, adding bracings, adding wing wall, wall thickening, mass reduction, base isolation, mass dampers.

Local Retrofitting Technique: To avoid failure of the component and also thereby enhance the overall performance of the structure. Local retrofitting technique include- Jacketing of Beams, jacketing of columns, jacketing of beam-column joints, strengthening of individual footings.

AIM OF STUDY

The aim of the following study is to propose the use of both Shear Wall and Steel X Bracing system in the identical structure to make a structure safe and economical. Also, in this work emphasis is given on the use of Shear Wall and Steel X Bracing system so as to manage the design eccentricity within the limits laid down by standard codes of practices.

OBJECTIVES

- Check for the seismic vulnerability of RC buildings using a finite element program (ETABS)
- To evaluate the seismic behavior of RCC high rise building stiffened with both shear walls and X-bracing system of Steel (section-ISMB 250) subjected to seismic load.
- To check out the effect on seismic performance of high rise building due to different relative positions of shear wall and Steel bracings (X-type) system.
- To study the seismic parameters for RCC frame, RCC frame with Steel Bracing system, and RCC frame with shear wall.
- To compare the results of different models based on use and relative position of shear wall and Steel X-bracing system.
- To figure out the safest and most economical model after going through the obtained values of seismic parameters like Base Shear, Storey Displacement, Storey Drift and Storey Stiffness.

II. THE ORETICAL BACKGROUND

Seismic Retrofitting

Seismic Retrofitting is the alteration of existing structures to make them more protected against seismic activity, ground motion, or soil failure due to earthquakes. With better awareness of seismic demand on structures retrofitting of existing structures with inadequate seismic resistance accounts for majority of the total cost of hazard remission. Thus, it is very important that the structures that need seismic retrofitting are recognized carefully and a proper retrofitting is performed in a cost-effective fashion.

Response Spectrum Analysis

RSA is a linear-dynamic statistical analysis method which measures the contribution from each natural mode of vibration to show the probable maximum seismic response of an essentially elastic structure. Response Spectrum Analysis provides an imagination into dynamic behavior by measuring pseudo-spectral acceleration, velocity, or displacement as a function of structural period for a given time history and level of damping. It is practical to envelope response spectra such that a smooth curve constitutes the peak response for each accomplishment of structural period.

It is a method to estimate the structural response to short, non-deterministic transient dynamic events. Examples of such events are Earthquakes and shocks. Since the exact time history of the load is not known, it is difficult to perform a time dependent analysis. Due to short length of the event, it cannot be considered as a stationary process, so a random response approach is not applicable either. The Response Spectrum method is based on a special type of mode superposition. The idea is to provide an input that gives a limit to how much an eigen mode having a certain natural frequency and damping can be excited by an event of this type.Response Spectrum Analysis is useful for design decision-making because it relates structural type categorization to dynamic performance. Structures of shorter period experience greater acceleration, whereas those of longer period experience greater displacement.

RSA provides judgement into how damping affects structural response. A series of response curves may be developed with alterable levels of damping. As damping increases, response spectra move downwards.

The International Building Code (IBC) is based on 5% damping. This accounts for insignificant damping from hysteretic behavior, which is not clearly modeled during RSA. All response quantities are positive; therefore, RSA is not acceptable for torsional irregularity. A static lateral load process is best for measuring accidental torsion. The same is applicable when considering uplift and compression during foundation design. Modal response may be combined using SRSS, CQC, ABS or GMC methods. CQC is best when periods are very closely spaced with cross-disassociation between mode shapes. SRSS is suitable when period varies by more than 10%. Ritz vectors are endorsed for RSA because this expression is computationally efficient.

Certain terminologies which needs to be given an eye on for becoming familiar with the process of Response Spectrum Analysis are as follows :

Base Shear : Base Shear is an estimate of the maximum expected lateral force on the base of the structure due to seismic activity. It is calculated using seismic zone, soil material, and the building code lateral force equations.

As per IS 1893, Part 1-2002, the design base shear is calculated according to the equation VB = Ah x W

where Ah = Design horizontal seismic coefficient W= Building WeightAs per Clause 6.4.2 of IS 1893 Part 1:2002,
Ah= (Z x I x Sa/ 2R x g) where Z- zone factor

I- Importance Factor
R- Response Reduction factor
Sa/g- Spectral Acceleration Coefficient

Mass Participation Factor: The effective mass participation factor represents the percentage of the system mass that participates in a particular mode. It provides a measure of the energy contained within each resonant mode.

Modal Mass: The modal mass is equal to the product of the total mass of the structure and the squared length.

Mode: A characteristic manner in which vibration occurs. In a freely vibrating system, oscillation is restricted to a certain characteristic pattern of motion at certain characteristic frequencies; these motions are called Normal modes of vibration.

Mode Shape: A mode shape is the deformation that the component would show when vibrating at the natural frequency.

Natural Frequency: Natural frequency is the frequency at which a system tends to oscillate in the absence of any damping or driving force.

Response Reduction Factor: It is the factor by which the actual base shear force should be reduced to obtain the design lateral force during design basic Earthquake shaking.

Spectral Acceleration Coefficient: Spectral acceleration is a unit measured in g(the acceleration due to Earth's gravity) that describes the maximum acceleration in an Earthquake on an object specifically a damped harmonic oscillator moving in one physical dimensions.

Pushover Analysis

Pushover Analysis is a static analysis used to examine how far into the inelastic range a building can proceed before total or partial collapse. It can help exhibit how successive failure in building occurs really and recognize the mode of final failure. In the process, the method also sees the possible weak areas in the structure, by keeping tabs on the sequence of damages of each and every member in the structure (by use of what are called 'hinges' they hold.).

Pushover vs Conventional Analysis

- In order to understand the PA the best approach would be to first notice the closeness between PA and the conventional seismic analysis (SA), both seismic coefficient and Response Spectrum methods described in IS 1893-2002.
- Both SA and PA apply lateral load of a predetermined perpendicular distribution style on the structure. In SA, the lateral load is assigned either parabolically (in Seismic Coefficient Method) or equivalent to the modal combination (in the direct combination method of Response Spectrum). In PA, the dissemination in proportional to heights raised to the power of 'k' where k (equivalent to 2 in the equation under Cl 7.7.1 in IS 1893-2002) can be equal to zero (uniform distribution).
- In both SA and PA, the peak lateral load calculated for the structure is computed based on the fundamental time period of the structure.
- And the ultimate point above is precisely where the difference starts. While in SA the first time period is taken to be a constant (equal to its initial value) in PA this is constantly recalculated as the analysis progresses. The difference between the process are as follows: -
- SA uses an elastic model, while PA uses a nonlinear model. In the latter this is embraced in the form of non-linear hinges placed into an otherwise linear elastic model which one produces using a common structural analysis and design software package (SAP 2000 or Staad.Pro), having facilities for PA.

Hinges

Hinges are points on a structure where cracking and yielding is expected to occur in comparably higher intensity so that they show high flexural (or shear) displacement, as it reaches its ultimate strength under cyclic loading. These are those locations where cross diagonal cracks in an actual building structure is expected after a seismic destruction, and they are formed at either ends of beams and columns, the 'cross' of the cracks being at a small distance from the joint-that is where one is supposed to insert the hinges in the beams and columns of the corresponding computer analysis model. Hinges are of various types namely, flexural hinges, shear hinges and axial hinges. The first two are placed into the ends of beams and columns. Since the presence of masonry infills have powerful impact on the seismic behavior of the structure, modeling them using equivalent diagonal struts is usual in PA, unlike in conventional analysis, where its insertion is a scarcity. The axial hinges are inserted at either ends of the diagonal struts thus modeled, to replicate cracking of infills during analysis.

Shear Walls

A shear wall is a structural panel that can resist lateral forces acting on it. Lateral forces are those that are parallel to the plane of the wall, and are typically wind and seismic loads. In simple terms, lateral forces could push over parallel structural panels of a building were if not for perpendicular shear walls keeping them upright. When a structural member records failure by shear, two parts of it are pushed in distinct directions, for example, when a piece of paper is cut by scissors.

Shear Walls are specially important in large, or high-rise buildings, or buildings in areas of high wind and seismic activity.

Shear Walls are generally constructed from materials such as concrete or masonry. Shear forces can also be repelled by steel braced frames which can be very effective at thrashing out lateral forces but may be more uneconomical. Shear Walls can be positioned at the perimeter of buildings or they may create a shear core-a structure of shear walls in the centre of a building, typically enclosing a lift shaft or stairwell.

Lateral pressures looks after creating a rotational force on the shear wall which, due to the shear wall reacting as one member, produces a compression force at one corner and a tension force at another. When the lateral force is put on from the opposite direction, this ‘couple’ is reversed, meaning that both sides of the shear wall need to be competent of resolving both types of forces.

Steel Bracings

Steel Bracing is a highly effective and economical method of withstanding horizontal forces in a frame structure. Bracing has been used to sustain laterally the most of the world’s tallest building structures as well as one of the major retrofit measures. Bracing is effective because the diagonals work in axial stress and therefore call for minimum member sizes in imparting stiffness and strength against horizontal shear. A number of researchers have checked out various techniques such as infilling walls, adding walls to existing columns, encasing columns, and adding steel bracings to enhance the strength and/or ductility of existing buildings. A bracing system improves the seismic performance of the frame by enlarging its lateral stiffness and capacity. Through addition of the bracing system, load could be passed out of the frame and intothe braces, bypassing the weak columns while improving strength. Steel braced frames are effective structural systems for buildings subjected to seismic or wind lateral loadings. Therefore, the use of steel-bracing systems for retrofitting reinforced-concrete frames with limited lateral resistance is attractive.

Types of Bracings

There are two types of bracing systems, Concentric Bracing System and Eccentric Bracing System.

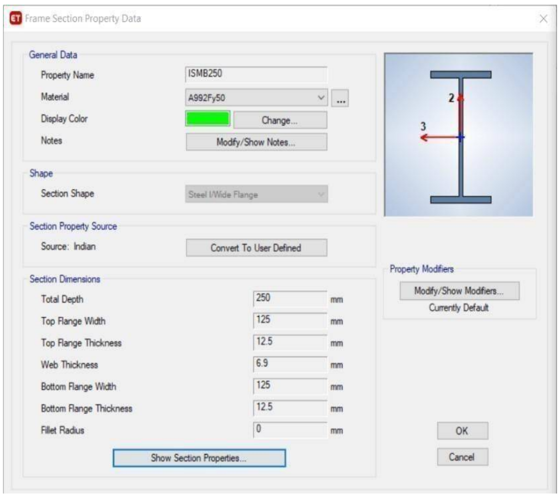
The steel braces are generally placed in vertically oriented spans. This system allows to acquire a great increase of stiffness with a least added weight, and so it is very efficient for prevailing structure for which the poor lateral stiffness is the primary cause of worry.

The concentric bracings increase the lateral stiffness of the frame, thus improving the natural frequency and also usually reducing the lateral drift. However, increase in the stiffness may engage a large inertia force due to earthquake. Further while the, bracings reduce the bending moments and shear forces in columns, they raise the axial compression in the columns to which they are connected. Since reinforced concrete columns are robust in compression, it may not cause a problem to retrofit in RC frame using concentric steel bracings.

Eccentric Bracings decreases the lateral stiffness of the system andincreases the energy depletion capacity. Due to eccentric connection of the braces to beams, the lateral stiffness of the system relies upon the flexural stiffness of the beams and columns, thus reducing the lateral stiffness of the frame. The vertical component of the bracing forces due to earthquake causes lateral concentrated load on the beams at the point of bond of the eccentric bracings.

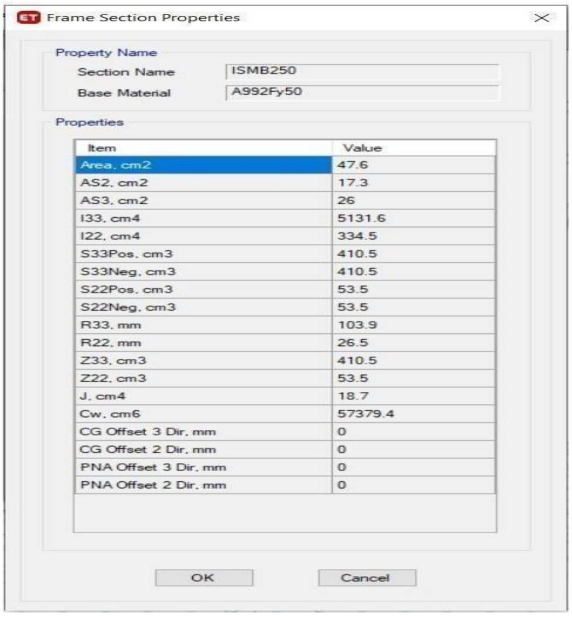
Type of Steel Bracing adopted in this work :

Steel section ISMB 250 is taken as a lateral load resisting system in this work. The section dimensions and properties associated with this section are as follows :



Frame Section Property Data

General Data
Property Name: ISMB250
Material: A992Fy50
Display Color: 🟩
Shape
Section Shape: Steel I/Wide Flange
Section Property Source
Source: Indian
Section Dimensions
Total Depth: 250 mm
Top Flange Width: 125 mm
Top Flange Thickness: 12.5 mm
Web Thickness: 6.9 mm
Bottom Flange Width: 125 mm
Bottom Flange Thickness: 12.5 mm
Fillet Radius: 0 mm
Property Modifiers: Currently Default



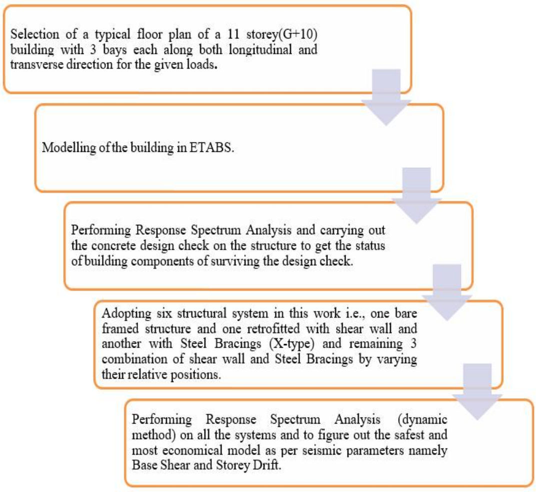
Frame Section Properties

Property Name
Section Name: ISMB250
Base Material: A992Fy50

Properties

Item	Value
Area, cm2	47.6
AS2, cm2	17.3
AS3, cm2	26
I33, cm4	5131.6
I22, cm4	334.5
S33Pos, cm3	410.5
S33Neg, cm3	410.5
S22Pos, cm3	53.5
S22Neg, cm3	53.5
R33, mm	103.9
R22, mm	26.5
Z33, cm3	410.5
Z22, cm3	53.5
J, cm4	18.7
Cw, cm6	57379.4
CG Offset 3 Dir, mm	0
CG Offset 2 Dir, mm	0
PNA Offset 3 Dir, mm	0
PNA Offset 2 Dir, mm	0

III. METHODOLOGY



Selection of a typical floor plan of a 11 storey(G+10) building with 3 bays each along both longitudinal and transverse direction for the given loads.

Modelling of the building in ETABS.

Performing Response Spectrum Analysis and carrying out the concrete design check on the structure to get the status of building components of surviving the design check.

Adopting six structural system in this work i.e., one bare framed structure and one retrofitted with shear wall and another with Steel Bracings (X-type) and remaining 3 combination of shear wall and Steel Bracings by varying their relative positions.

Performing Response Spectrum Analysis (dynamic method) on all the systems and to figure out the safest and most economical model as per seismic parameters namely Base Shear and Storey Drift.

LISTOFREFERENCECODES

- IS 1893 (Part -1): 2016 (Code for Indian Standard Criteria for Earthquake Resistant Design of Structures)
- IS CODE 875: 1987 (Part 1) (Code of Practice for design loads other than Earthquake for Buildings and Structures)
- IS CODE 875: 1987 (PART 2) (Code of Practice for design loads other than Earthquake for Buildings and Structures)

STATEMENT OF THE PROJECT

➢ **Building Plan**	**15mx15m**
➢ **Type of Building**	**Residential**
➢ **Grade of Concrete**	**M 30**
➢ **Grade of Steel**	**HYSD FE 500**
➢ **Column Size**	**550mmx550mm**
➢ **Beam (Ground Floor and First Storey)**	**550mmx650mm**
➢ **Beam (2nd storey to 10th Storey)**	**450mmx550mm**
➢ **Steel X Bracing**	**ISMB 250**
➢ **Storey Height**	**3m**
➢ **Thickness of Slab**	**150mm**
➢ **Thickness of Shear Wall**	**230mm**
➢ **Response Spectra**	**As per IS 1893 (Part1) 2016**
➢ **Seismic Zone**	**Zone V**
➢ **Importance Factor**	**1**
➢ **Damping of Structure**	**5%**
➢ **Seismic Zone Factor**	**0.36**
➢ **Soil Type**	**II**
➢ **Response Reduction Factor**	**5**

Loads Considered

1. Dead Load:

Load on Beam (550mmx650mm) = 9 kN/m

Load on Beam (450mmx550mm) = 6kN/m

Slab Load = 3.75 kN/m^2

Dead load of floor materials and floor finishes on all the floors except roof =3.5kN/m^2

Dead load of roof materials and roof finishes =2kN/m^2

2. Live Load:

Load on all the floors except roof = 4kN/m^2

Load on Roof = 2kN/m^2

3. Seismic Load:

As per IS 1893 (Part-1):2016

IV. RESULTS AND DISCUSSIONS

1) Shear Walls are very high in plane stiffness and strength, which can be applied to concurrently resist large horizontal loads and sustain gravity loads, making them fully suitable in many structural engineering applications. Lateral Bracing systems provides stiffness and stability to the structure, and is cost-effective. Also, as per the IS codes for buildings greater than three storeys located in seismic zones, requires the provision of lateral force resisting system to counteract the effect of lateral forces experienced due to earthquake or wind forces.
2) Also, as per ASCE7 16 the location of the shear walls or lateral bracings should be so fixed such that the following conditions are fulfilled –
3) (Eccentricity in X direction /Length of the building plan along X direction) < 15% (Eccentricity in Y direction /Length of the building plan along Y direction) < 15%
4) So, in this work it has been ensured that the design eccentricity in all the models whether be it bare framed model, or models strengthened with shear wall in different patterns and also models strengthened with both shear walls and steel bracings in different fashion is well within the limits.

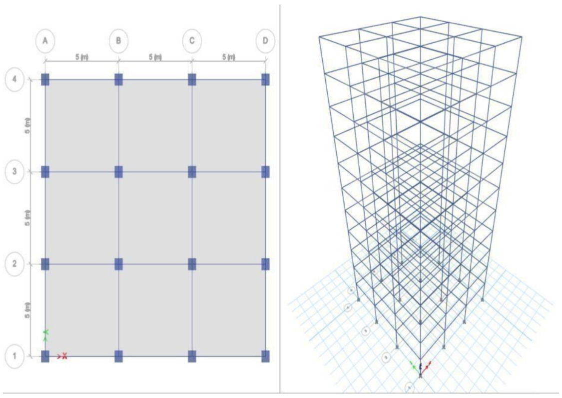
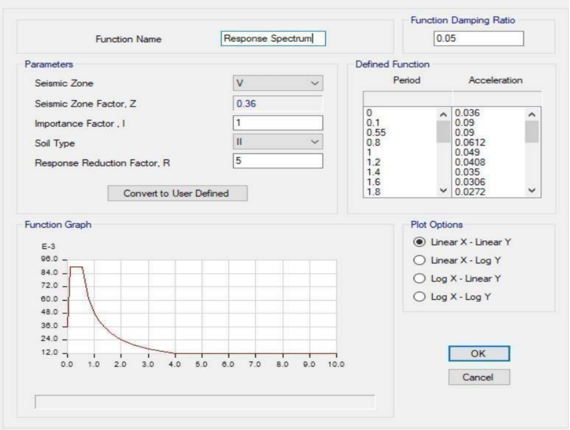


Fig1.Planand3DviewoftheR.C.buildingtakenforassessingtheseismicvulnerability.



Function Name: Response Spectrum

Function Damping Ratio: 0.05

Parameters

Seismic Zone: V

Seismic Zone Factor, Z: 0.36

Importance Factor , I: 1

Soil Type: II

Response Reduction Factor, R: 5

Defined Function

Period	Acceleration
0	0.036
0.1	0.09
0.55	0.09
0.8	0.0612
1	0.049
1.2	0.0408
1.4	0.035
1.6	0.0306
1.8	0.0272

Plot Options: ● Linear X - Linear Y ○ Linear X - Log Y ○ Log X - Linear Y ○ Log X - Log Y

Fig. 2 Chart showing the commencing point of Response Spectrum Analysis (dynamic method) to be performed on the 1st model

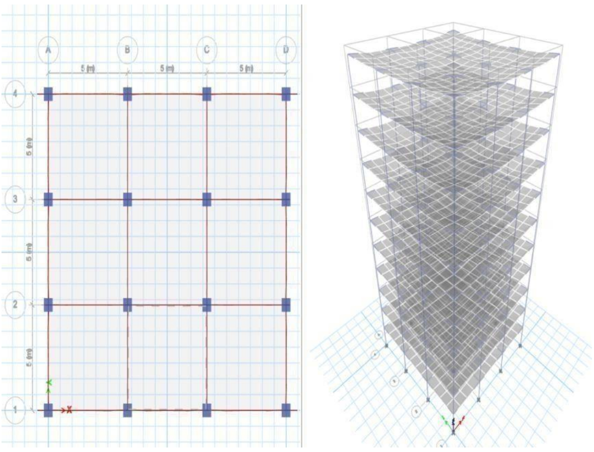
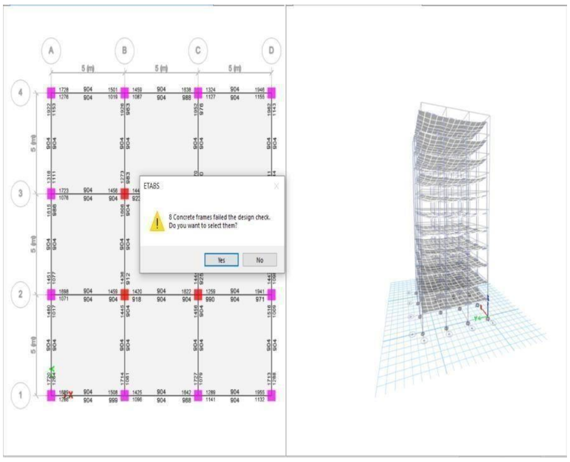


Fig 3 Deformed shape of the Bare framed Model i.e., Model 1 after Response Spectrum Analysis is completed.



ETABS

8 Concrete frames failed the design check.
Do you want to select them?

Fig 4. Eight members fails the concrete design check carried out after Response Spectrum Analysis.

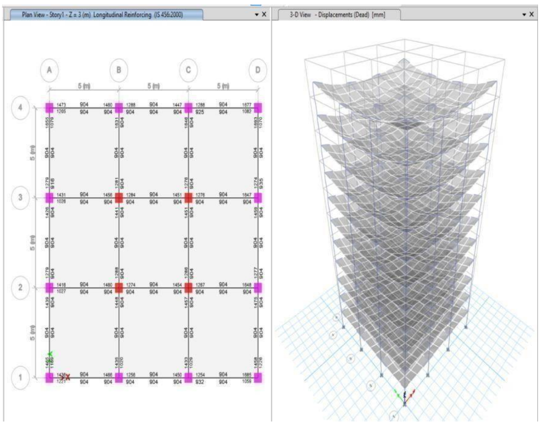


Fig 5 Four members of the Bare Frame Model fail at an elevation of 3m after being exposed to seismic forces in zone V.

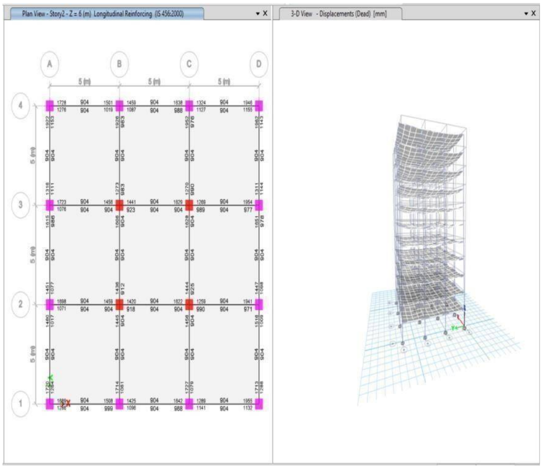


Fig 6. Four more members of the 1st model fail at an elevation of 6 meters.

Storey	Drift (X)	Drift (Y)
Storey 11	1.143	1.143
Storey 10	1.777	1.777
Storey 9	2.284	2.284
Storey 8	2.644	2.644
Storey 7	2.906	2.906
Storey 6	3.116	3.116
Storey 5	3.31	3.31
Storey 4	3.441	3.441
Storey 3	3.113	3.113
Storey 2	2.704	2.704
Storey 1	1.94	1.94

Table 1 Storey wise values of inter storey drift along X and Y directions for the Bare Framed Model.

Base Shear in X (kN)	Base Shear in Y (kN)
1649.1115	1649.1115

Table 2 Base Shear values along both X and Y direction for the Bare Framed Model

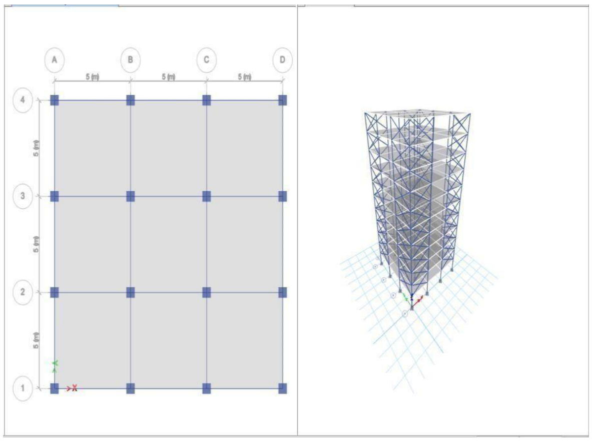


Fig7 Moment Resisting Frame with Steel X Bracing System (Model 2)

Storey	Center of mass X(m)	Center of mass Y(m)	Center of Rigidity X (m)	Center of Rigidity Y (m)	Eccentricity (X) %	Eccentricity (Y) %
Storey 11	7.3858	7.5761	7.4986	7.5005	-0.752	0.504
Storey 10	7.5	7.5	7.496	7.4991	0.026	0.006
Storey 9	7.5	7.5	7.4975	7.4995	0.0166	0.033
Storey 8	7.5	7.5	7.4983	7.4997	0.00133	0.002
Storey 7	7.5	7.5	7.499	7.4999	0.0066	0.00066
Storey 6	7.5	7.5	7.4994	7.4999	0.004	0.00066
Storey 5	7.5	7.5	7.4997	7.5	0.002	0
Storey 4	7.5	7.5	7.4998	7.5	0.00133	0
Storey 3	7.5	7.5	7.4999	7.5	0.00066	0
Storey 2	7.5	7.5	7.5	7.5	0	0
Storey 1	7.5	7.5	7.5	7.5	0	0

Eccentricity along X = -0.0621%<15%, Eccentricity along Y = 0.049%<15%. Hence Ok.

Table 3 Table giving the co-ordinates of Centre of mass and Centre of rigidity and the values of eccentricity in percentage along both X and Y direction for the 2nd model.

Storey	Drift (X)	Drift (Y)
Storey 11	1.226	1.222
Storey 10	1.517	1.519
Storey 9	1.749	1.75
Storey 8	1.92	1.921
Storey 7	2.037	2.037
Storey 6	2.103	2.104
Storey 5	2.127	2.127
Storey 4	2.108	2.108
Storey 3	1.935	1.935
Storey 2	1.839	1.839
Storey 1	2.356	2.356

Table 4 Storey wise values of inter storey drift along X and Y directions for the 2nd Model.

Base Shear in X (kN)	Base Shear in Y (kN)
2255.63	2255.749

Table 5 Base Shear values along both X and Y direction for the 2nd Model

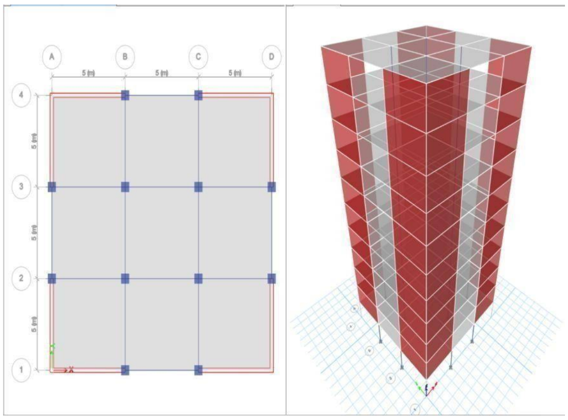


Fig 8 Moment Resisting Frame with Shear Wall system. (Model 3)

Storey	Center of Mass (X) (m)	Center of Mass (Y) (m)	Center of Rigidity (X) (m)	Center of Rigidity (Y) (m)	Eccentricity (X) %	Eccentricity (Y) %
Storey 11	7.5	7.5	7.5	7.5	0	0
Storey 10	7.5	7.5	7.5	7.5	0	0
Storey 9	7.5	7.5	7.5	7.5	0	0
Storey 8	7.5	7.5	7.5	7.5	0	0
Storey 7	7.5	7.5	7.5	7.5	0	0
Storey 6	7.5	7.5	7.5	7.5	0	0
Storey 5	7.5	7.5	7.5	7.5	0	0
Storey 4	7.5	7.5	7.5	7.5	0	0
Storey 3	7.5	7.5	7.5	7.5	0	0
Storey 2	7.5	7.5	7.5	7.5	0	0
Storey 1	7.5	7.5	7.5	7.5	0	0

Eccentricity along X = 0%<15%, Eccentricity along Y = 0%<15%. Hence Ok.

Table 6 Table giving the co-ordinates of Centre of mass and Centre of rigidity and the values of eccentricity in percentage along both X and Y direction for the 3rd model

Storey	Drift (X)	Drift (Y)
Storey 11	1.382	1.382
Storey 10	1.427	1.427
Storey 9	1.465	1.465
Storey 8	1.492	1.492
Storey 7	1.501	1.501
Storey 6	1.487	1.487
Storey 5	1.446	1.446
Storey 4	1.381	1.381
Storey 3	1.287	1.287
Storey 2	1.225	1.225
Storey 1	3.565	3.565

Table 7 Storey wise values of inter storey drift along X and Y directions for the 3rd Model.

Base Shear in X (kN)	Base Shear in Y (kN)
2846.991	2846.991

Table 8 Base Shear values along both X and Y direction for the 3rd Model.

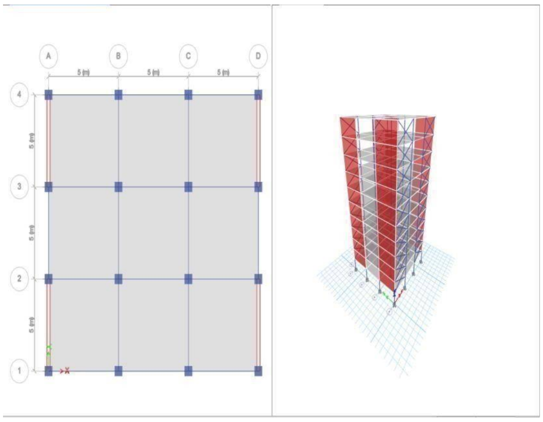


Fig 9 Moment Resisting Frame with Shear Wall positioned at the transverse bays of each corner and Steel X-bracing system positioned at the longitudinal bay of each corner (Model 4).

Storey	Center of Mass X(m)	Center of Mass Y(m)	Center of Rigidity X (m)	Center of Rigidity Y (m)	Eccentricity (X) %	Eccentricity (Y)%
Storey 11	7.4472	7.5352	7.5	7.5	-0.352	0.2346
Storey 10	7.4571	7.5286	7.5	7.5	-0.286	0.1906
Storey 9	7.5	7.5	7.5	7.5	0	0
Storey 8	7.5	7.5	7.5	7.5	0	0
Storey 7	7.5	7.5	7.5	7.5	0	0
Storey 6	7.5	7.5	7.5	7.5	0	0
Storey 5	7.5	7.5	7.5	7.5	0	0
Storey 4	7.5	7.5	7.5	7.5	0	0
Storey 3	7.5	7.5	7.5	7.5	0	0
Storey 2	7.5	7.5	7.5	7.5	0	0
Storey 1	7.5	7.5	7.5	7.5	0	0

Eccentricity along X =-0.058%<15%, Eccentricity along Y =0.0386%<15%

Table 9 Table giving the co-ordinates of Centre of mass and Centre of rigidity and the values of eccentricity in percentage along both X and Y direction for the 4th model.

Storey	Drift (X)	Drift (Y)
Storey 11	0.962	1.47
Storey 10	1.256	1.523
Storey 9	1.504	1.567
Storey 8	1.699	1.594
Storey 7	1.847	1.593
Storey 6	1.953	1.556
Storey 5	2.023	1.474
Storey 4	2.058	1.341
Storey 3	1.941	1.139
Storey 2	1.917	0.91
Storey 1	2.526	2.727

Table 10 Storey wise values of inter storey drift along X and Y directions for the 4th Model.

Base Shear in X (kN)	Base Shear in Y (kN)
2416.9846	3002.4937

Table 11 Base Shear values along both X and Y direction for the 4th Model.

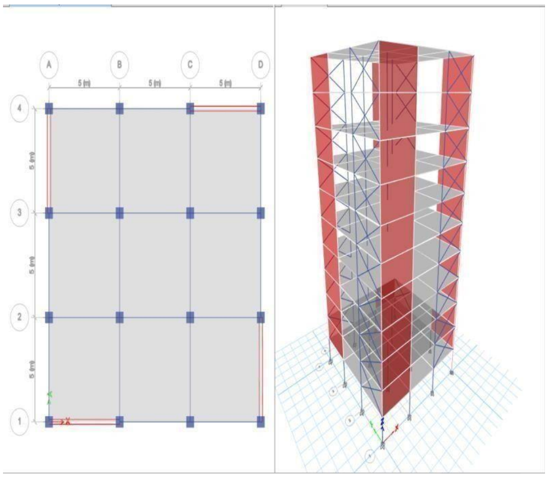


Fig 10 Moment Resisting Frame with Shear Wall and Steel X-Bracing system positioned at alternate bays at each corner (Model 5).

Storey	Center of mass (X) (m)	Center of mass (Y) (m)	Center of Rigidity (X) (m)	Center of Rigidity (Y) (m)	Eccentricity (X)%	Eccentricity (Y)%
Storey 11	7.4409	7.5575	7.6013	7.5245	-1.069	0.22
Storey 10	7.4064	7.5912	7.6181	7.5251	-1.411	0.4406
Storey 9	7.4064	7.5912	7.6396	7.5254	-1.554	0.4386
Storey 8	7.4064	7.5912	7.6643	7.525	-1.72	0.441
Storey 7	7.4064	7.5912	7.6944	7.5236	-1.92	0.4506
Storey 6	7.4064	7.5912	7.7311	7.5209	-2.1646	0.4686
Storey 5	7.4064	7.5912	7.7764	7.5162	-2.466	0.5
Storey 4	7.4064	7.5912	7.8292	7.5091	-2.818	0.547
Storey 3	7.4064	7.5912	7.8915	7.4989	-3.234	0.615
Storey 2	7.4125	7.5851	7.9336	7.4867	-3.474	0.656
Storey 1	7.4561	7.5426	8.0034	7.4757	-3.648	0.446

Eccentricity along X =-2.316%<15%, Eccentricity along Y =0.4748%<15%. Hence Ok.

Table 12. Table giving the co-ordinates of Centre of mass and Centre of rigidity and the values of eccentricity in percentage along both X and Y direction for the 5th model.

Storey	Drift (X)	Drift (Y)
Storey 11	1.339	1.34
Storey 10	1.425	1.428
Storey 9	1.507	1.511
Storey 8	1.576	1.58
Storey 7	1.617	1.62
Storey 6	1.621	1.623
Storey 5	1.576	1.576
Storey 4	1.474	1.473
Storey 3	1.285	1.278
Storey 2	1.066	1.056
Storey 1	2.467	2.322

Table 13 Storey wise values of inter storey drift along X and Y directions for the 5th Model.

Base Shear in X (kN)	Base Shear in Y (kN)
2588.0242	2599.7958

Table 14 Base Shear values along both X and Y direction for the 5th Model.

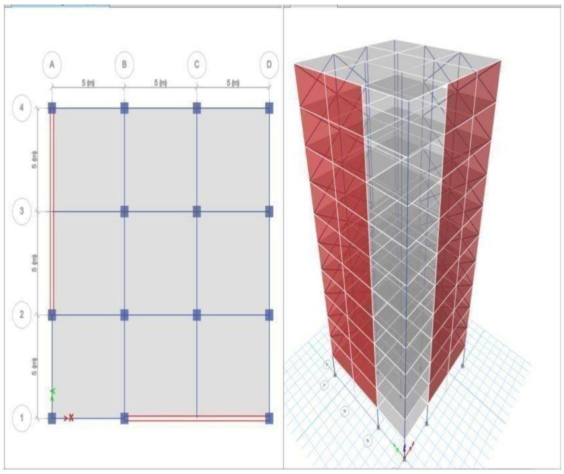


Fig 11 Moment Resisting Frame with shear walls positioned at two longitudinal bays at corners and at two transverse bays at corners, while Steel X Bracing is placed in similar ways as shear walls at corners (Model 6).

Storey	Center of mass (X) (m)	Center of mass (Y) (m)	Center of Rigidity (X) (m)	Center of Rigidity (Y) (m)	Eccentricity (X) %	Eccentricity (Y)%
Storey 11	7.5394	7.5394	4.8972	4.8972	17.614	17.614
Storey 10	7.4408	7.4408	4.7607	4.7607	17.867	17.867
Storey 9	7.4408	7.4408	4.6671	4.6671	18.49	18.49
Storey 8	7.4408	7.4408	4.6188	4.6188	18.81	18.81
Storey 7	7.4408	7.4408	4.6281	4.6281	18.75	18.75
Storey 6	7.4408	7.4408	4.7121	4.7121	18.191	18.191
Storey 5	7.4408	7.4408	4.8951	4.8951	16.97	16.97
Storey 4	7.4408	7.4408	5.2134	5.2134	14.85	14.85
Storey 3	7.4408	7.4408	5.7245	5.7245	11.442	11.442
Storey 2	7.4961	7.4961	6.4264	6.4264	7.131	7.131
Storey 1	7.5955	7.5955	7.6924	7.6924	-0.646	-0.646

Eccentricity along X = 14.49%<15%, Eccentricity along Y = 14.49%<15%. Hence Ok.

Table 15 Table giving the co-ordinates of Centre of mass and Centre of rigidity and the values of eccentricity in percentage along both X and Y direction for the 6th model.

Storey	Drift (X)	Drift (Y)
Storey 11	1.025	1.025
Storey 10	1.164	1.164
Storey 9	1.281	1.281
Storey 8	1.376	1.376
Storey 7	1.442	1.442
Storey 6	1.48	1.48
Storey 5	1.487	1.487
Storey 4	1.467	1.467
Storey 3	1.361	1.361
Storey 2	1.316	1.316
Storey 1	3.331	3.331

Table 16 Storey wise values of inter storey drift along X and Y directions for the 6th Model.

Base Shear in X (kN)	Base Shear in Y (kN)
2917.6855	2917.6855

Table 17 Base Shear values along both X and Y direction for the 6th Model.

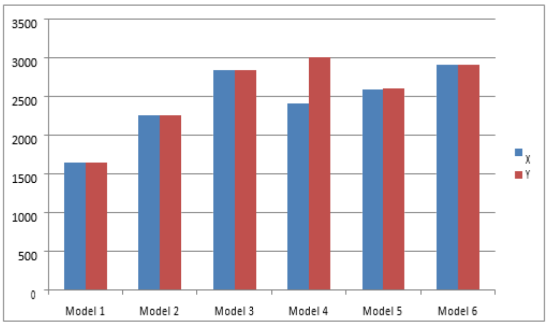


Fig 12 Base Shear Graph

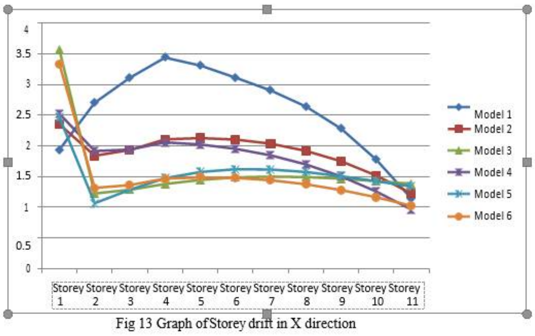


Fig 13 Graph of Storey drift in X direction

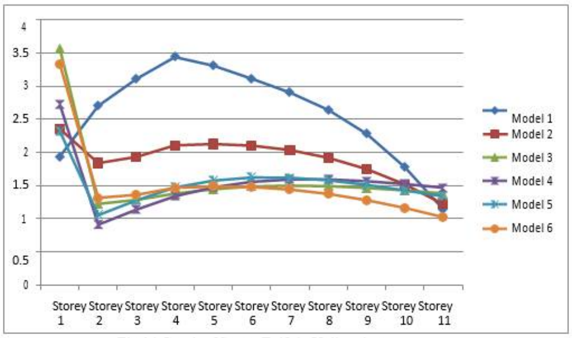
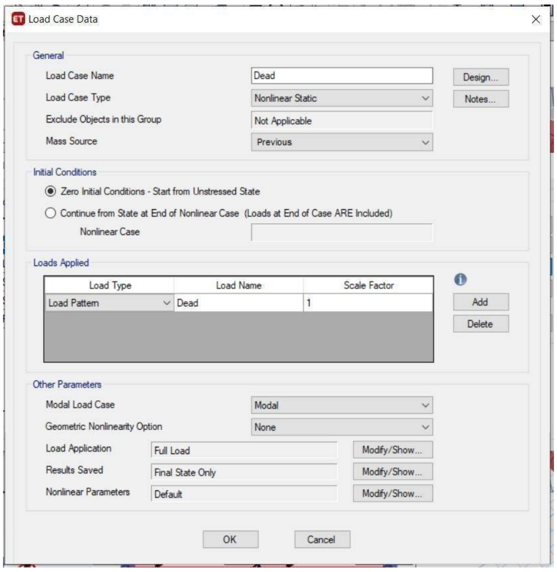


Fig 14 Graph of Storey Drift in Y direction

Pushover Analysis performed on model 6 to ascertain the seismic vulnerability.

After the retrofitting is performed on the basic bare framed model and response spectrum analysis (dynamic method) being carried out, it is desirable to check the seismic vulnerability of the building by conducting any one of the non linear methods. So to fulfill this criteria we have conducted Non –Linear static Analysis i.e. Pushover Analysis on the model 6 which has given the most satisfactory results in terms of Storey Drift, Base Shear, etc. In the Pushover Analysis the no. of hinges and of what nature that will be formed as the building is pushed in steps so as to drive the building through the complete displacement that will be experienced as a result of the seismic forces in X direction and Y direction is shown in the following pages.


Load Case Data

General

Load Case Name: Dead

Load Case Type: Nonlinear Static

Exclude Objects in this Group: Not Applicable

Mass Source: Previous

Initial Conditions

● Zero Initial Conditions - Start from Unstressed State

○ Continue from State at End of Nonlinear Case (Loads at End of Case ARE Included)

Nonlinear Case:

Loads Applied

Load Type	Load Name	Scale Factor
Load Pattern	Dead	1

Other Parameters

Modal Load Case: Modal

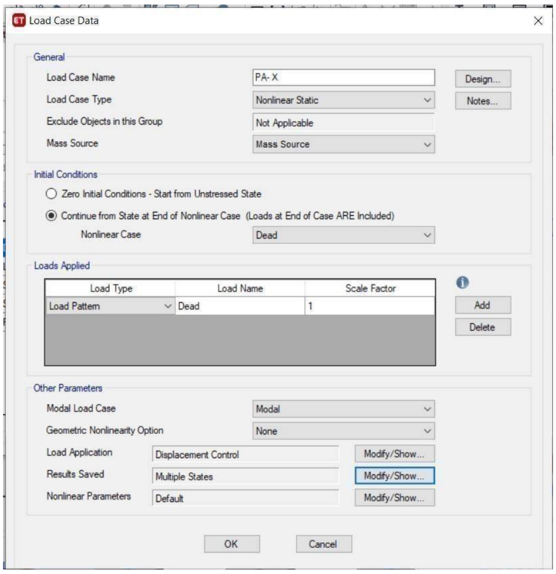
Geometric Nonlinearity Option: None

Load Application: Full Load

Results Saved: Final State Only

Nonlinear Parameters: Default

Fig 15 Beginning of Non linear static analysis which is likely to be performed on the 6th model for assessing its seismic vulnerability.


Load Case Data

General

Load Case Name: PA- X

Load Case Type: Nonlinear Static

Exclude Objects in this Group: Not Applicable

Mass Source: Mass Source

Initial Conditions

○ Zero Initial Conditions - Start from Unstressed State

● Continue from State at End of Nonlinear Case (Loads at End of Case ARE Included)

Nonlinear Case: Dead

Loads Applied

Load Type	Load Name	Scale Factor
Load Pattern	Dead	1

Other Parameters

Modal Load Case: Modal

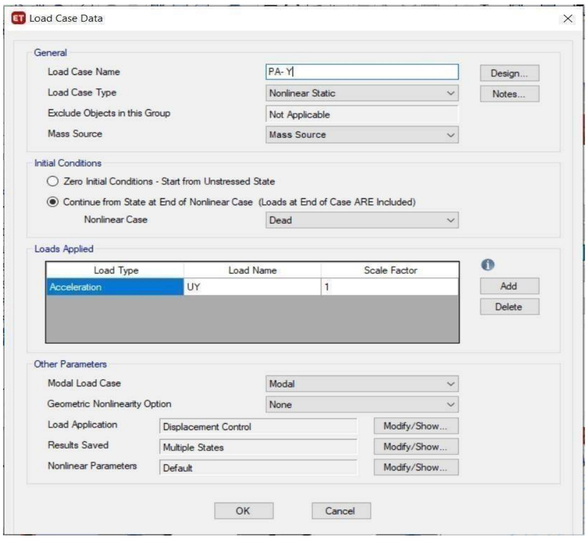
Geometric Nonlinearity Option: None

Load Application: Displacement Control

Results Saved: Multiple States

Nonlinear Parameters: Default

Fig 16 Addition of PA-X load case as non linear static case for PA method.


Load Case Data

General

Load Case Name: PA- Y

Load Case Type: Nonlinear Static

Exclude Objects in this Group: Not Applicable

Mass Source: Mass Source

Initial Conditions

○ Zero Initial Conditions - Start from Unstressed State

● Continue from State at End of Nonlinear Case (Loads at End of Case ARE Included)

Nonlinear Case: Dead

Loads Applied

Load Type	Load Name	Scale Factor
Acceleration	UY	1

Other Parameters

Modal Load Case: Modal

Geometric Nonlinearity Option: None

Load Application: Displacement Control

Results Saved: Multiple States

Nonlinear Parameters: Default

Fig 17 Addition of PA-Y load case as non linear static case for PA method.

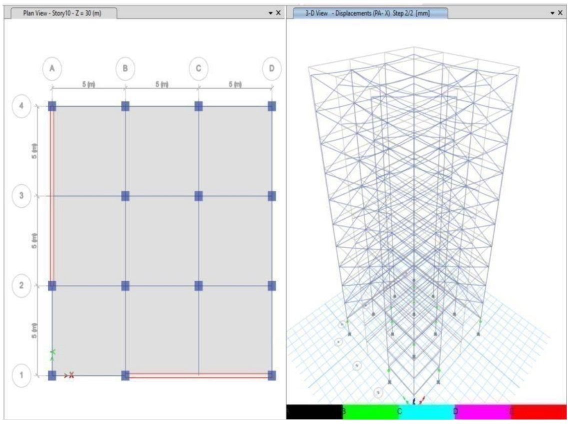


Fig 18 Formation of green color hinges after the successful completion of Pushover Analysis upon pushing the building in X direction.

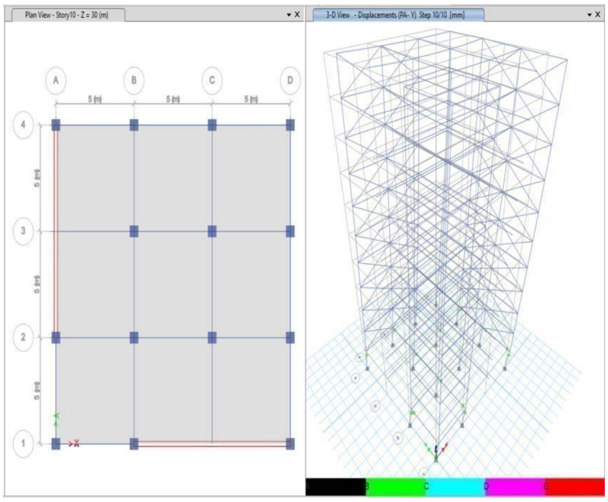


Fig 19 Formation of green color hinges after the successful completion of Pushover Analysis upon pushing the building in Y direction.

Here after the completion of Pushover Analysis the building model 6 is pushed in steps to complete the total amount of displacements that will be experienced by the building due to earthquake as per the non linear static case of Pushover Analysis performed in the Etabs software. It is visible that both in X direction and Y direction green color hinges are formed after being the building is pushed in steps so as to drive the building through the complete amount of displacement that it will experience during earthquakes. This means that the building is safe against earthquake forces and no member is likely to fail as there are no red color hinges seen to exist.

V. CONCLUSIONS

The following conclusions were drawn out from the study of six different models and altogether seven analysis including linear and nonlinearanalysis:

- The Base Shear of buildings with shear wall and Steel bracing system is more as compared to the building without shear wall and bracing system which results in the increase of stiffness of the building.
- The storey drift of the building is reduced by the use of shear walls and Steel Bracing system.
- It is concluded that storey drift in case of structures stiffened with shear Walls (model 3) is more as compared to structures stiffened with either Steel X bracing system or both shear walls and Steel X Bracing system.
- The model 3 and 6 show higher base shear value.
- The model 5 and 6 show less storey drift values both along X and Y axis as can be seen from the graph.
- The model 6 is the most economical of all the six models analyzed.
- Also, the model 6 shows better performance both in terms of storey drift and Base Shear. The Base shear is increased by 76.92% along both the axes and the storey drift are reduced on an average by 35.26% along both X and Y when compared to the Bare framed model.
- Hence model 6 is suggested as the preferable option to be adopted while doing retrofitting to a multistoried building in seismic zone V.

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