NON LINEAR STATIC ANALYSIS OF DUAL RC FRAME STRUCTURE

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Abstract - *The performance-based modeling and analysis of a 10-story building with special moment resisting frame (SMRF) as seismic force-resisting system and SMRF with shear wall (Dual System), is presented here. In performance based seismic analysis, evaluates how building is likely to perform. It is an iterative process with selection of performance objective followed by development of preliminary design, an assessment whether or not the analysis meets the performance objective. For structural design and assessment of reinforced concrete members, the non-linear static analysis has become an important tool, method can be used to study the behaviour of reinforced concrete structures including force redistribution. The paper presents a simple computer-based push-over analysis technique for performance-based design of building using non-linear static analysis to developed the capacity and demand curve, push over curve, rotation of hinge for CP (collapse prevention) performance point. The seismic response of RC building frame and dual system in terms of performance point and the effect of earthquake forces on multi storey building frame with the help of pushover analysis is carried out in this paper. In the present study the building frame is analyzed using ETAB'S V.16.03, as per IS 456:2000 and IS 1893:2002 and for non-linear parameter ASCE-41-13 and EC8-2004 is used.*

***Key Words*: Nonlinear-static analysis, Push over analysis, Performance based assessment, Dual system**

1. INTRODUCTION

Many intra-tectonic plate regions are considered to have low to moderate seismic risk. However, after devastating earthquakes, Bhuj (2001) occur in these regions and result in high consequences in terms of casualties and damage. Low to medium rise reinforced concrete (RC) structures built in the majority of these regions are analyze and designed primarily for combinations of gravity loads. Therefore, during an unpredictable seismic excitation, satisfactory response of such framed structures relies on their inherent factors of ductility and overstrength, also the lack of knowledge regarding site specific earthquake records in these regions makes it difficult to develop suitable design spectra for seismic analysis. Venerability to damage of structures should be identified and an acceptable level of safety must be determined. To achieve such assessment, simplified linear-elastic methods are not proportionate. Thus, the structural engineering people has developed a new method of analysis and design that incorporate performance based analysis of structures and is moving away from Simplified linear elastic methods and towards a more better assessment of structure during an earthquake.

The dual system consist combination of the two lateral load resisting systems *i.e*. bare frame and structural wall or bracing as a major lateral [5] load resisting system. In these systems the shape of the deformation will differ from those in frames and wall systems, where effecting interlaced force occur and change the shape of shear and moment diagrams.

A new method based on the nonlinear model of structural behaviour due to seismic action, broadly called the *Nonlinear Static Pushover Analysis* or (NSPA), has been developing over the past two decades, and an extensive [7] research aimed at its further improvement is still under way. The NSPA analysis is founded on the modelling of geometrically and materially non-linear behaviour of structures, while treating seismic actions as a static load, explicitly through forces or implicitly through displacements. The NSPA analysis is generally conducted in two phase. The first phase is performed using the multi degree of freedom (MDOF) model, while in the second phase the target displacement analysis is done using the single degree of-freedom (SDOF) system, or a direct approach is used.

2. NON LINEAR STATIC ANALYSIS

Nonlinear static analysis procedures (pushover analysis) have been developed for routine application in the practice of performance-based earthquake engineering due to their conceptual simplicity and computational effectiveness. A pushover analysis is performed by subjecting a structure to a monotonically increasing pattern of lateral loads, representing the inertial forces which would be experienced by the structure when subjected to ground shaking. This will lead to development capacity curve. Based on capacity curve target displacement is determined under incrementally increasing loads various structural elements may yield sequentially [8]. Consequently, at each event, the structure experiences a loss in stiffness. Using a pushover analysis, a characteristic non-linear force displacement relationship can be determined. Several practical methodologies involving nonlinear pushover analysis using an invariant height-wise lateral force distribution, such as the ATC-40, FEMA-356, FEMA-440, EC8-2004 and ASCE 41-13. Many structural systems will experience nonlinear response sometime during their life, any moderate to strong earthquake will drive a structure designed by conventional methods into the inelastic range, particularly in certain critical regions. This is very useful numerical integration technique for problems of structural dynamics is the so called step-by-step integration procedure.

3. PERFORMANCE OBJECTIVES

A performance objective has two essential parts a damage state and a level of seismic hazard. Seismic performance is described by designating the maximum allowable damage state with drift limit as defined in FEMA-356 [5]. A performance objective [Fig.1] may include consideration of damage states for several levels of ground motion and would then be termed a dual or multiple-level performance objective. Based on performance objective the capacity and demand curve is drawn and based on it the suitable design is chosen.

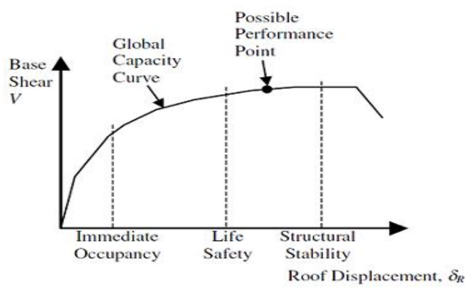


Figure-1: capacity curve of structure

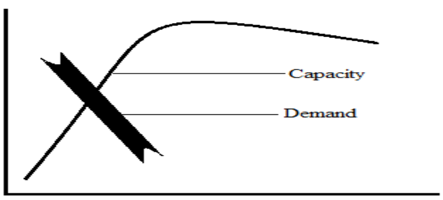


Figure-2: (a) capacity vs. demand curve (Safe design)

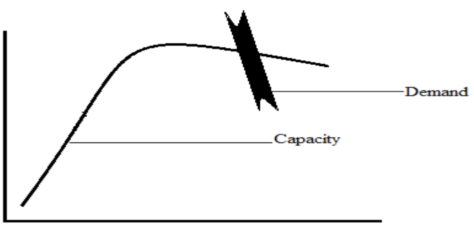


Figure-2: (b) capacity vs. demand curve (unsafe design)

4. INELASTIC BEHAVIOUR OF STRUCTURE

The structural elements may themselves comprise of an assembly of elements such as columns, beam, wall piers, wall spandrels etc. It is important to identify the failure mechanism for these primary structural elements and define their non-linear properties accordingly [7]. The properties of interest of such elements are relationships between the forces (axial, bending and shear) and the corresponding inelastic displacements (displacements, rotations, drifts). Using the component load-deformation data and the geometric relationships among components and elements, a global model of the structure relates the total seismic forces on a building to it overall lateral displacement to generate the capacity curve. During the pushover process of developing the capacity curve as brittle elements degrade, ductile elements take over the resistance and the result is a saw tooth shape that helps visualize the performance.

5. HINGE PROPERTIES AND MECHANISM

We may insert plastic hinges at any number of locations along the clear length of any Frame element or Tendon object. ETAB's also admits hinges in vertical Shear wall elements. Each hinge represents concentrated post-yield behavior in one or more degrees of freedom. Hinges only affect the behavior of the structure in nonlinear static and nonlinear time history analysis. [8] Hinges can be assigned to a frame element at any location along the clear length of the element. Uncoupled moment, torsion, axial force and shear hinges are available. There are also coupled P-M2-M3 hinges which yield based on the interaction of axial force and bi-axial bending moments at the hinge location. Sub sets of these hinges may include P-M2, P-M3, and M2-M3 behaviour.

6. TERMINOLOGY USED IN N.S.P. ANALYSIS

Capacity: The expected ultimate strength (in flexure, shear, or axial loading) of a structural component excluding the reduction factors commonly used in design of concrete members. The capacity usually refers to the strength at the yield point of the element or structure's [4] capacity curve. For deformation-controlled components, capacity beyond the elastic limit generally includes the effects of strain hardening. Pushover capacity curves approximate how structure behaves after exceeding the elastic limits.

Demand: A representation of the earthquake ground motion or shaking that the building is subjected to nonlinear static analysis procedures, demand is represented by an estimation of the displacements or deformations that the structure is expected to undergo. This is in contrast to conventional, linear elastic analysis procedures in which demand is represented by prescribed lateral forces applied to the structure.

Deformation Controlled: Refers to components, elements, actions, or systems which can, and are permitted to, exceed their elastic limit in a ductile manner. Force or stress levels for these components are of lesser importance.

Force Controlled: Refers to components, elements, actions, or systems which are not permitted to exceed their elastic limits. This category of elements, generally referred to as brittle or Nonductile, experiences significant degradation after only limited post-yield deformation.

Target Displacement: The target displacement is intended to represent the maximum displacement likely to be experienced for the selected Seismic Hazard Level. In the displacement coefficient method. The target displacement is the equivalent of the performance point in the capacity spectrum method [9]. The target displacement is calculated by use of a series of coefficients.

7.MATERIAL PROPERTIES AND DATA DESCRIPTION

In the model, the support condition was assumed to be fixed Building was a symmetric structure with respect to both the horizontal directions. soil structure interaction is not considered during analysis, the data used during analysis tabulated here.

Table -1 : Modeling Detail of Structure

1	Number of story	10 (G+9)
2	Floor to floor height	3.2m
3	Bottom story height	4.0m
4	Slab thickness	150mm
5	Size of beam	350mm x 500mm
6	Size of column	550mm x 550mm
7	Thickness of shear wall and it's grade	150mm, M40
8	Zone and zone factor	IV, 0.24
9	Importance factor	1
10	Response factor (R)	5
11	Soil type	II (Medium)
12	Grade of concrete and rebar in beam	M35, Fe500
13	Grade of concrete (Slab)	M35
14	Grade of concrete and rebar in column	M40, Fe415
15	Grade of shear wall	M40
16	Live load and floor finish load	3kN/m^2 and 1kN/m^2 kN/m^2
17	Top floor load	2kN/m^2
18	Masonry load	Half brick wall, 7.2 kN/m

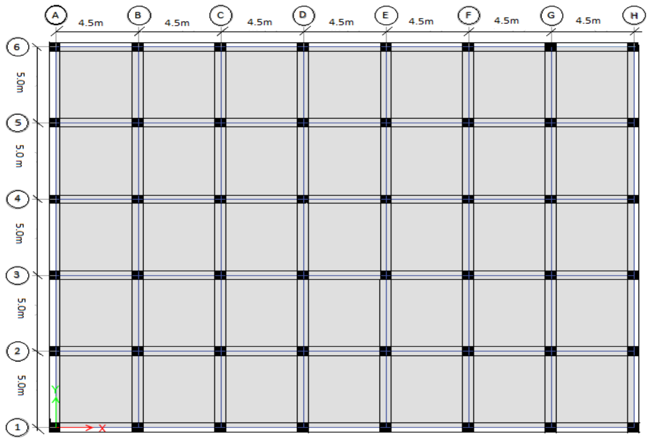


Figure-3: Plan of bare RC frame

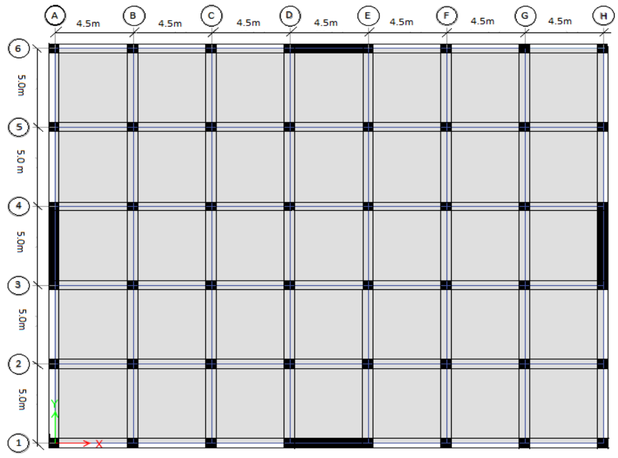


Figure-4: Plan of dual R.C frame with side center shear wall

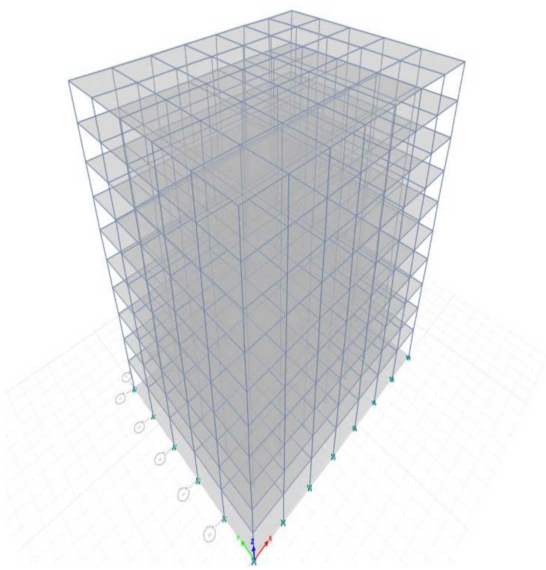


Figure-5: 3-D view of bare RC frame structure

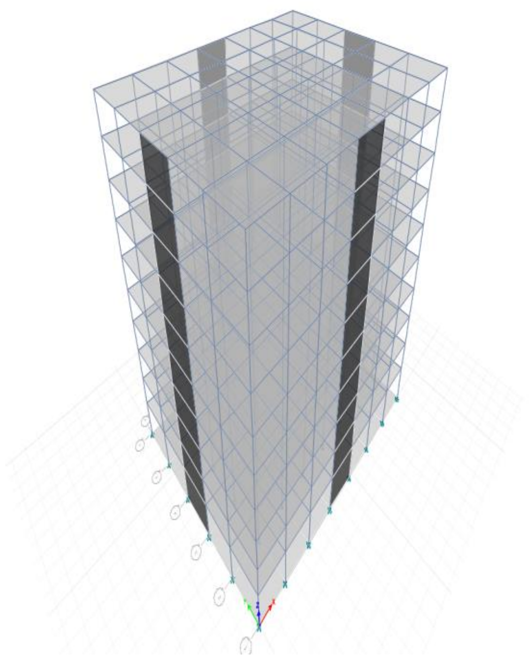


Figure-6: 3D view of dual RC frame structure with side center shear wall.

8.TARGET DISPLACEMENT CALCULATION

a. As Per ASCE 41-13

As per ASCE 41-13 the target displacement is given by equation

$$\delta_t = C_0 C_1 C_2 S_a \frac{T_e^2}{4\pi^2} g \quad (1.0)$$

Where T_e is calculated as

$$T_e = T_i \sqrt{\frac{K_i}{K_e}} \quad (1.1)$$

T_e is the effective fundamental period in the direction under consideration shall be based on the idealized force–displacement curve.

T_i, is Elastic fundamental period (in seconds) in the direction under consideration calculated by elastic dynamic analysis.

K_i , is Elastic lateral stiffness of the building in the direction under consideration.

K_e , is Effective lateral stiffness of the building in the direction under consideration.

S_a, is Response spectrum acceleration at the effective fundamental period and damping ratio of the building in the direction under consideration.

C_0, is Modification factor to relate spectral displacement of an equivalent single-degree-of-freedom (SDOF) system to the roof displacement of the building multi degree of-freedom (MDOF) system.

C_1, is Modification factor to relate expected maximum inelastic displacements calculated for linear elastic response.

C_2 is modification factor to represent the effect of pinched hysteresis shape, cyclic stiffness degradation, and strength deterioration on the maximum displacement response.

b. As Per EC 8-2004

The following relation between normalized lateral forces $\bar{F}_i$ and normalized displacements $\emptyset_i$ is assumed,

$$F_i = m_i \emptyset_i \quad (2.0)$$

Where m_i is mass at i[th] storey

The mass of an equivalent SDOF system m^* is determined as:

$$m^* = \sum m_i \emptyset_i = \sum \bar{F}_i \quad (2.1)$$

And the transformation factor is given by:

$$\gamma = \frac{m^*}{\sum m_i \emptyset_i^2} \quad (2.2)$$

The force F^* and displacement d^* of equivalent SDOF is computed as:

$$F^* = \frac{F_b}{\gamma} \quad \text{and} \quad d^* = \frac{d_n}{\gamma}$$

Where F_b and d_n are respectively, the base shear force and the control node displacement of the Multi Degree of Freedom (MDOF) system.

Based on this assumption, the yield displacement of the idealized SDOF system d_y^* is given by:

$$\mathrm{d}_y^* = 2\left(\mathrm{d}_m^* - \frac{E_m^*}{\mathrm{F}_y}\right) \quad (2.3)$$

Where, E_m^* is the actual deformation energy up to the formation of the plastic mechanism.

The period T^* of the idealized equivalent SDOF systen1 is determined by:

$$T^* = 2\pi \sqrt{\frac{m^* d_y^*}{F_y^*}} \quad (2.4)$$

For the determination of the target displacement d_t^* for structures in the short-period range and for structures in the medium and long-period ranges different expressions.

$$d_t^* = \frac{d_{et}^*}{q_u}\left(1 + (q_u - 1)\frac{T_c}{T^*}\right) \geq d_{et}^* \quad (2.5)$$

The target displacement of the MDOF system corresponding to control node is given by:

$$d_t = \gamma d_t^* \quad (2.6)$$

9. RESULT

As per the objective, work methodology and structural modeling, analysis of both structure bare RC frame and dual RC frame structure is done with help of ETAB v16.03.The result of the analyzed structure is presented using codes, ASCE 41-13, and EC 8-2004. The result is so presented that we can easily compare both structure for concerned objectives.

9.1 PUSH OVER DATA

Push over (base shear vs. roof displacaement) data for bare RC and dual RC frame in X and Y direction

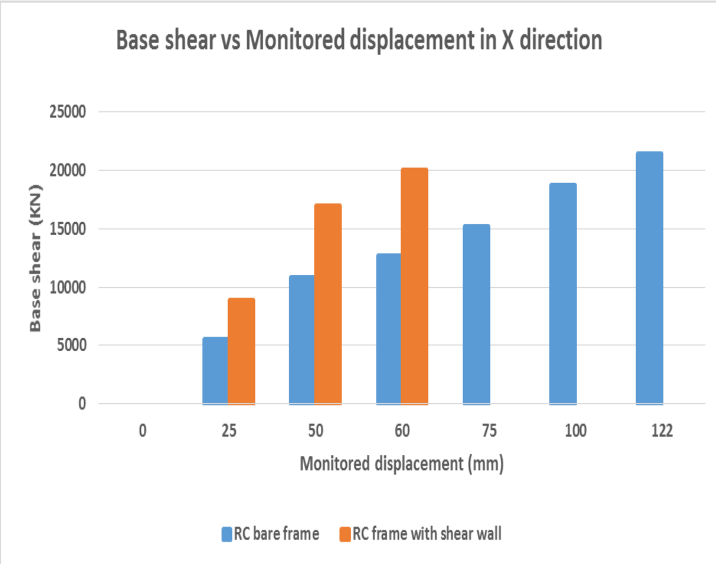


Chart-1: Push over data in X direction

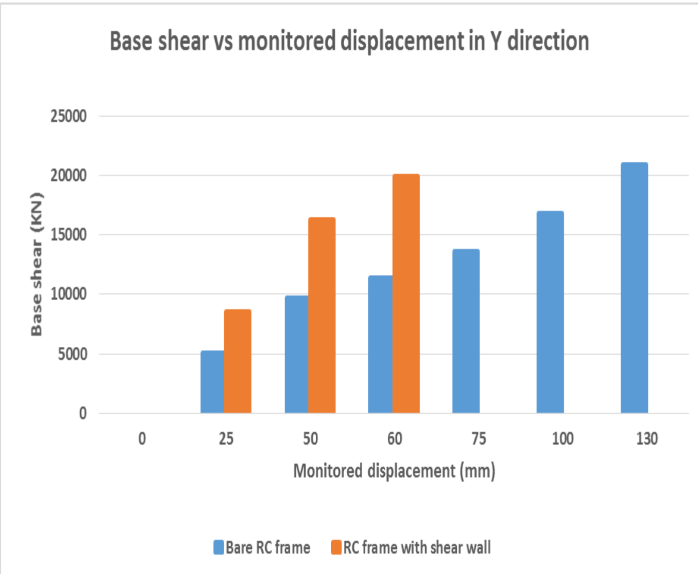
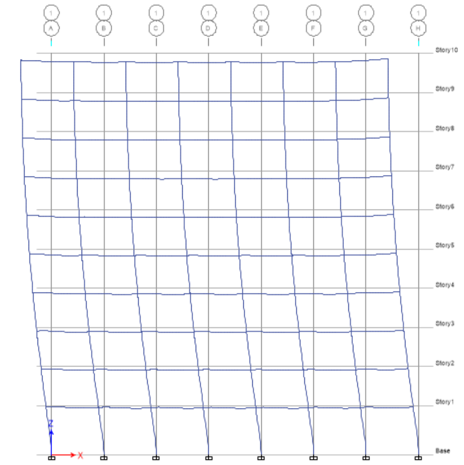
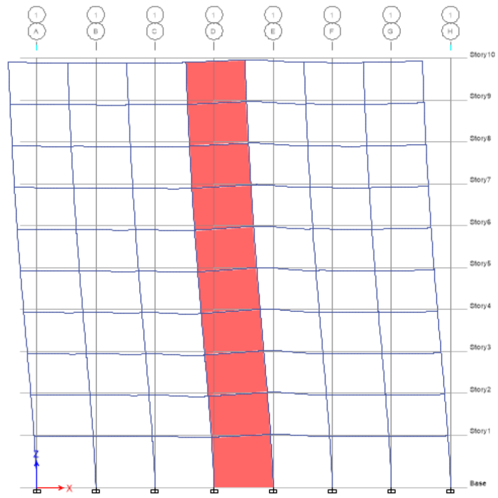


Chart-2: Push over data in Y direction

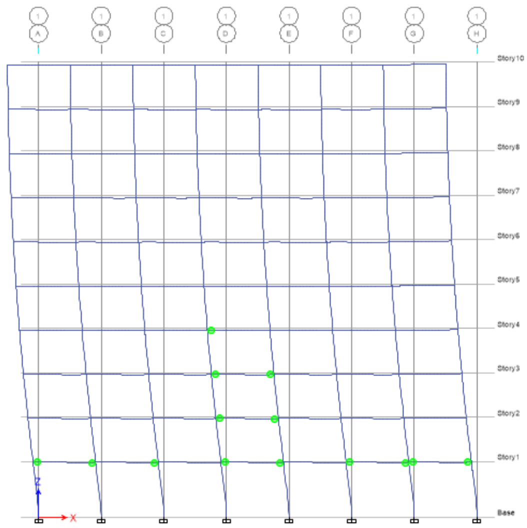
9.2 SEQUENTIAL HINGE FORMATION

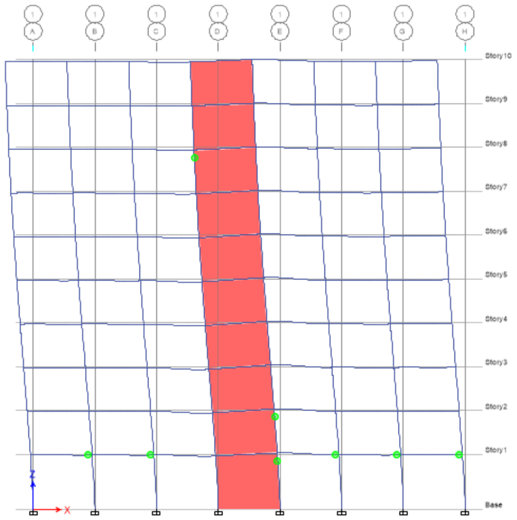
Step1



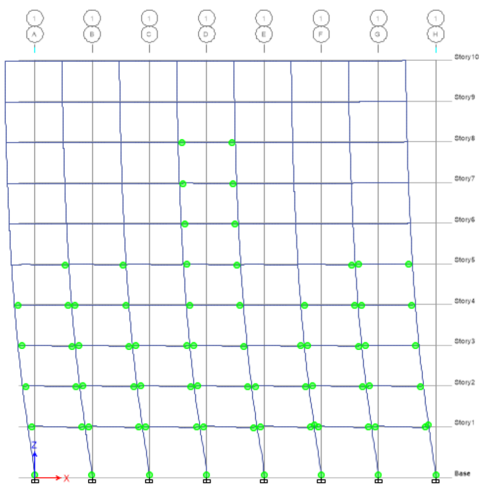


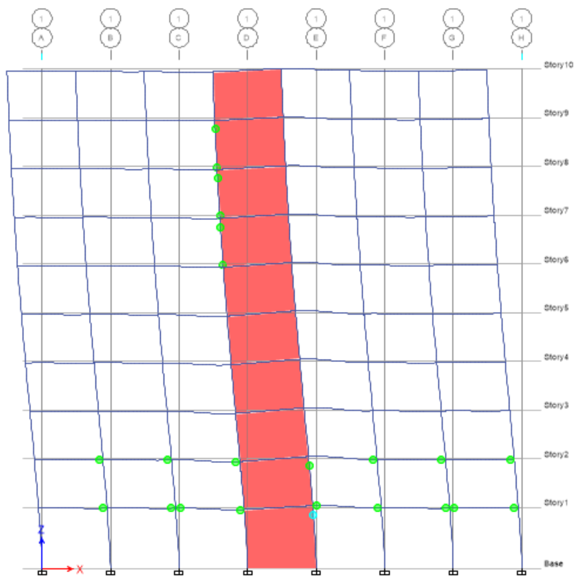
Step 2



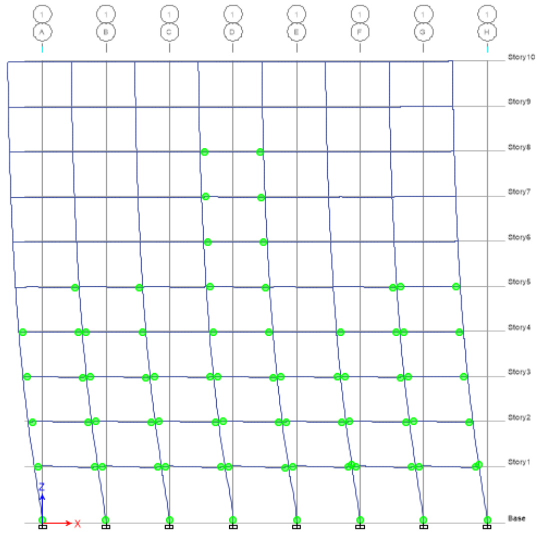


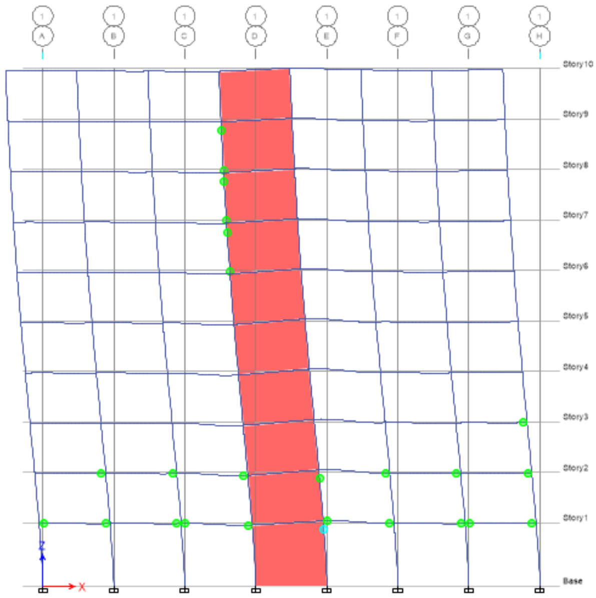
Step 5





Step 6





In Y direction of bare frame out of 2600 hinges only 21 is in the region of > CP and final roof displacement was 138.91 mm found. Whereas in dual RC frame out of 2640 hinges none is in the region of > CP and final roof displacement was 60.48mm found

In X direction out of 2600 hinges only 12 is in the region of > CP and roof displacement was 122.0mm found.whereas in dual RC frame structure out of 2640 hinges only 1 hinges in the region of >CP and final roof displacement was 58.41mm found.

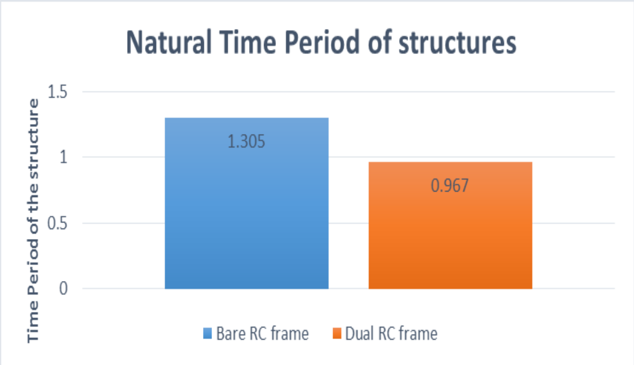


Chart-3: Natural time period of the structure

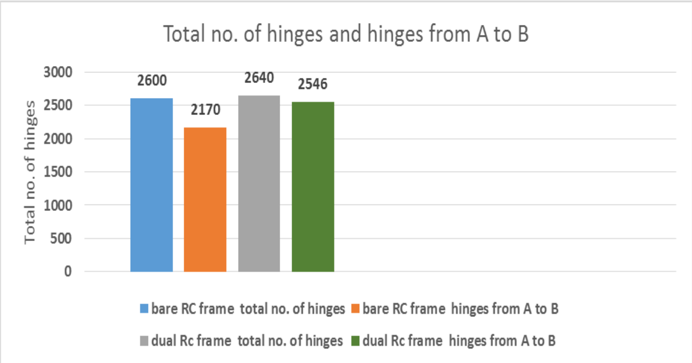


Chart-4: Total no. of hinges in elastic region

9.3 TARGET DISPLACEMENT AS PER ASCE 41-13

Table-2: Target displacement In X direction of bare RC frame

Target Displacement (δ)	182.65mm	Maximum Shear (V)	21459.73 kN
Yield displacement (D_y)	56.15mm	Yield base shear (V_y)	12556.76 kN

Table-3: Target displacement In X direction of dual RC frame

Target Displacement (δ)	198.64mm	Maximum Shear (V)	20051.61 kN
Yield displacement (D_y)	64.10mm	Yield base shear (V_y)	11771.21 kN

9.4 TARGET DISPLACEMENT AS PER EC-8 2004

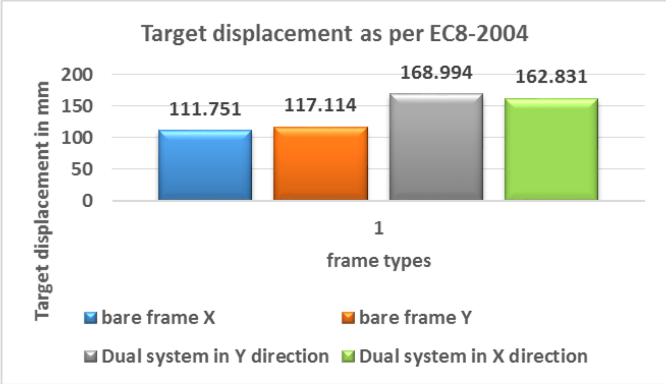


Chart-5: Target dispalcement as per EC-8 2004

CONCLUSIONS

The performance of reinforced concrete bare and dual frame with side center shear wall was investigated using the pushover Analysis in ETAB's. The conclusions drawn from the analysis is given here.

(a) We can conclude from the sequential hinge formation data that when we analyze the structure for C.P. performance point, collapse hinges formed in dual RC frame is less as compared to bare RC frame.

(b) From Pushover data of both structure we can say that displacement in both X and Y direction is less for RC dual frame structure and dual RC frame has more base shear at less displacement which shows that dual RC frame shows more resistance against lateral loads.

(c) The critical time period for bare RC frame is 1.305s, more as compared to dual RC frame which has 0.967s, which shows the stiffness of the dual RC frame is increased and the dual system behaves better during lateral load.

(d) Target displacement data shows that shear wall is more suitable for non-linear range where yield displacement is not much more affected in case of dual RC frame.

(e) Target displacement as per EC-8-2004 is more accurate as compare to ASCE because it is based on MDOF.

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