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DESIGN COMPARISON & RELIABILITY OF RCC & SRC COLUMNS FOR G+7 BUILDINGS

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ABSTRACT

With rapid urbanization there is an increased demand of public and residential spaces in cities with limited areas. Along with the living area, the land must be used for various other purposes such as farming, recreational activities, warehousing etc. Because of the fixed availability of the land to the mankind, the space cannot be increased. This has resulted in the construction to go upwards to mitigate the increasing demand for the housing spaces, i.e. high-rise buildings. Traditional RCC frame buildings face challenges of high section sizes and high reinforcement if the building is present in high seismic zones. In such cases utilization of SRC columns is beneficial if the cost of a pure steel frame building is deemed excessive. In present work a case study of two cases consists of RC and SRC Columns, (1) Seven story tall rectangular building (G+7) (regular geometry) and (2) Seven story tall L Shape building (G+7) (irregular geometry) is presented. The FEM modelling is performed on ETABS v16.2.1 and a validation study is presented for one typical column with AISC 360-05 and ETABS. The linear static analysis is performed, and results are presented to observe the effect of Steel reinforced column (SRC) in comparison with normal reinforced concrete column (RCC) building. Nonlinear static pushover analysis is also performed to study the performance of two building scenario against lateral loads. A parametric study is also performed with different column sizes and column arrangements to ascertain the reliability of SRC columns compared to RCC columns.

1.INTRODUCTION

A steel concrete composite column is a unique style of element which comprises of both a steel section and a concrete section. The system provides the rigidity and formability of reinforced concrete with the strength and speed of construction associated with the structural steel to produce an economic structure [Adapted from Caihua Chen et al. (2014)]. The composite action of the two materials results in higher load carrying capacity for a smaller cross section size as the composite section exploits the properties of all the materials of which it is made up of.

Apart from the general enhanced load carrying capacity some more benefits of composite columns are as below

- Concrete encasing provides resistance to fire and corrosion among steel sections
- Composite columns show high stiffness, ductility and high energy absorption capacity and thus, are more earthquake resistant
- Concrete encasing also provides buckling resistance.
- As smaller cross section provides higher load carrying capacity, the method is space utilisation effective. Furthermore, any cross section can be defined to obtain required resistance.

Depending on how the steel and concrete are placed composite column can be of three types [Adapted from Thunga Kartheek et al. (2020)].

i. Concrete Filled Tubes (CFT) – Concrete is filled inside steel tubes
ii. Fully Encased Columns (FEC) – Steel section is fully enclosed by concrete cross section
iii. Partially Encased Columns (PEC) – Steel section is partially encased by the concrete cross section

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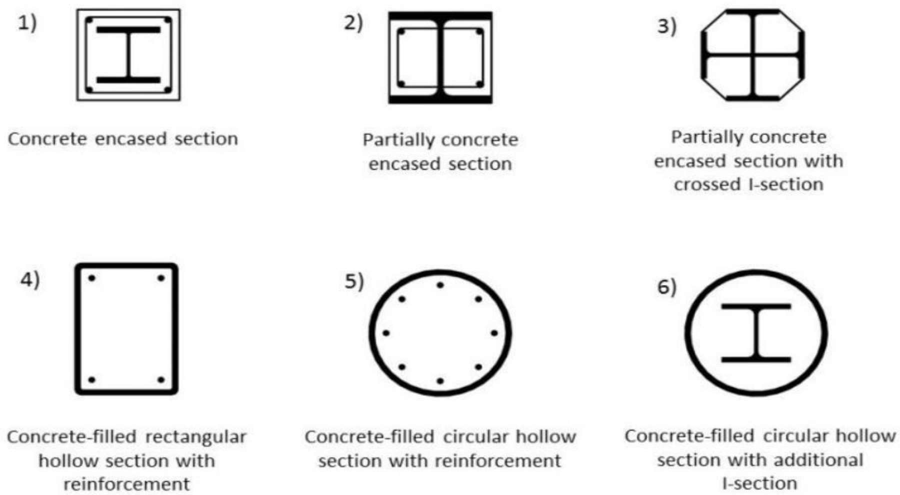

Types of Steel Concrete Cross Sections [Adapted from Cheng-Chih Chen et al. 2020]

2. Background and Motivation

In the metro cities, there is an increasing crunch of commercial and residential space due to the ever-increasing population and rapid urbanization. To mitigate the crisis of land shortage, the construction is now being carried in the vertical direction (both under and above the ground) instead of horizontal i.e. tall / high rise buildings.

Delhi NCR lies in a high seismic zone and as such special measures are required to make the buildings earthquake resistant. Many times, it is difficult to design an earthquake resistant Reinforced Cement Concrete (RCC) frame without compromising on the space utilization.

Considering this limitation, a study has been performed considering the effects of RCC and Steel Reinforced Concrete (SRC) columns in a building on its earthquake response and failure mechanisms. In the present study G+7 story buildings with different geometries have been considered subjected to similar loading. Two types of analysis have been performed for all buildings, linear analysis and static nonlinear analysis or Pushover analysis. For linear analysis comparisons have been made based on base shear, story drift, story displacement. While from the pushover analysis hinge formation and failure mechanisms have been observed.

It is observed that by using SRC columns the building response during earthquake events can be improved. Further, by using SRC columns the failure pattern of the building can be controlled i.e. in case of RCC columns, the buildings in the study, represent strong beam weak column relation, which can lead to global failure. While by using SRC columns this can be controlled, and we observe weak beam strong column relation, which is local failure situation. This improves the buildings safety performance criteria and ultimately the SRC building is safer considering public health.

3.Scope of the present work

The main objective of the present study has been discretized in various points as follows.

- To investigate material and cross section utilization for a high-rise building (G+7 RCC & G+7 SRC building, rectangular building; G+7 RCC & SRC L Shaped Building; G+7 RCC & G+7 SRC, rectangular double span building; G+7 RCC & G+7 SRC, rectangular building with opening).
- To validate design code and software design approach.
- To investigate building behavior by performing static nonlinear pushover analysis. And recommend structural provisions to prevent failure.
- To identify reliability of composite columns when subjected to same forces as concrete columns for different building geometries.

4. General & Literature Review

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4.1 General

The literature review aims to explore and analyze existing research and studies related to the design and performance of Reinforced Concrete (RCC) and Steel Reinforced Concrete (SRC) columns in the context of mid-rise buildings. The focus is specifically on seven-story buildings and the comparison between the two column types.

The review encompasses scholarly articles, research papers, conference proceedings, and relevant technical reports that discuss various aspects such as structural behavior, material properties, design methodologies, construction techniques, and performance evaluation of RCC and SRC columns. The goal is to gather a comprehensive understanding of the advantages, limitations, and

structural behavior of these types of columns within the specific context of mid-risebuildings.

By critically analyzing the reviewed literature, this thesis aims to provide valuable insights and recommendations for engineers, researchers, and practitioners involved in the design and construction of G+7 buildings. The findings of this literature review will contribute to making informed decisions regarding column selection, design approaches, material utilization, and overall

structural performance, ultimately aiding in the advancement and optimization of building design practices.

4.2 Literature Review

The reviewed literature for the study is presented below:

3D modelling and analysis of encased steel concrete composite column using ABAQUS

Thunga Kartheek, T. Venkat Das, have, in this paper, performed a comparison between experimental results and software analysis of FEC and RCC columns casted with normal and high strength concrete. Four columns divided into two groups normal strength (fcu 26MPa) and high strength concrete (fcu 42 MPa), 2 RCC columns and 2 FEC columns with ISMB have been casted. The columns are then tested for axial compression and deformations with load are observed. The same is then verified through ABAQUS software and compared. Through the study it is observed that SRC columns improved the ultimate capacity of the columns. It was observed that for normal and high strength concrete the improvement in ultimate load bearing capacity is ~10-15%.

Experimental Study on Seismic Behaviour of Full Encased Steel-Concrete Composite Columns

Caihua Chen, Cuikun Wang, Huizhong Sun, in this paper, investigated the influence of axial compression ratio, steel section shape, section embedment depth and stirrup ratio on the seismic behaviour of steel concrete composite columns. The investigation is performed on 26 columns with different steel sections, lateral ties and embedment depths. The columns are subjected to low cyclic reversed loading to simulate earthquake and the failure patterns, hysteresis loops, energy dissipation capacity etc has been analyzed. It was concluded that, steel composite concrete columns show bending failure under seismic loads and hence are favorable for seismic events. The columns show lesser seismic resistance for higher axial compression ratio. As ratio of stirrups is increased the seismic behavior improves. Higher the confinement of concrete due to steel section the better the seismic behaviour.

Analytical model for predicting axial capacity and behaviour of concrete encased steel composite stub columns

Cheng-Chih Chen, Nan-Jiao Lin, in this paper, investigated the axial compressive capacity and force-deformation behavior of concrete encased steel stub columns. Constitutive relationships were established for all elements of a composite columns such as, confined concrete, unconfined concrete, steel section and longitudinal reinforcement. In the study, through comparison with experimental results, it was observed that the axial capacity of the composite column can be determined from strengths contributed from each material. In the study 26 columns were study with different steel sections, longitudinal reinforcement & lateral ties. It was observed with more confinement the axial compressive capacity is more. Furthermore, cross shape section has high confinement compared to I shape.

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Concrete Confinement for different sections [Adopted from Cheng-Chih Chen et al.

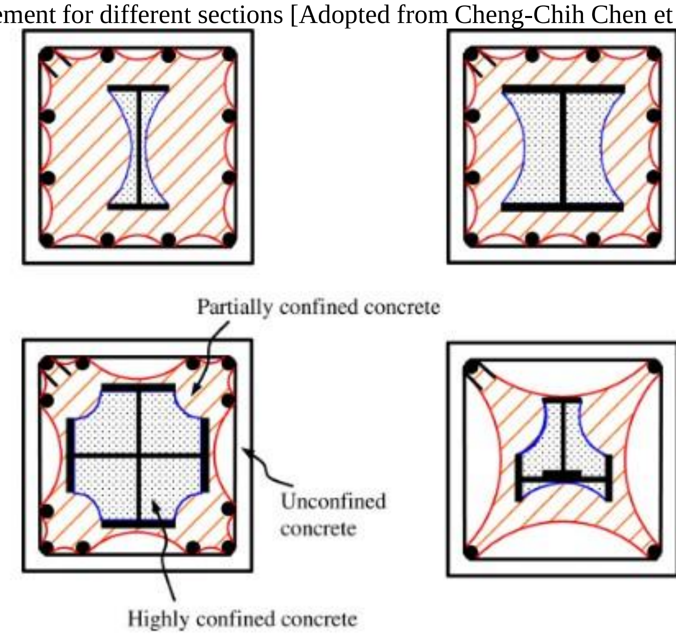

Fig. 7. Regions for unconfined, partially confined, and highly confined concrete in various composite cross sections.

(2006)]

Behaviour of steel beam to concrete filled SHS column frames: Finite element model and verifications
Lin-Hai Han, Wen-Da Wang, Xiao-Ling Zhao, in this paper a comparative study is performed to analyse the behaviour of a composite frame with concrete filled square hollow section and steel beam. A finite element modelling is carried out in ABAQUS and analysis is performed based on application of constant axial load and lateral cyclic load. The analytical model is then compared with experimental results, performed on 6 specimens. Through both analysis it was observed that Concrete filled steel tube frames have excellent earthquake resistance. In all cases the beam failed first i.e. weak beam strong column strategy. It was also observed that lateral load carrying capacity decreased with increasing axial load.
Eccentric Axial Load Capacity of High Strength Steel-Concrete Composite Columns of Various Sectional Shapes
Chang-Soo Kim, Hong-Gun Park, Kyung-Soo Chung, In-Rak Choi, in this study, two concrete filled steel tubes and 4 concrete encased columns using high strength steel & concrete were tested to investigate the effect of various sectional shapes and configurations n the eccentric axial load capacity. The study is performed to maximise the contribution of high strength steel, preventing early crushing of concrete by, one using steel tubes or closely placed ties; two, using ultra high strength concrete (200MPa); three, by placing L shape steel sections at corner of columns. Axial eccentric load is applied and, axial & lateral deformations along with torsion is monitored. It was observed that concrete filled tubes showed development of full plastic strength despite local buckling. Concrete encased tubes showed good ductile behaviour when provided good confinement. The columns with L shape section at corners showed better confinement and hence better axial capacity than encased sections.
Eccentric Axial Load Capacity of High Strength Steel-Concrete Composite Columns of Various Sectional Shapes
Georgios S. Papavasileiou, Dimos C. Charmpis, in this study, a structural optimisation has been performed based on controlling the cost objective function for composite buildings with fully encased concrete columns & steel beams and steel L bracings. The design of elements is based on EC3 & EC4. Five analysis have been performed, one force controlled linear static analysis, two pushover analysis and two eigen value analysis. IT was observed that same group of columns may require different sections as per optimisation. The steel bracings significantly improved the seismic behaviour.
5. Problem Statement & Methodology

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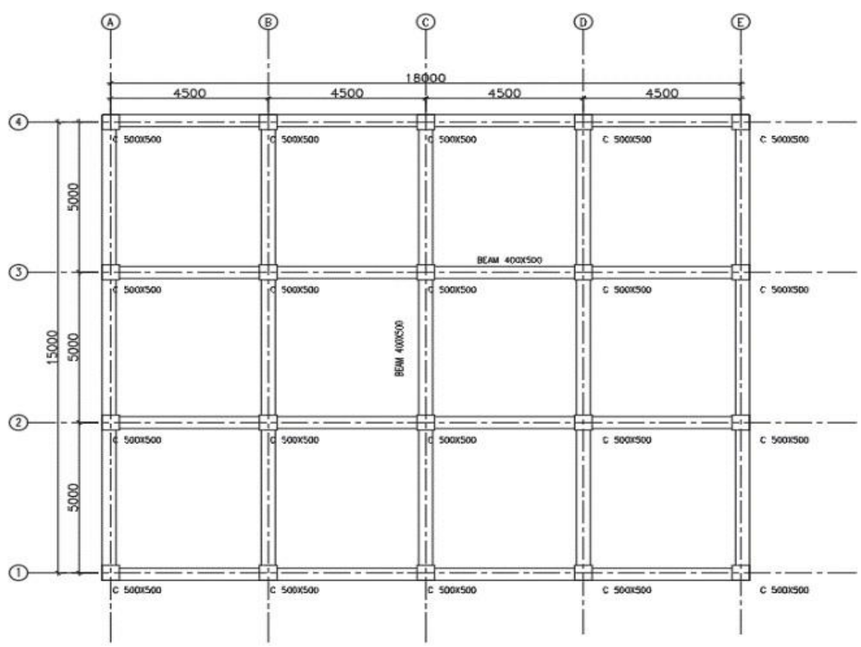
With increases urbanization and limited space in cites, there is a crunch on land availability. Due to this the structures are now converted to tall/ high rise structures. Nowadays, all structures whether, healthcare, residential, office spaces or commercial are all tall/ high rise structures. These structures have a high safety requirement for public health and safety. The research available on seismic event studies and pushover analysis of these buildings is limited. Hence, in this study the effect of SRC columns on building safety has been investigated.

The study has been performed for four sets of G+7 Buildings

1. G+7 Rectangular Building
2. G+7 L Shape Building
3. G+7 Rectangular building with Openings
4. G+7 Rectangular Building with Double Span as building in 1.

For each type, 2 3D models have been considered. One, with RCC columns & the other with SRC columns. In the current analysis all the columns in all floors are assigned similar properties. The different sets of models form part of a parametric study based on the building geometry i.e the number of columns & the building shape. The general plan and elevations have been shown in Figures below.



COLUMN LAYOUT PLAN AT 1st
Floor G+7 WITH RCC COLUMNS

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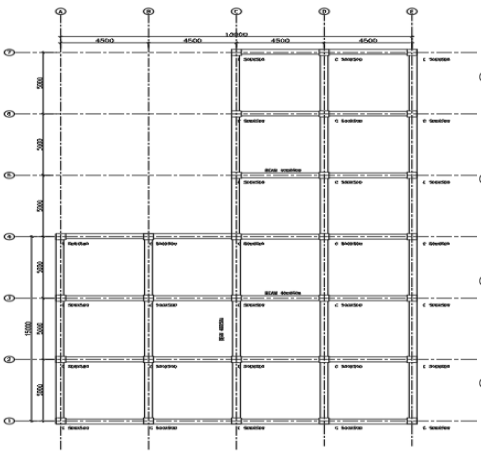
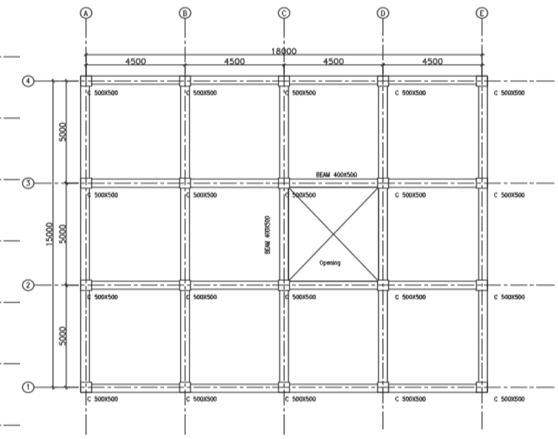


COLUMN LAYOUT PLAN AT 1st Floor G+7 WITH RCC COLUMNS L SHAPE BUILDING



COLUMN LAYOUT PLAN AT 1st Floor G+7 WITH RCC COLUMNS + OPENING

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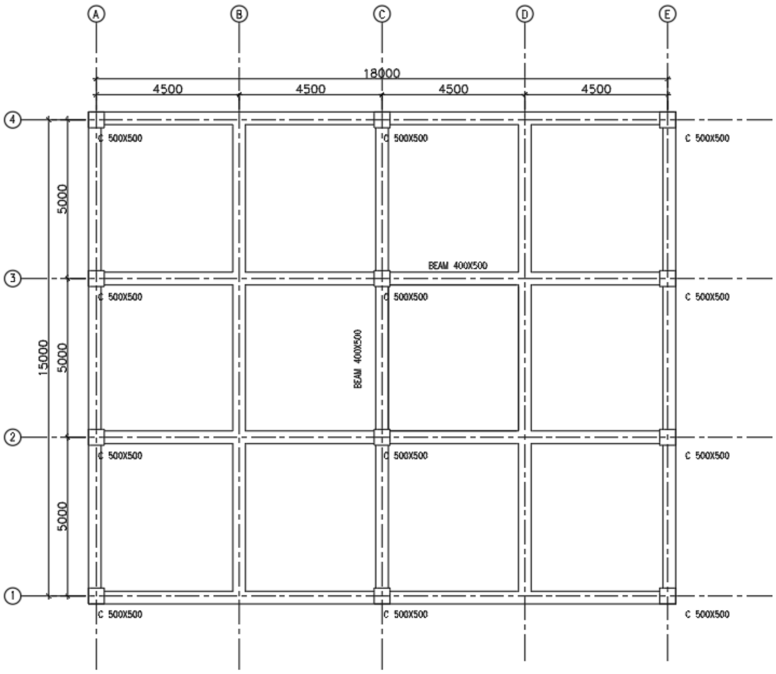
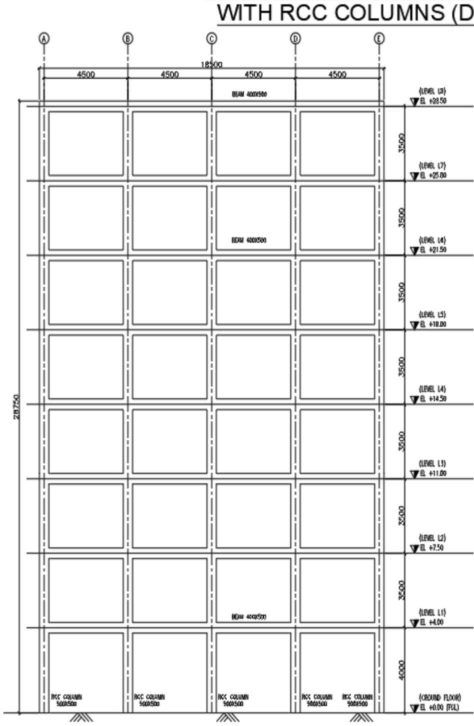
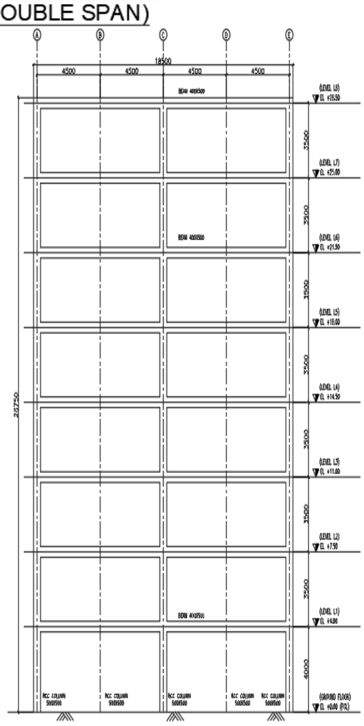


COLUMN LAYOUT PLAN AT 1st Floor G+7
WITH RCC COLUMNS (DOUBLE SPAN)



RCC BUILDING ELEVATION
(G+7 TYP.)



RCC BUILDING ELEVATION
(G+7 TYP.) (DOUBLE SPAN)

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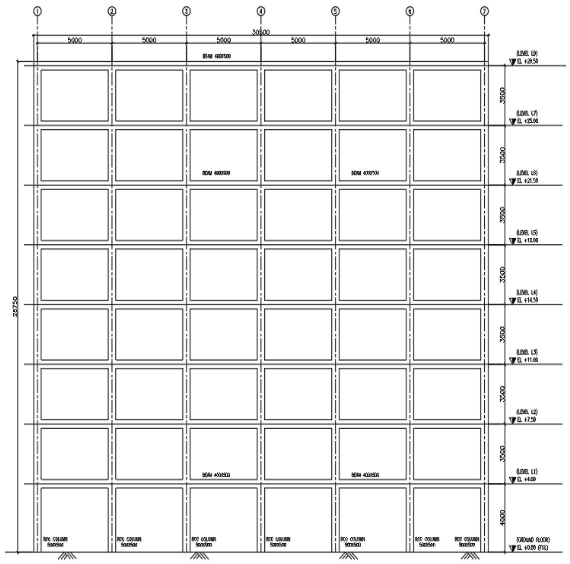
RCC BUILDING ELEVATION
(G+7 TYP.) (L SHAPE BUILDING)

The structures considered have similar geometry/ layout on all floors. The general rectangular building consists of 4 longitudinal bays (Grid A to E) and 3 transverse bays (Grid 1 to 4). While the L shape building has 3 extra transverse bays between Grid C to E. The Transverse bays are 5m wide while the longitudinal bays are 4.5m wide. The height of the first story (Ground to 1st floor) is 4m while the remaining floors have a height of 3.5m. The columns are made of RCC of Grade M30, while the steel section used is UC305x305x240 of Grade Fe345. Reinforcement is of Grade Fe500 is as per Software Design..

Element	**Material**	**Size**
Column	M30	500 x 500mm (General)
Steel Section for SRC	Fe345	UC 305x305x240
Beam	M30	400(Width) x 500 (Depth)mm
Slabs	M30	Roof–125mm Floor – 150mm
Reinforcement Steel	Fe500	As per Design

It is assumed that all beam–column joints are fully rigid. The dead load is based on density of the material in addition to it Superimposed dead load is 1kN/m² for all the floors and 0.5kN/m2 for Roof. Live load is 3kN/m² for all the floors and 1.5kN/m2 for Roof. In addition to these loading for external wall has been applied on the outer beams. The wall thickness is assumed to be 200mm thick. Loading has been considered from IS 875:2015 Part 2. The loadings and parameters are described ahead.

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S.No.	Load Case	Value	Remarks
1	Dead Load		
a)	Self-Weight	25 kN/m^3	Defined as material property
b)	Weight of Slab	=0.15*25 = 3.75 kN/m^2	
c)	Weight of Roof Slab	= 0.125*25 = 3.125 kN/m^2	
d)	Wall Load	= 0.2*25*3 = 15kN/m	200mm thick wall for a 3m clear height
2	Live Load		IS 875 2015 Part 2
a)	Floor Live Load	3 kN/m^2	
b)	Roof Live Load	1.5 kN/m^2	
3	SIDL		
a)	Floor Load	1 kN/m^2	
b)	Roof Load	0.5 kN/m^2	
4	Earthquake Load		IS 1893 – 2016 Part 1
a)	Zone	V	Delhi Region
b)	Zone Factor	0.36	
b)	Importance Factor	1.5	
d)	Response Reduction	5	
e)	Site Type	II	

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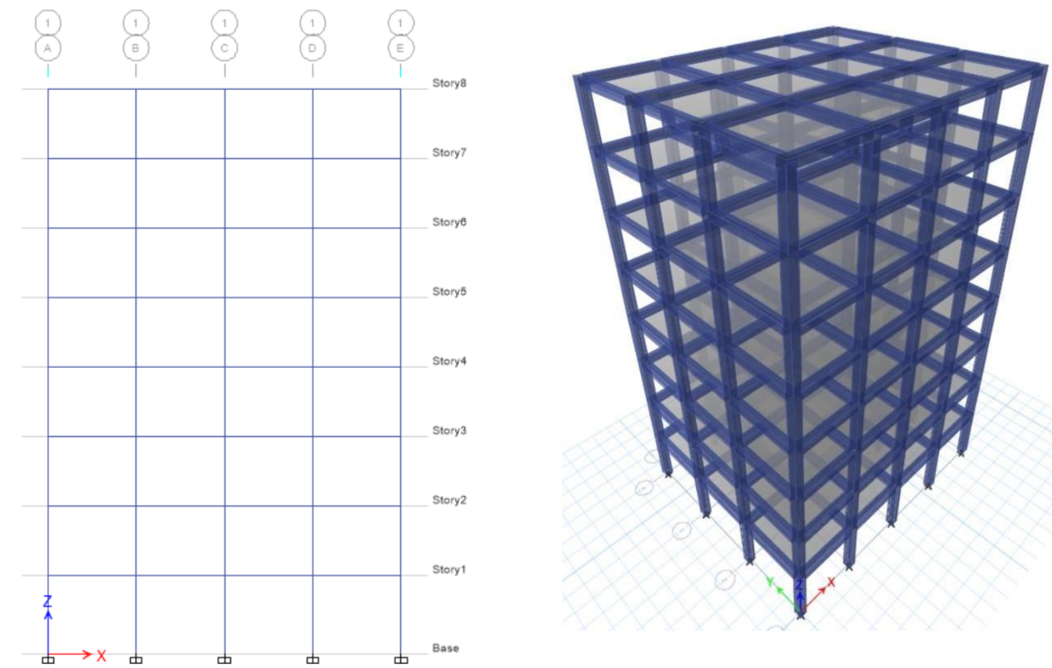
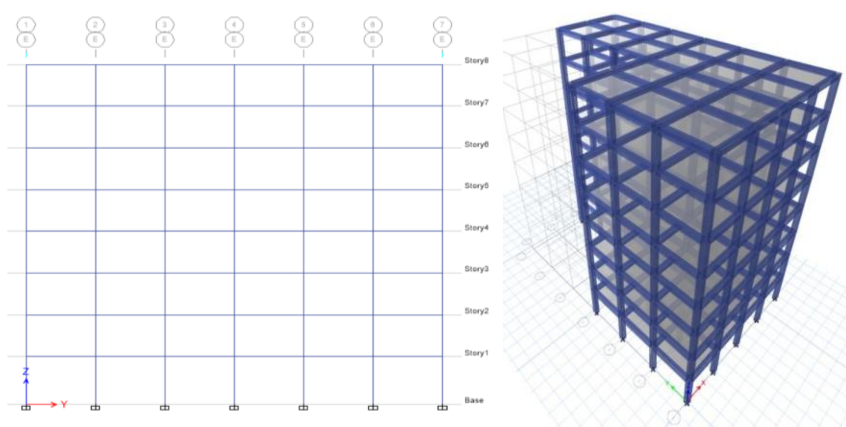
For the earthquake analysis as well as Pushover analysis, the software ETABS has been used to predict the building behaviour and response. The mass is considered to be acting at the centre line of each floor. The mass participation has been defined 100% of Dead load and 50% of live load. The columns have been assumed to be fixed at base.
Since the buildings are asymmetrical in shape the analysis has been performed for both direction X (Transverse) & Y (Longitudinal). The different mass participations, time periods and failure patterns are then utilized for comparison of the two types of columns.



Rectangular Building Elevation & 3D Shape ETABS Model



L Shape Building Elevation & 3D Shape ETABS Model

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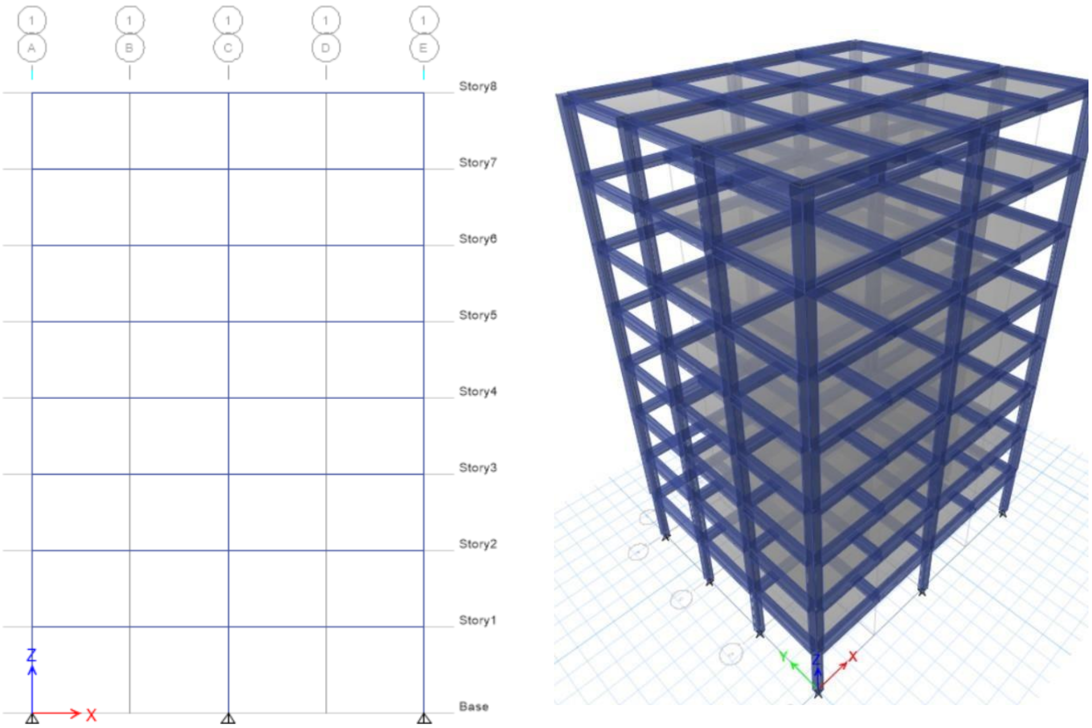

Rectangular Building Elevation & 3D Shape ETABS Model (Double Span)

Non-Linear Static Analysis or Pushover analysis is a static procedure that uses a simplified nonlinear technique to estimate seismic structural deformations. The analysis utilises the principle that structures redesign themselves during earthquakes i.e. if a member yields or fails the forces redistribute. The analysis simulates this by applying loads until the weak link in the structure is found and then revising the model to incorporate the changes in the structure caused by the weak link. A second iteration indicates how the loads are redistributed. The structure is “pushed” again until the second weak link is discovered. This process continues until a yield pattern for the whole structure under seismic loading is identified [Adapted from Earthquake Resistant Structures, Mohiuddin Ali Khan]. The analysis is an approximate tool to understand the building behaviour.

To perform the pushover analysis, the following assumptions were adopted: (i) possible plastic hinges usually form at the ends of beams and columns under earthquake actions (No loads acting on mid spans of beams and columns); (ii) for beam elements, plastic hinges are formed by uniaxial bending moments (Slab assumed to fully rigid, also no lateral loads); and (iii) for column elements, plastic hinges are formed due to combined axial loads and bi-axial bending moments.

The material model used in the pushover analysis is based on the provisions of FEMA 356 and documents defining force (moment)–displacement (rotation) criteria for the plastic hinges used in the pushover analysis. Figure ahead presents the typical force (moment)–displacement (rotation) relation. The points A, B, C, D and E define the force–displacement relation of the hinge while the points IO, LS and CP define the structural performance acceptance criteria for the hinges (points IO stands for Immediate Occupancy, LS Stands for Life Safety and CP stands for Collapse Prevention, respectively). The values assigned to each of these points vary depending on the type of member as well as many other parameters defined in the FEMA-356 documents.

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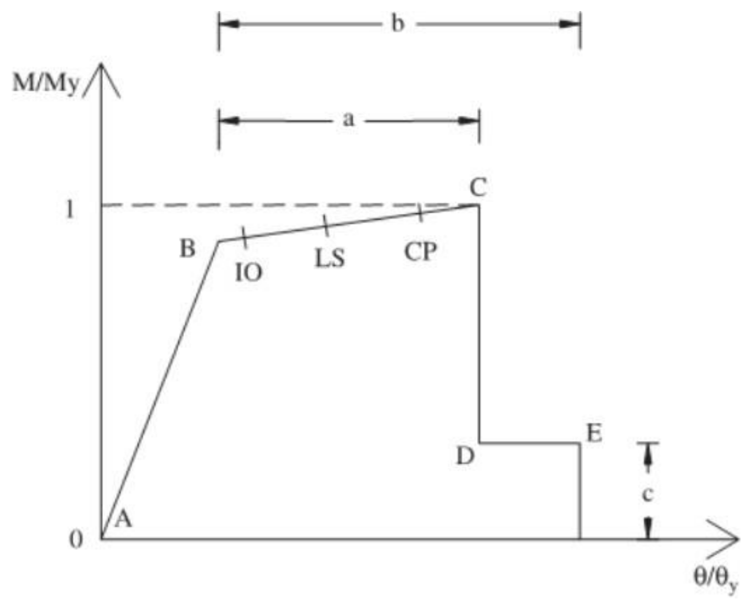

Moment Rotation Curve in Pushover Analysis

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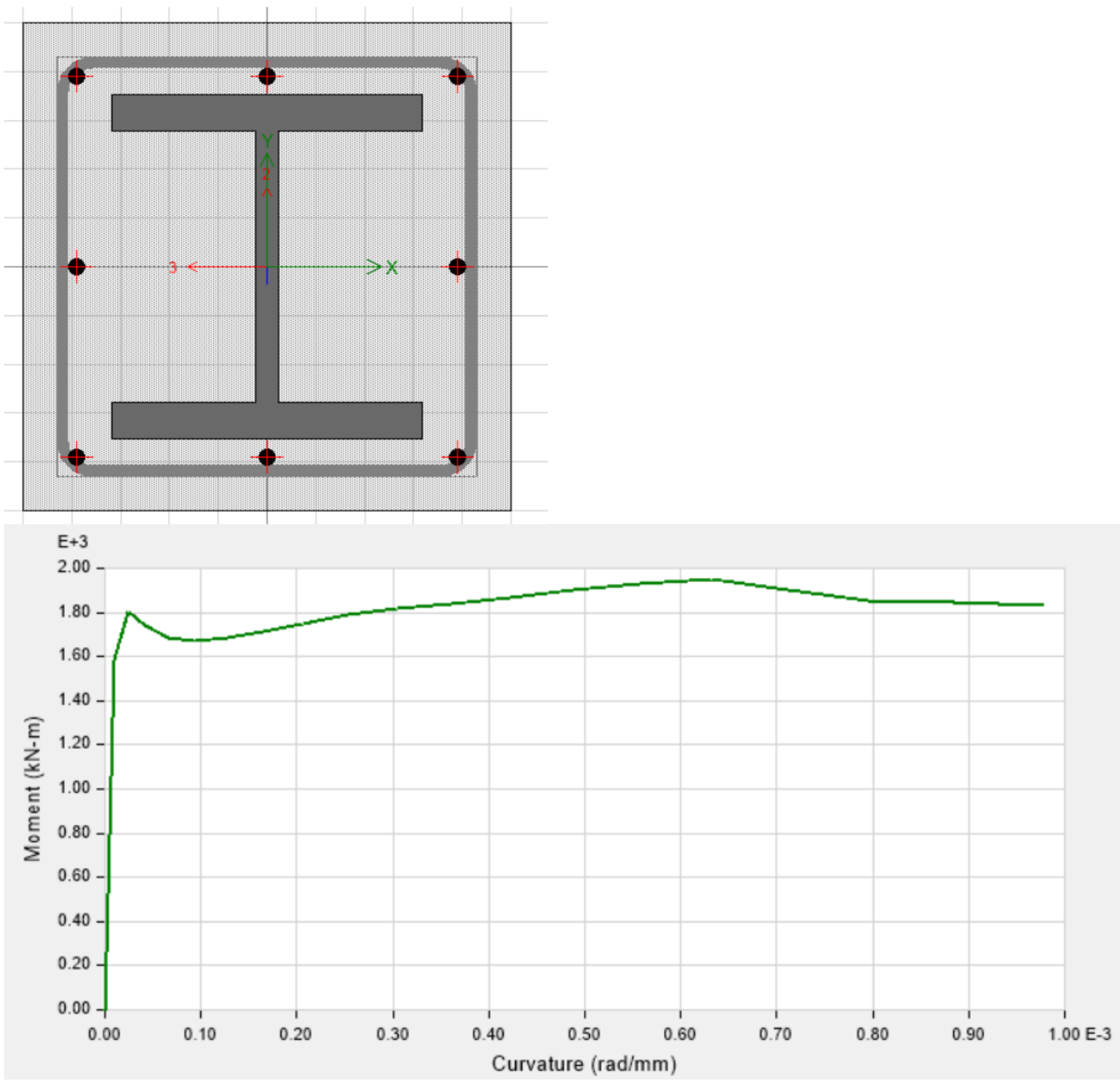
For the analysis of failure, hinges are assigned at 0.1 times of length of the member from the supporting point. The hinge definitions for RCC elements are predefined in ETABS and hence, defined through the options available in ETABS. For SRC columns the hinge is defined based on Moment-Curvature relationship from the section designer tab. Figure below demonstrate one typical arrangement of composite and corresponding moment – curvature relationship and accordingly hinge properties are assigned to the SRC member in ETABS.
Once the hinges are defined the Pushover load case is defined. The load is defined as an imposed deformation. The deformation increases based on the number of steps defined. And for each case hinge formation / failure pattern is observed.
A calculation validation has been first performed before all the required analysis to compute the accuracy of the ETABS software.



Cross Section & Moment Rotation Curve

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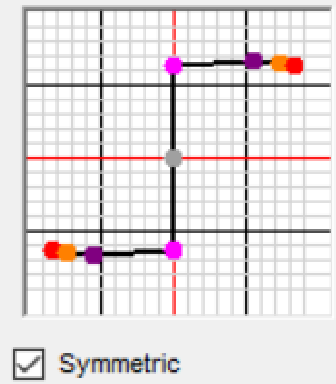
Point	Moment/SF	Curvature/SF
E-	-1800	-0.9
D-	-1850	-0.8
C-	-1900	-0.6
B-	-1800	0
A	0	0
B	1800	0
C	1900	0.6
D	1850	0.8
E	1800	0.9



Hinge Definition

6.ANALYSIS

The following two analysis, along with the particular results from each analysis, have been used for the comparison of RCC & SRC column buildings

1. Linear Analysis – Base Shear, Story Drift, Story Displacement etc
2. Non-Linear Static or Pushover Analysis – Hinge formation and failure pattern

6.1. Linear analysis

The linear analysis provides the section design and utilization ratios for both RCC & SRC columns, along with the respective base shears, story displacement & story drifts. Considering all the factors together helps in identifying which columns provide more earthquake resistance and overall better structural behaviour. All the required factors and calculations have been performed in the ETABS software and extracted directly.

It is observed that none of the RCC columns exceed the permissible limits in the linear analysis as the permissible reinforcement as per ACI is 8% while the maximum reinforcement observed through design is ~4%. However, considering the economic and practical constructability challenges any percentage between 3-4% is deemed excessive. It is then evident that the RCC columns in some cases result in excessive reinforcement and hence are not beneficial as compared to SRC columns. It is also observed from the study that optimization of the SRC column can be done as the maximum utilization observed is ~0.45.

It is observed that low utilization ratio of SRC columns is observed when the base shear of the SRC column buildings is much higher than that of RCC buildings. The SRC columns, also results in lesser story displacements and story drifts which are beneficial considering adjacent structures and damage to internal elements during an earthquake event. It is also observed that the relative story drift between ground and 1st floor is lesser considering SRC columns and hence, helps in reducing soft story failure.

However, the linear analysis alone cannot be considered a reliable factor for considering the efficiency of the SRC columns and hence, pushover analysis is performed to observe the failure pattern.

G+7 Rectangular Building

It is observed that a maximum of 1.4% reinforcement steel is required for the RCC building with a design utilization of ~0.9. Whereas, the SRC columns have a utilization of 0.155 with minimum reinforcement.

The Base shear of the SRC building is higher than RCC building by 25% in X direction & 18% in Y Direction (Table 4.1). Despite this the time period of the SRC building is lesser than RCC building by 13% (Table 4.1). The lateral displacement is also reduced by using SRC by 5mm i.e. 14%.

By using SRC the Story drift at the first floor is reduced by ~58% & hence, the SRC columns better control the Soft story effect.

ISSN: 2456-9348
Impact Factor: 7.936

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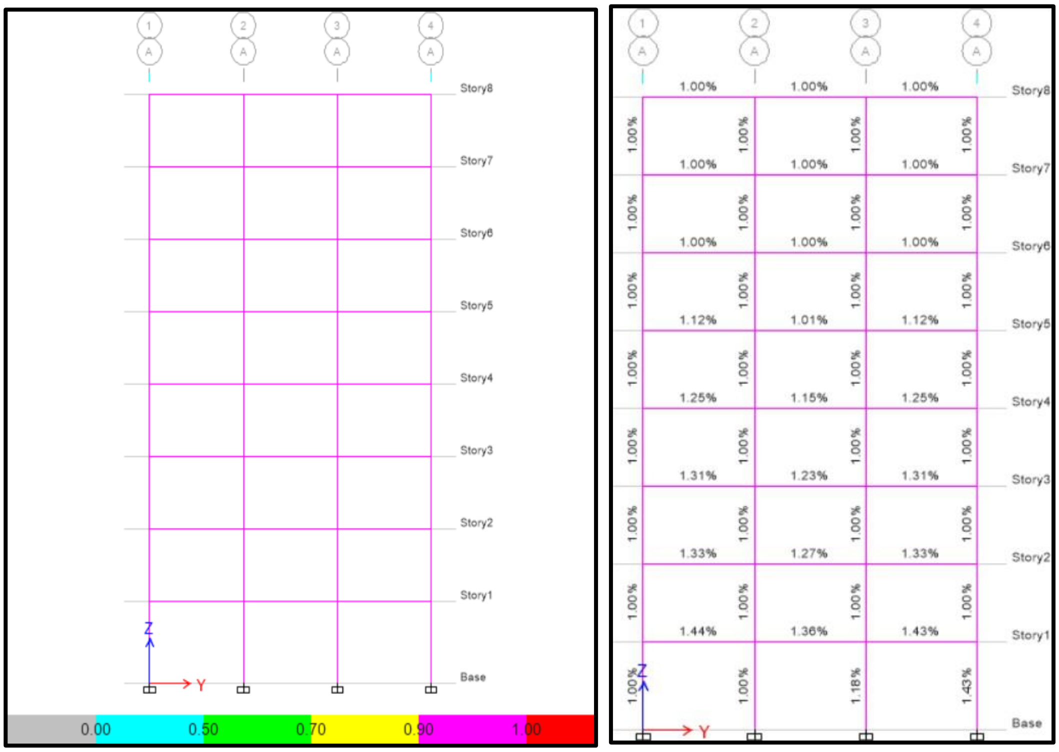
Considering that the base shear is much higher for SRC building and the fact that the story displacement & drifts are smaller in SRC building, the SRC columns option can be considered as a better alternative. It should however be noted that further section optimization can be done for both the buildings. However, this has not been considered considering Pushover results.



Utilisation Ratio & Percentage of Steel RCC

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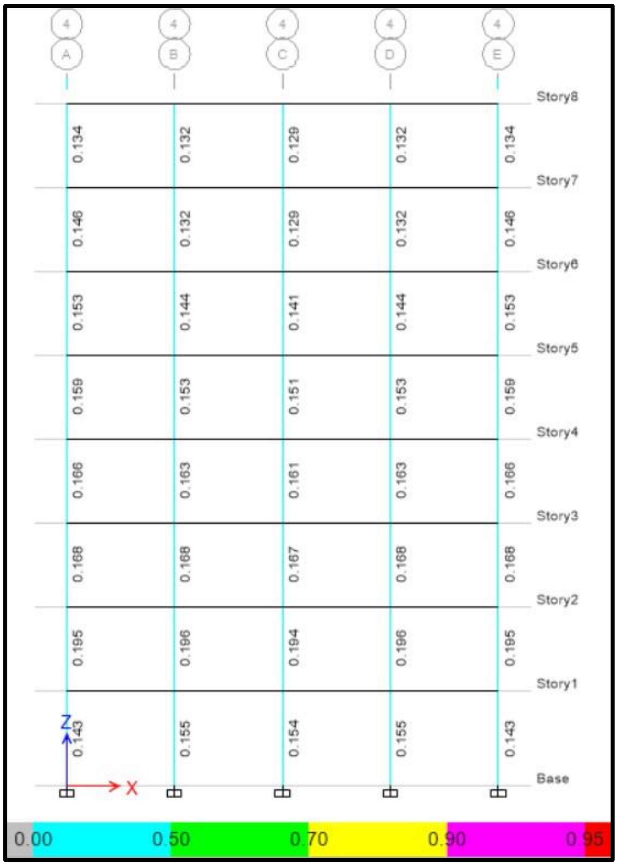
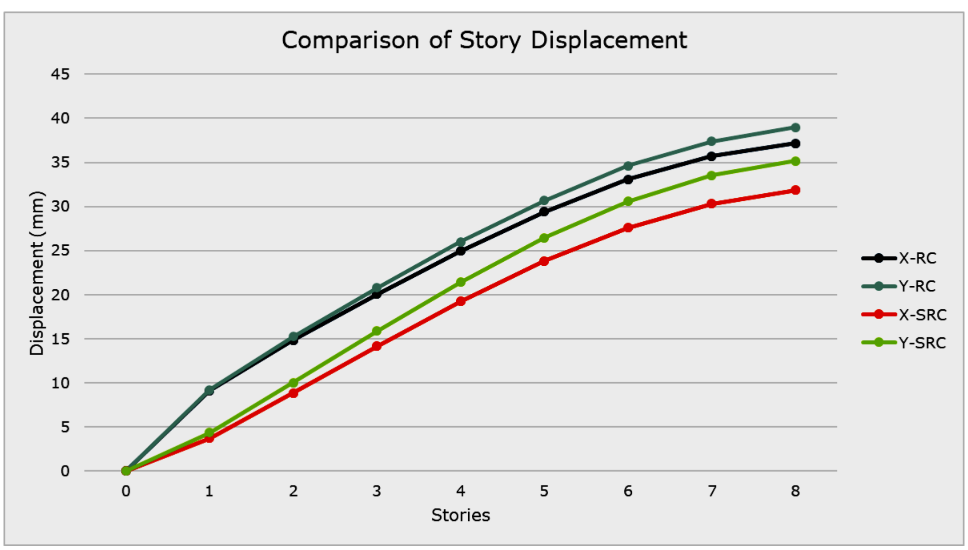


4.2 Utilisation Ratio SRC



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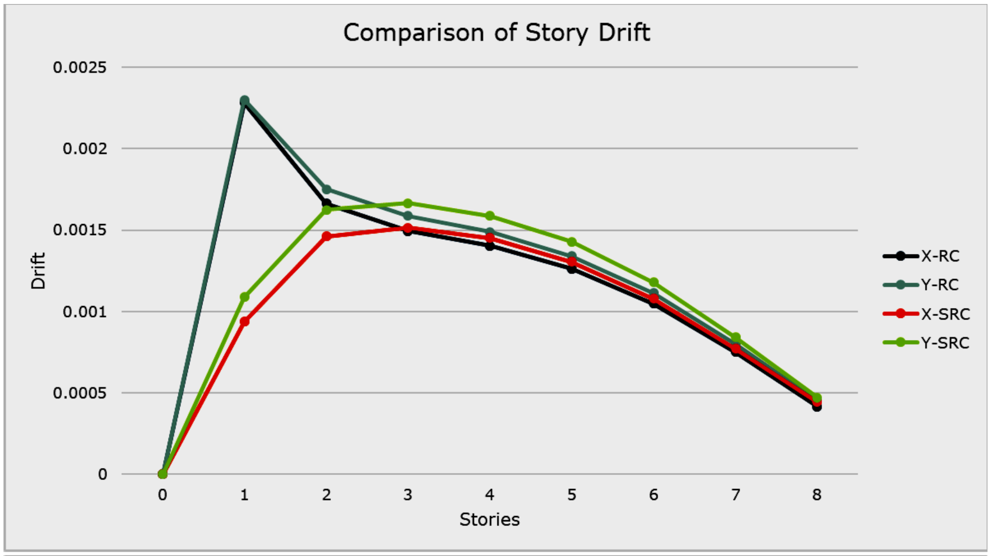

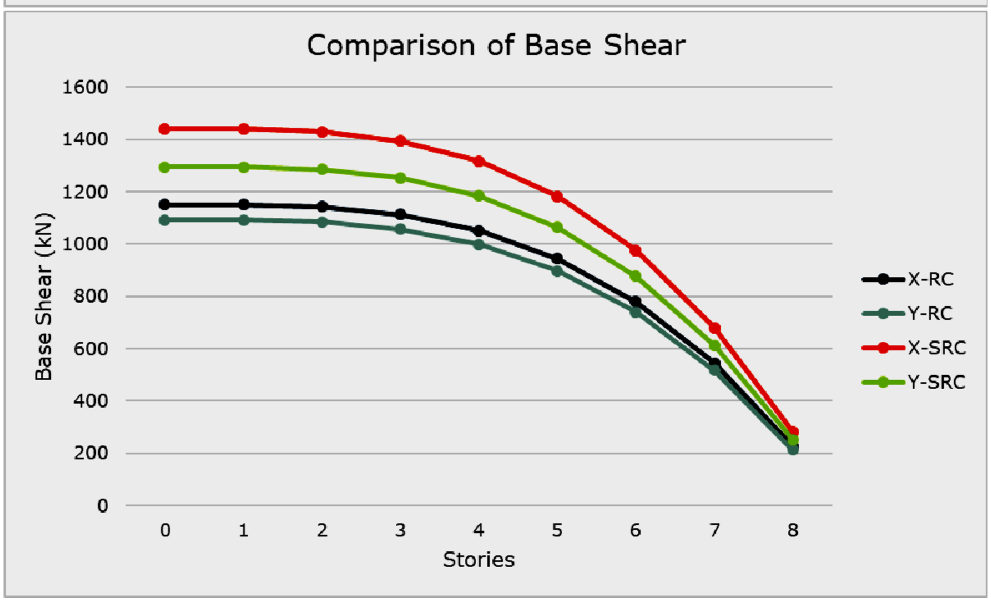

Story Displacement, Story Drift & Base Shear

G+7 L Shape Building

It is observed that a maximum of 1.0% reinforcement steel is required for the RCC building with a design utilization of ~0.9. Whereas, the SRC columns have a utilization of 0.23 with minimum reinforcement.

The Base shear of the SRC building is higher than RCC building by 12.5% in X direction & 6% in Y Direction. Despite this the time period of the SRC building is lesser than RCC building by 4%. The lateral displacement is also reduced by using SRC by 4mm i.e. 10%.

ISSN: 2456-9348
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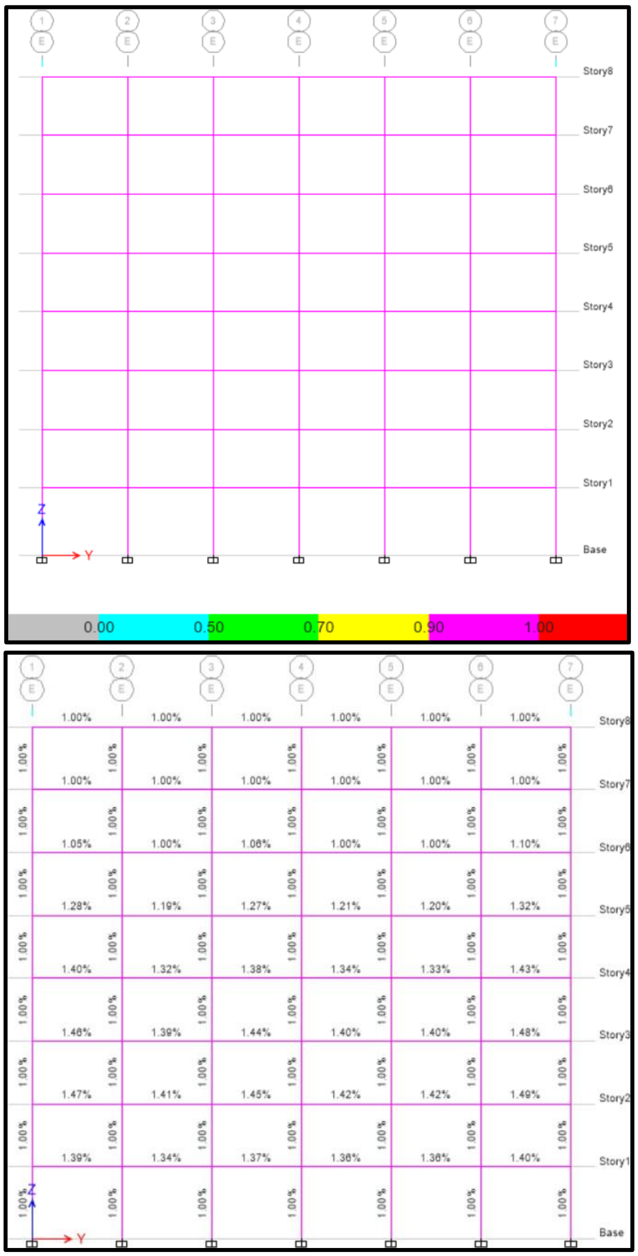
By using SRC the Story drift at the first floor is reduced by ~19% & hence, the SRC columns better control the Soft story effect.

Considering that the base shear is much higher for SRC building and the fact that the story displacement & drifts are smaller in SRC building, the SRC columns option can be considered as a better alternative. It should however be noted that further section optimization can be done for both the buildings. However, this has not been considered considering Pushover results.



Utilisation Ratio & Percentage of Steel RCC

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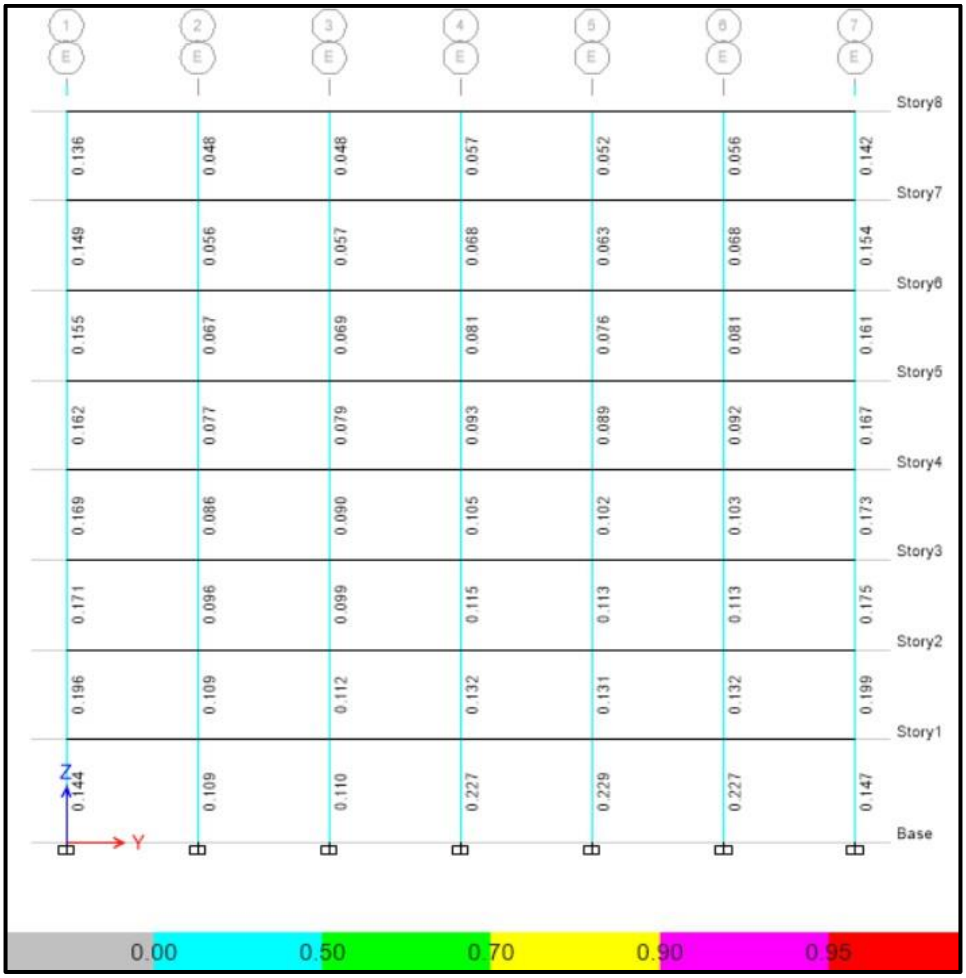

Utilisation Ratio SRC

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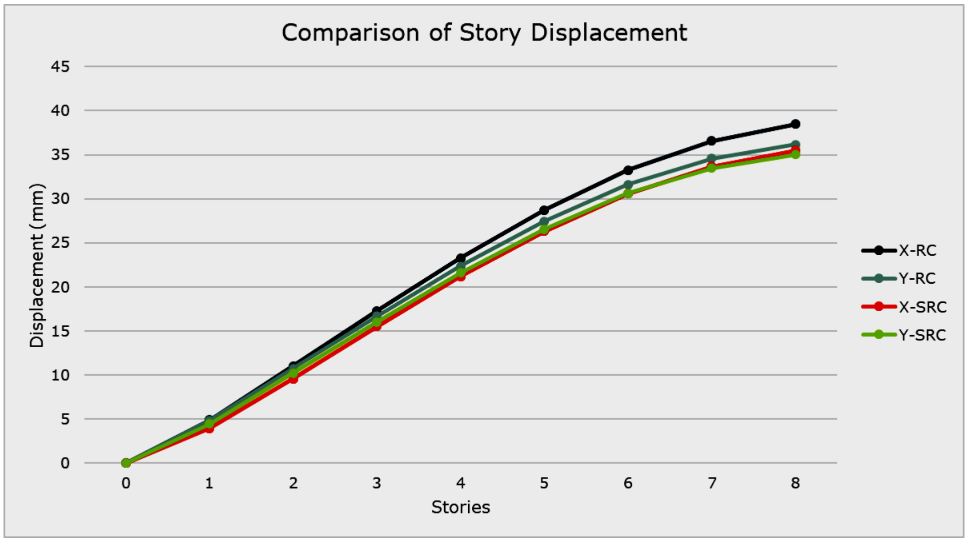

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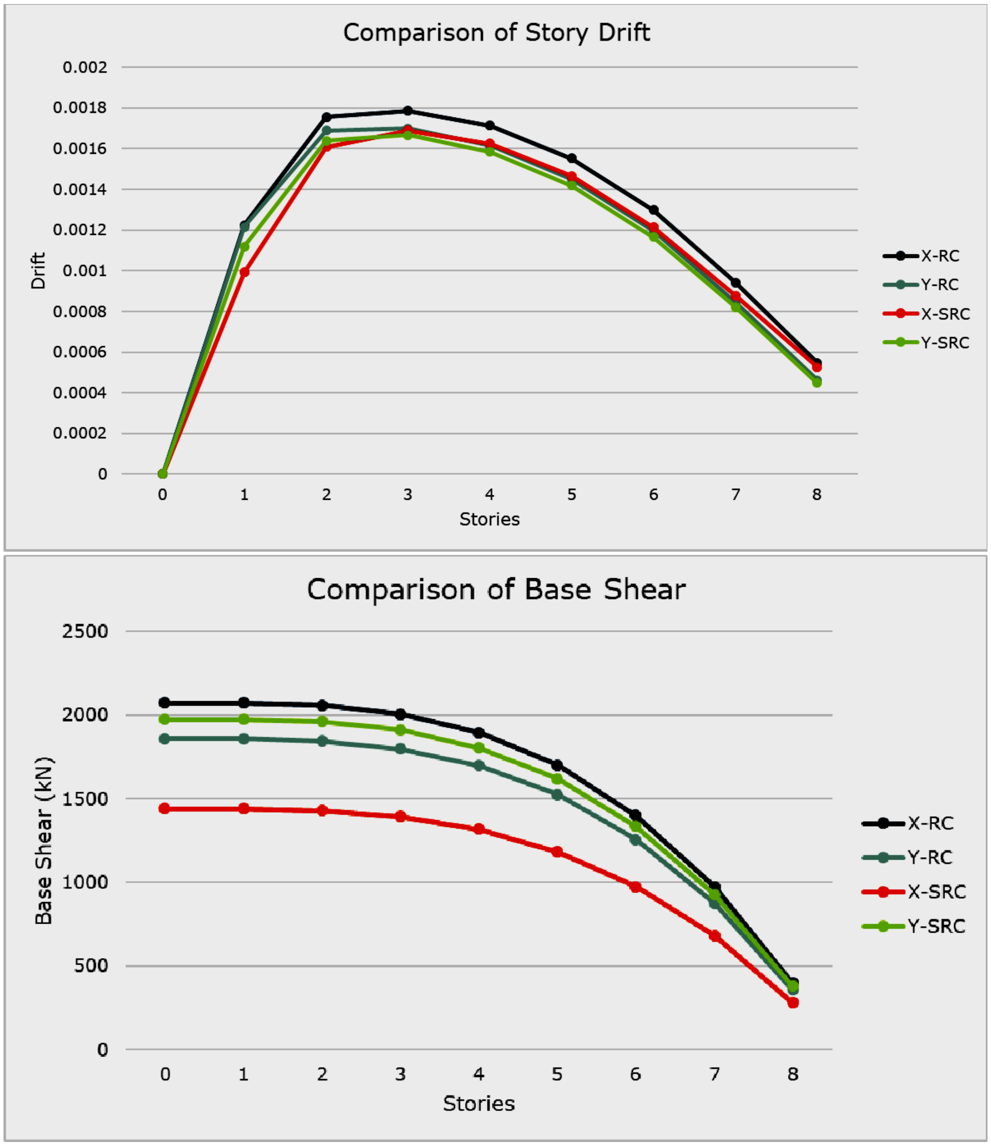

Story Displacement, Story Drift & Base Shear

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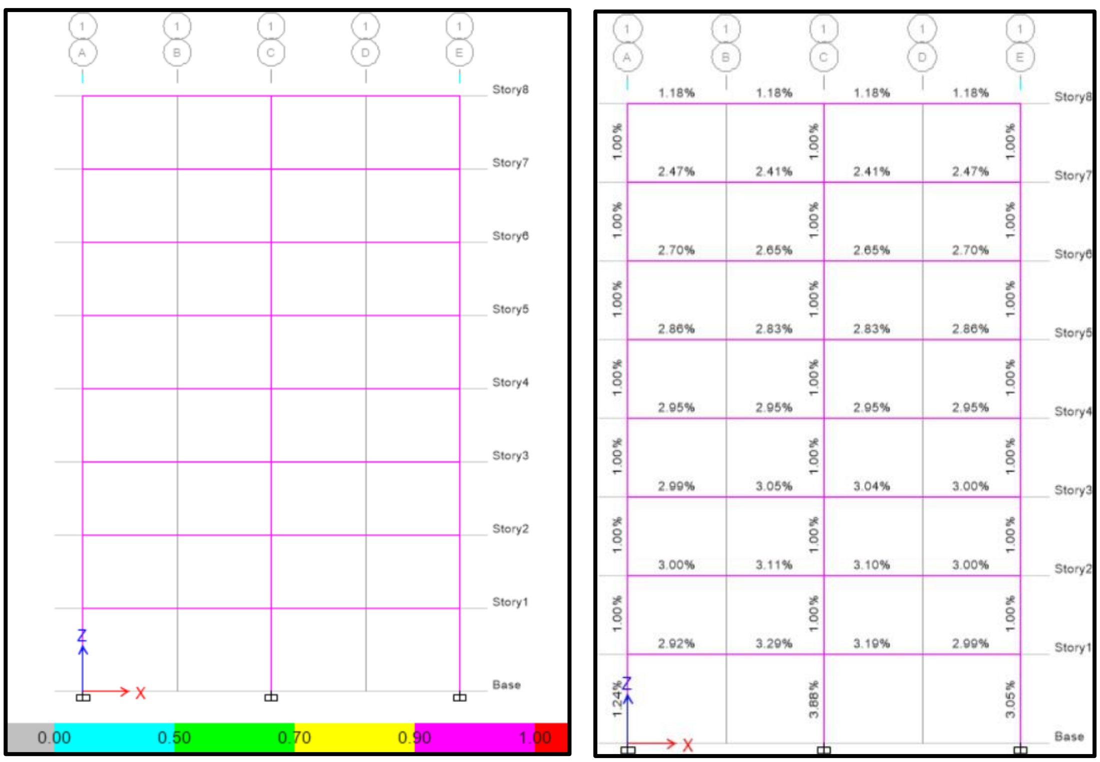
G+7 Rectangular Building Double Span

It is observed that a maximum of 3.9% reinforcement steel is required for the RCC building with a design utilization of ~0.9. Whereas, the SRC columns have a utilization of 0.46 with minimum reinforcement.

The Base shear of the SRC building is higher than RCC building by 17% in X direction & 16% in Y Direction (Table 4.1). Despite this the time period of the SRC building is lesser than RCC building by 12.5% (Table 4.1). The lateral displacement is also reduced by using SRC by 5.5mm
i.e. 9%.

By using SRC the Story drift at the first floor is reduced by ~50% & hence, the SRC columns better control the Soft story effect.

Considering that the base shear is much higher for SRC building and the fact that the story displacement & drifts are smaller in SRC building, the SRC columns option can be considered as a better alternative. It should however be noted that further 3.9% reinforcement is very high for a section and would require section increase. Furthermore, any increase in forces will lead the section to be insufficient and hence, the RCC section is not deemed beneficial in this case.



Utilisation Ratio & Percentage of Steel RCC

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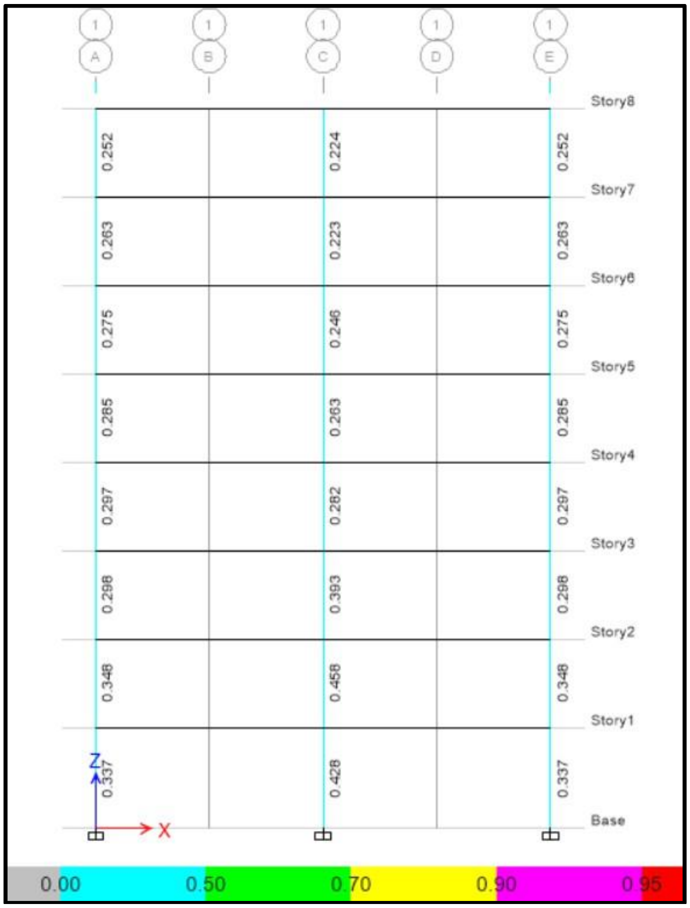
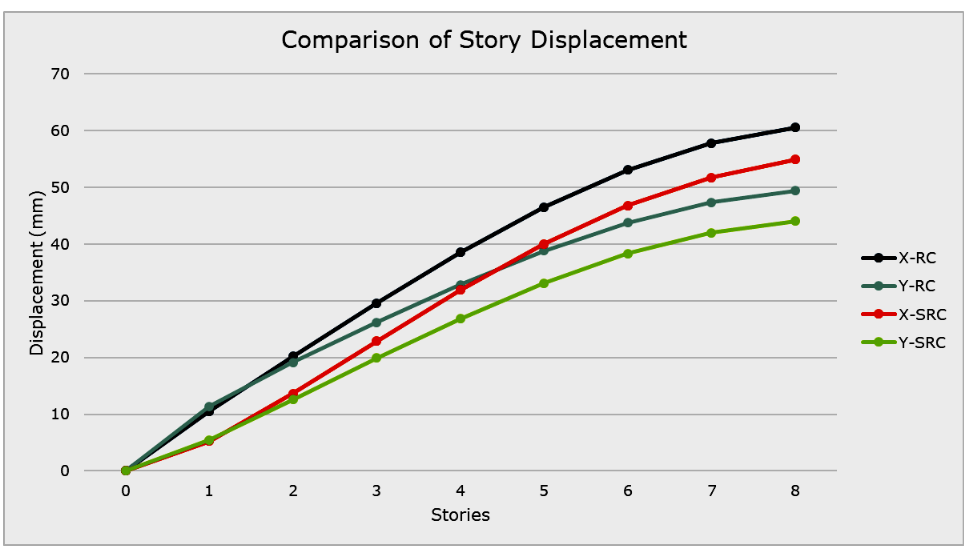


Utilisation Ratio SRC



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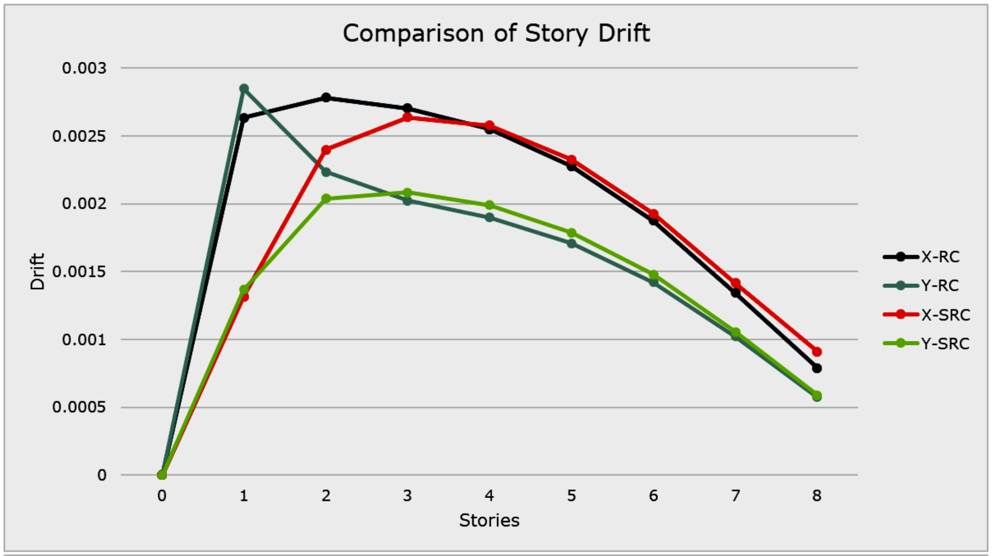

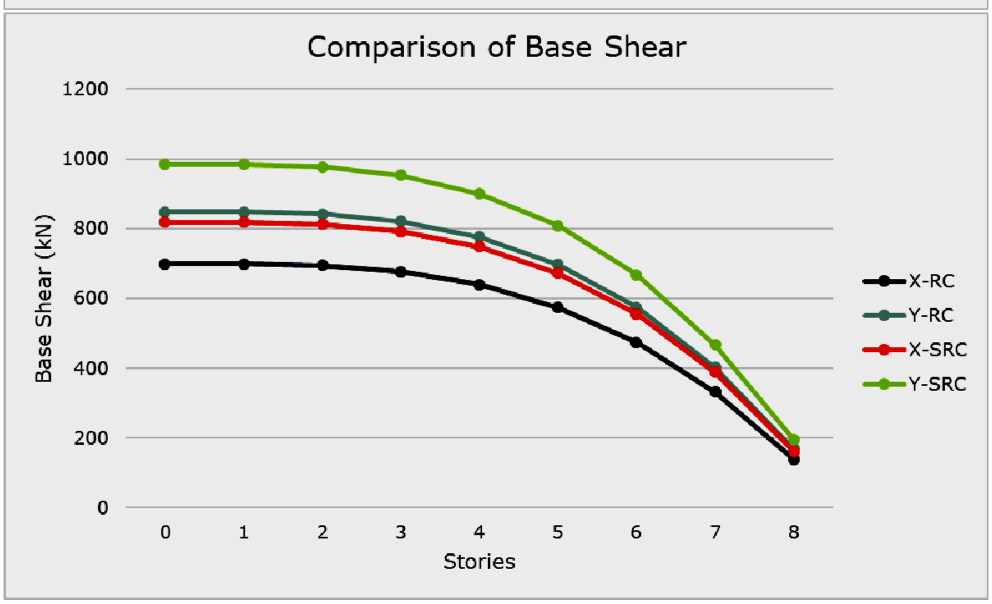

Story Displacement, Story Drift & Base Shear

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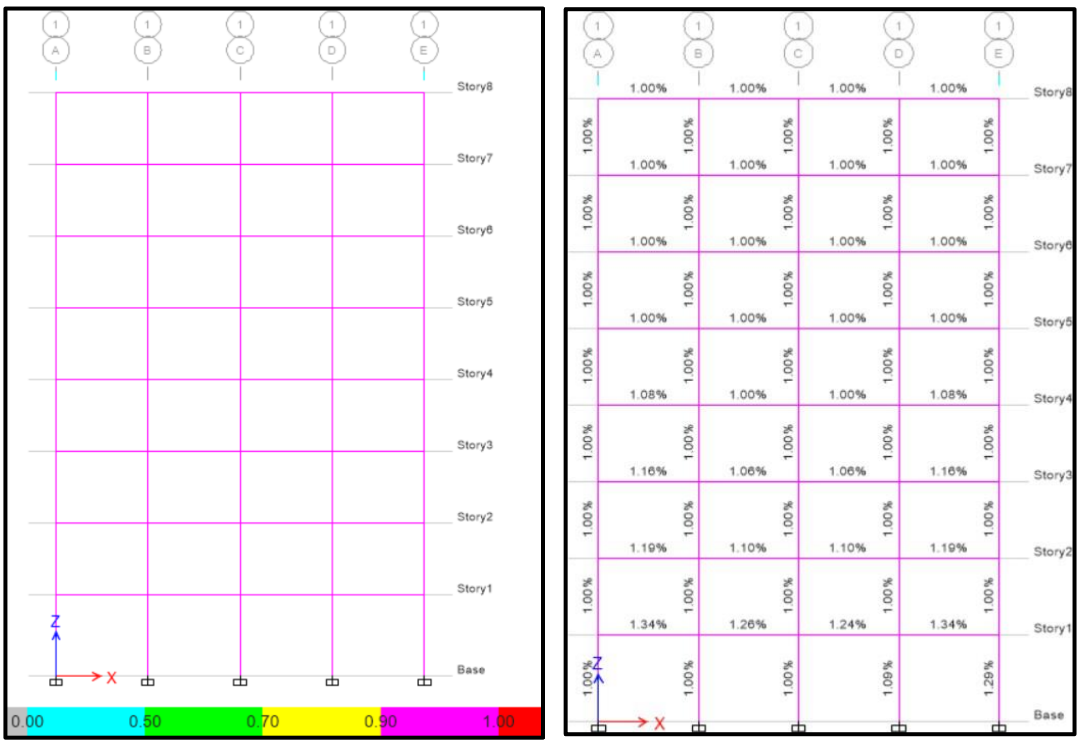
G+7 Rectangular Building with Opening

It is observed that a maximum of 1.3% reinforcement steel is required for the RCC building with a design utilization of ~0.9. Whereas, the SRC columns have a utilization of 0.155 with minimum reinforcement.

The Base shear of the SRC building is higher than RCC building by 25% in X direction & 18% in Y Direction (Table 4.1). Despite this the time period of the SRC building is lesser than RCC building by 12.5% (Table 4.1). The lateral displacement is also reduced by using SRC by 5mm i.e. 14%.

By using SRC the Story drift at the first floor is reduced by ~59% & Hence, the SRC columns better control the Soft story effect.

Considering that the base shear is much higher for SRC building and the fact that the story displacement & drifts are smaller in SRC building, the SRC columns option can be considered as a better alternative. It should however be noted that further section optimization can be done for both the buildings. However, this has not been considered considering Pushover results.



Utilisation Ratio & Percentage of Steel RCC

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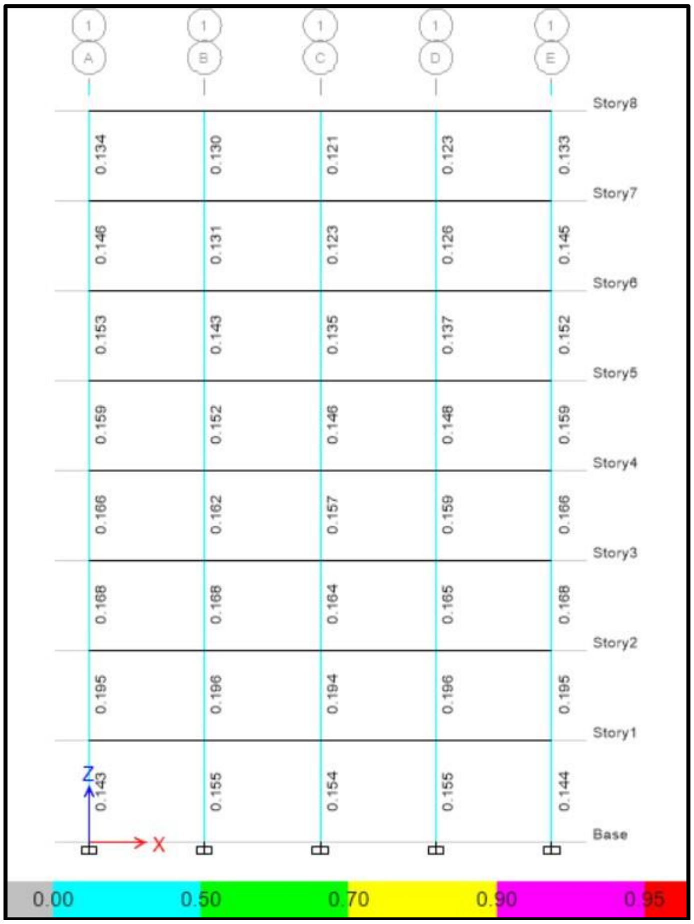
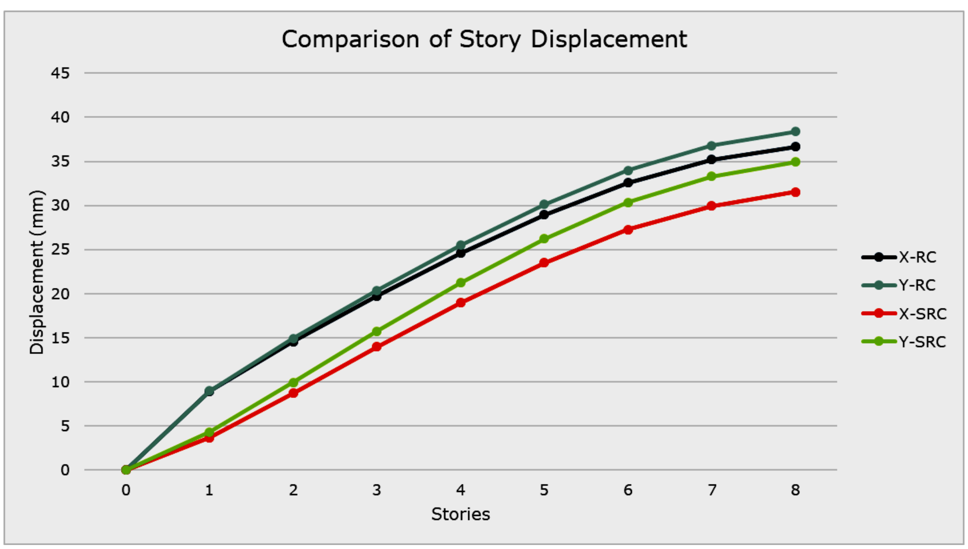


Utilisation Ratio SRC



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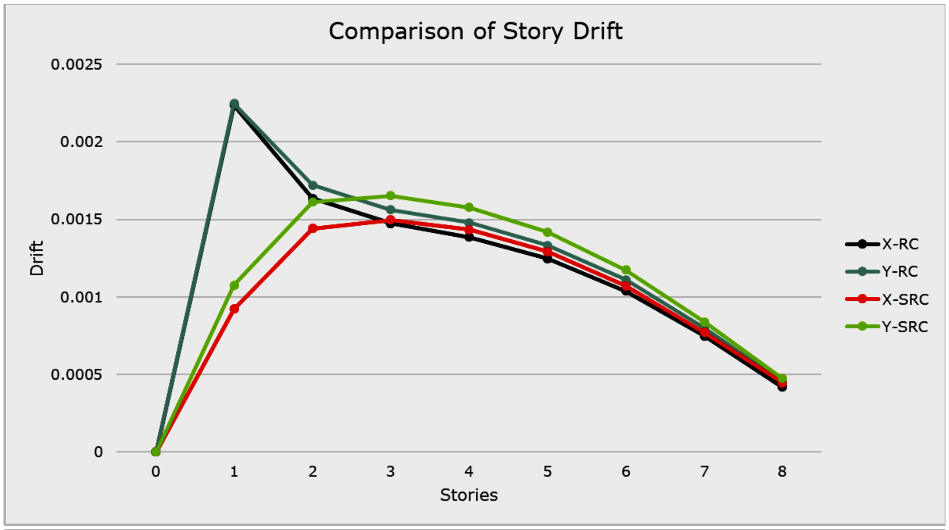

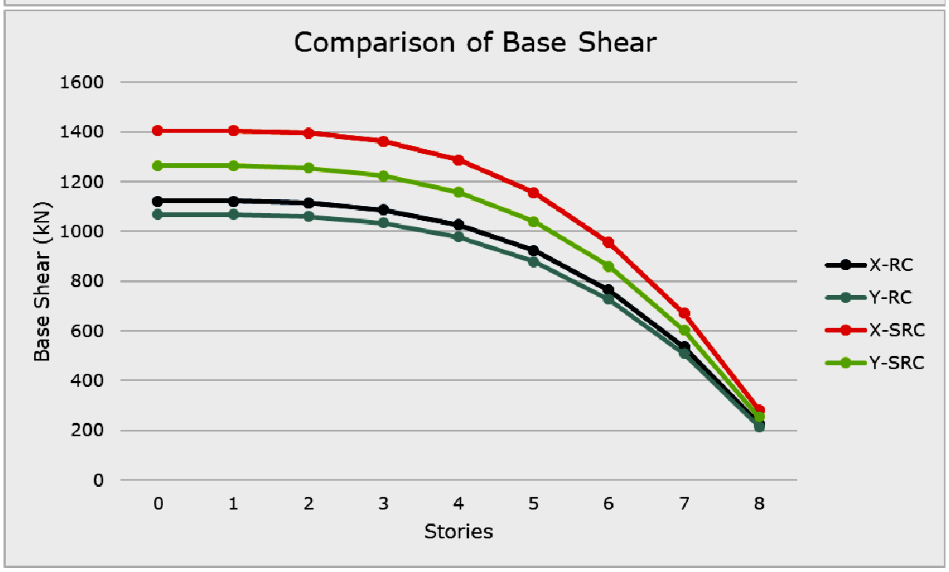

Story Displacement, Story Drift & Base Shear

6.2. Non Linear analysis

For Pushover analysis hinges have been defined at the beam column interfaces. The analysis has been performed by imposing a 300 mm deformation on the top floor. The deformation is applied as an acceleration which increases in steps. The step increase presents the structural deformations and consequently the hinge formations at the joints.

The hinge formation and propagation are crucial to determine buildings structural performance level. This helps in determining the damage the building will undergo during certain seismic events. All the hinges observed lie between Points B & C as described in §3.2. All the performance states IO, LS & CP lie between points B & C

It is observed that in case of RCC column buildings, the hinges form first in the columns, starting from the ground floor followed by the beams. Whereas, in case of SRC column buildings, hinge formation is observed only in the beams.

The hinge formation in column before beams indicates a strong beam weak columns relationship and can lead to global failure which can cause massive loss to life and property and will results in a lot of financial support for the building

Vol-08 Issue 07, July -2024 ISSN: 2456-9348
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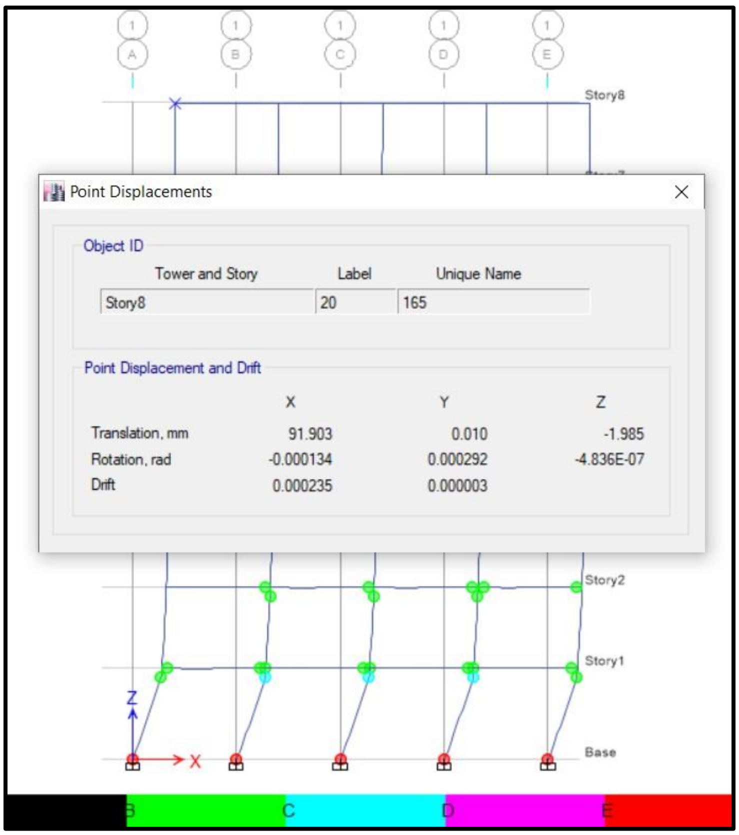
to be repaired for use again. While the formation of hinges only in the beams means that it is a strong column weak beam relationship. This means that there will be local failure and the structure has minor damage is not that life threatening as compared to global failure. The structure can be repaired with some efforts with lesser financial support and can be used again.
It is also observed in case of RCC columns the hinge formation is observed at lesser deformations as compared to SRC columns. And hence, RCC are comparatively less reliable.

G+7 Rectangular Building
Figures ahead show the hinge formation in the RCC & SRC buildings for both X & Y directions. Along with the comparison of pushover capacity of the RCC & SRC columns.
The RCC columns show hinge formation and collapse at a much smaller deformation i.e. 91mm whereas the SRC column buildings the hinge formation is only present in beams & hence, the building is overall safer as it shows strong column weak beam behaviour unlike the RCC building. It is also seen that the pushover capacity of RCC columns is significantly less than that of SRC columns.
Hinge Formation for RCC Rectangular Building (X direction)



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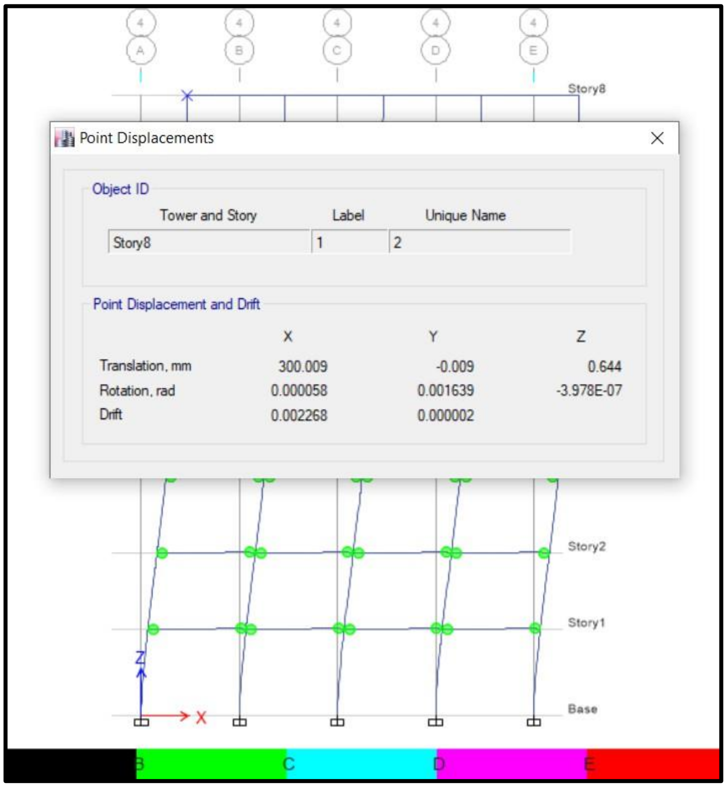

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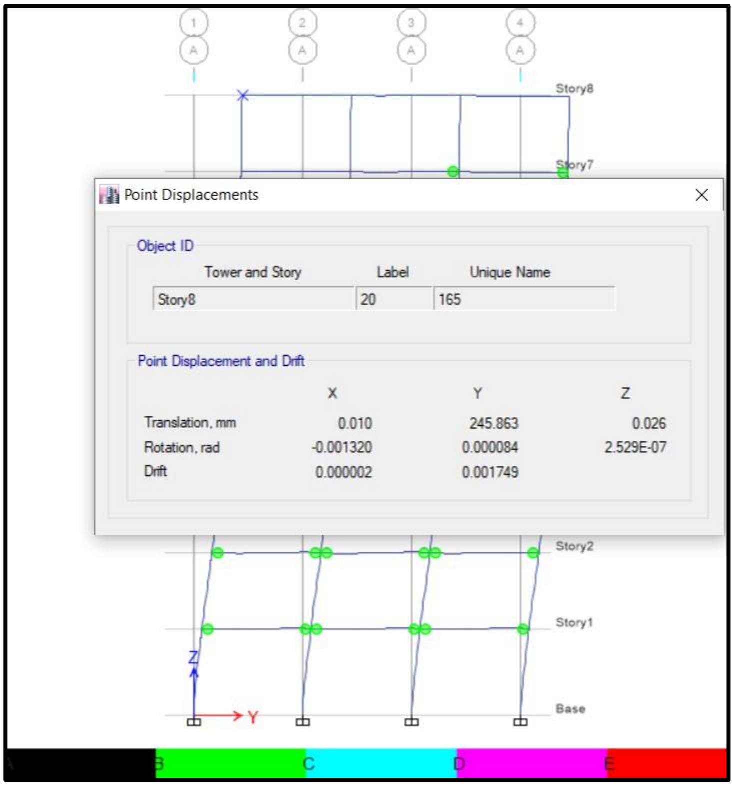
Hinge Formation for SRC Rectangular Building (X direction)
Hinge Formation for RCC Rectangular Building (Y direction)



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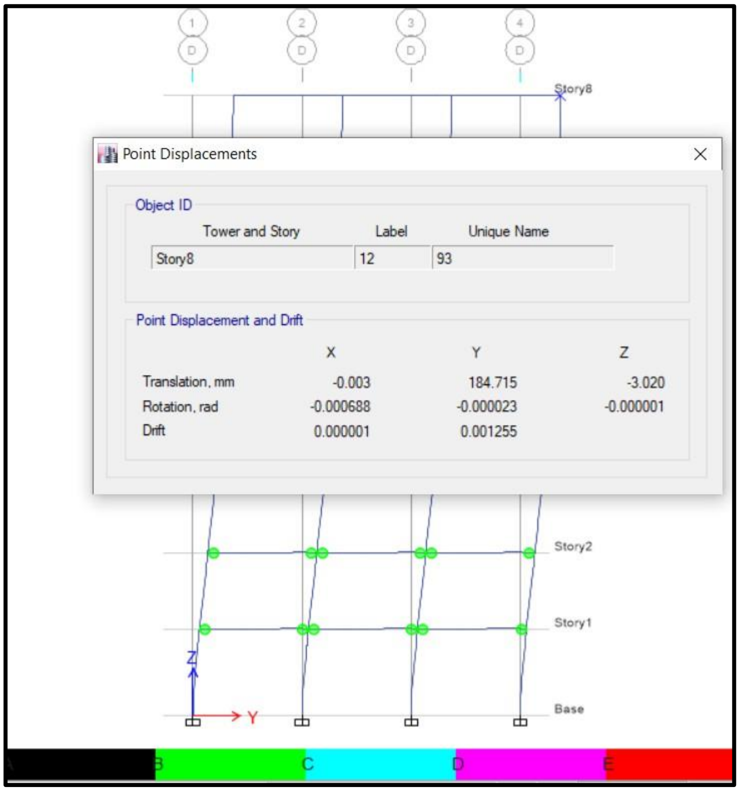
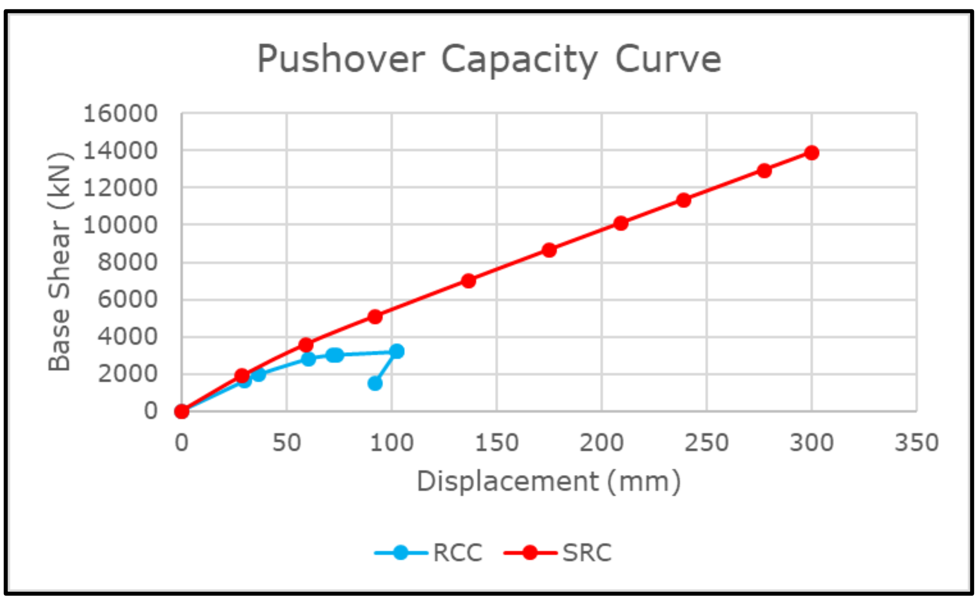


Hinge Formation for SRC Rectangular Building (Y direction)



Pushover Capacity Curve

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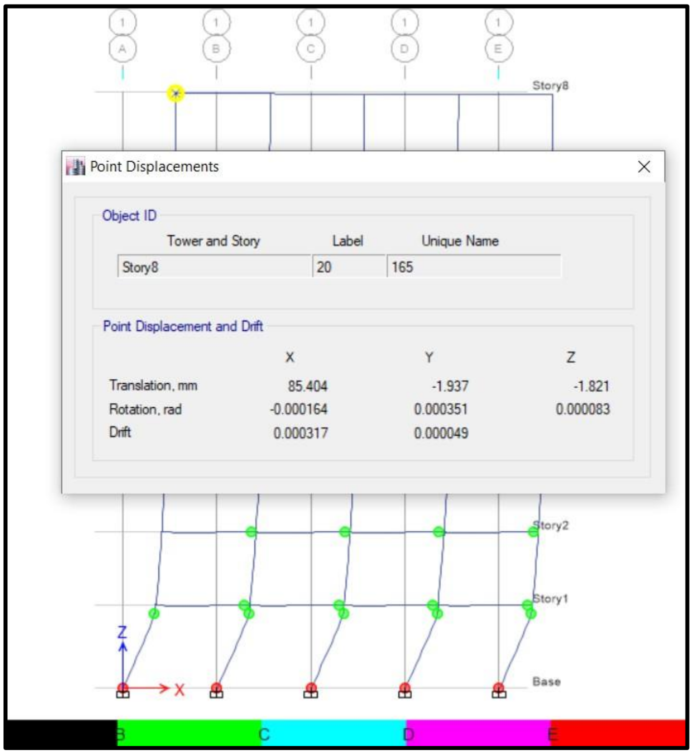
G+7 L Shape Building

Figures ahead show the hinge formation in the RCC & SRC buildings for both X & Y directions along with the comparison of pushover capacity of the RCC & SRC columns.

The RCC columns show hinge formation and collapse at a much smaller deformation i.e. 85mm whereas the SRC column buildings the hinge formation is only present in beams & hence, the building is overall safer as it shows strong column weak beam behaviour unlike the RCC building. It is also seen that the pushover capacity of RCC columns is significantly less than that of SRC columns.

Hinge Formation for RCC L Shape Building (X direction)



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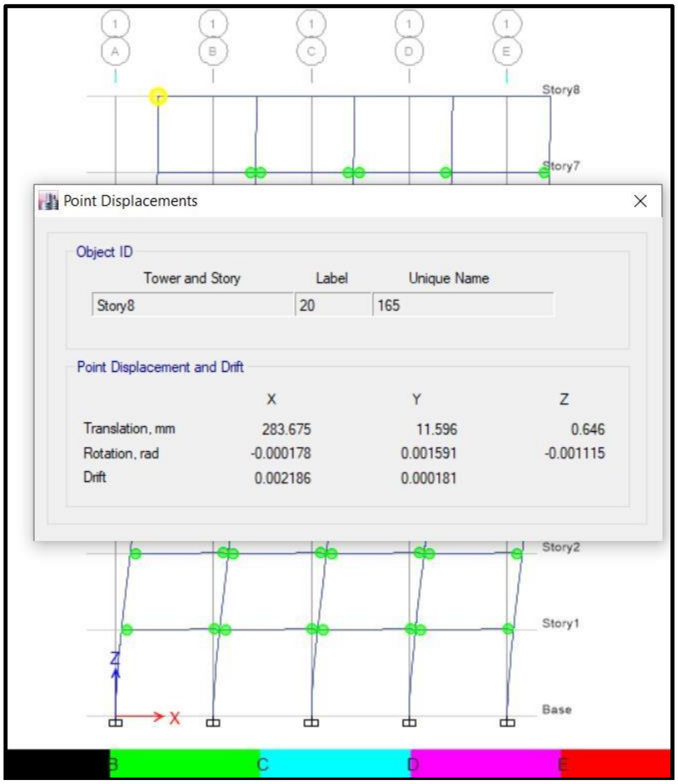
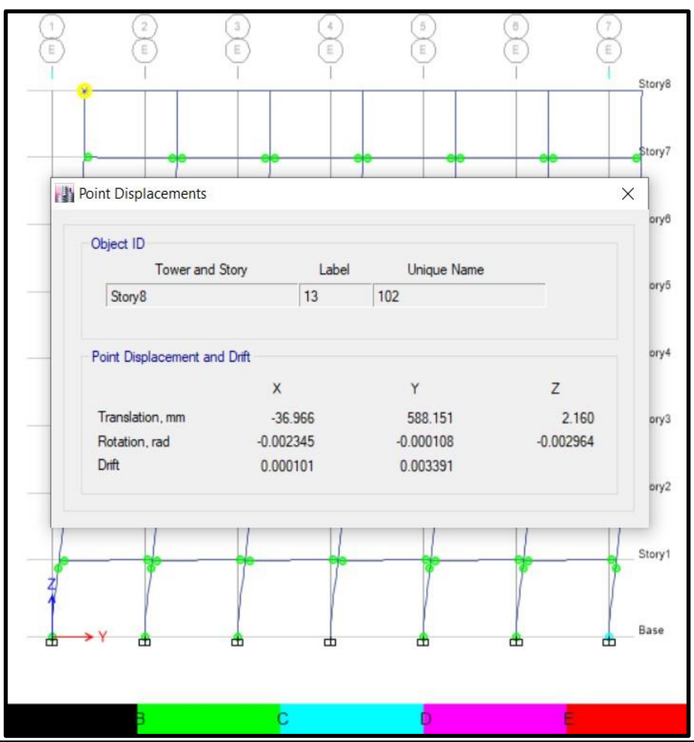


Hinge Formation for SRC L Shape Building (X direction)



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Hinge Formation for RCC L Shape Building (Y direction)

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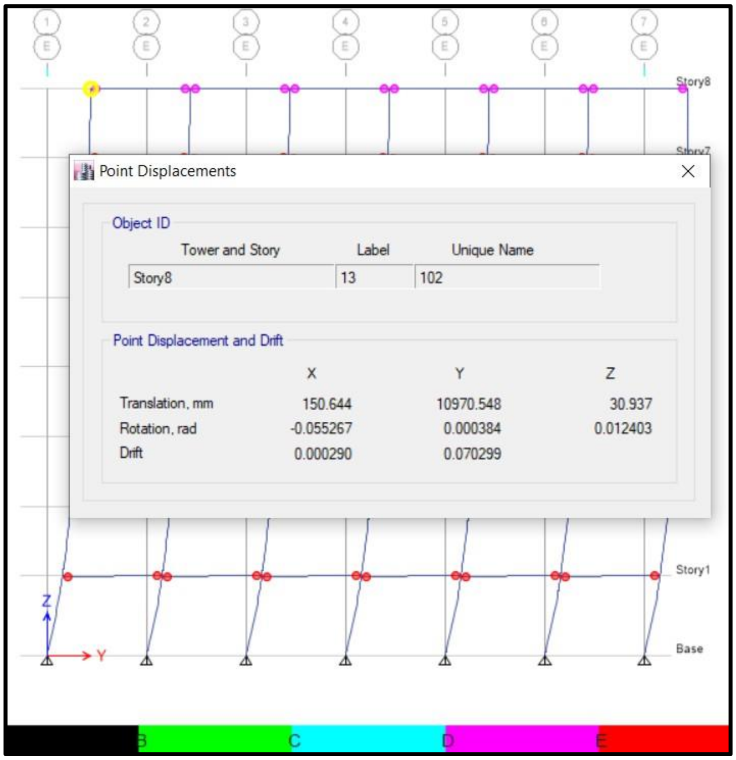
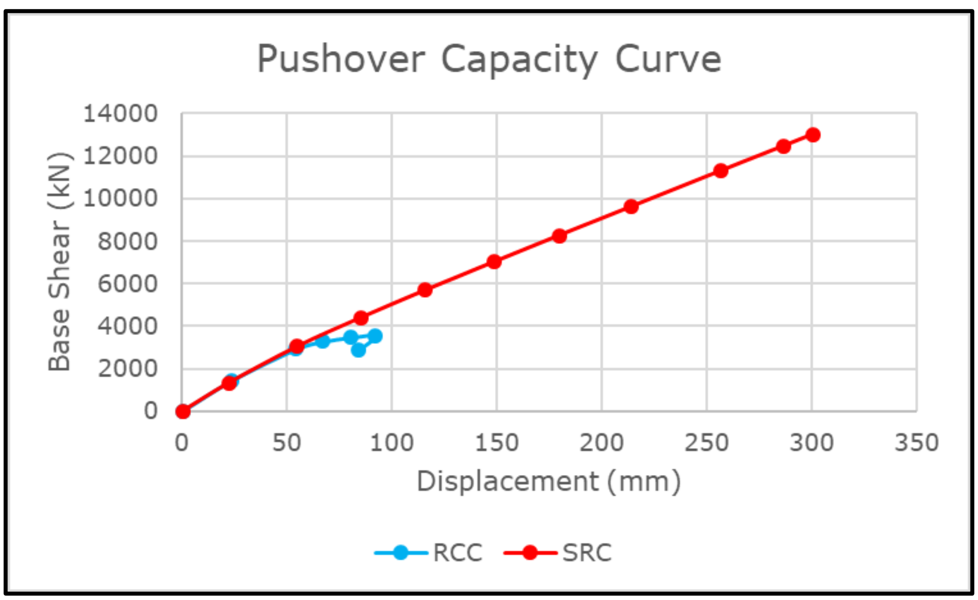


Hinge Formation for SRC L Shape Building (Y direction)



Pushover Capacity Curve

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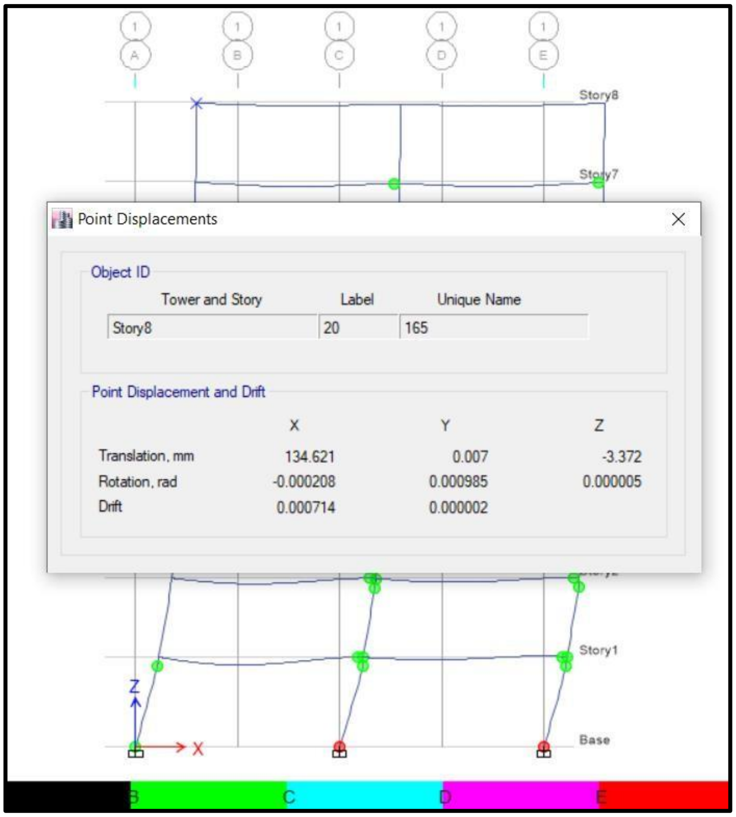
G+7 Rectangular Building Double Span

Figures ahead show the hinge formation in the RCC & SRC buildings for both X & Y directions along with the comparison of pushover capacity of the RCC & SRC columns.

The RCC columns show hinge formation and collapse at a much smaller deformation i.e. 134mm whereas the SRC column buildings the hinge formation is only present in beams & hence, the building is overall safer as it shows strong column weak beam behaviour unlike the RCC building. It is also seen that the pushover capacity of RCC columns is significantly less than that of SRC columns.



Hinge Formation for RCC Rectangular Building Double Span (X direction)

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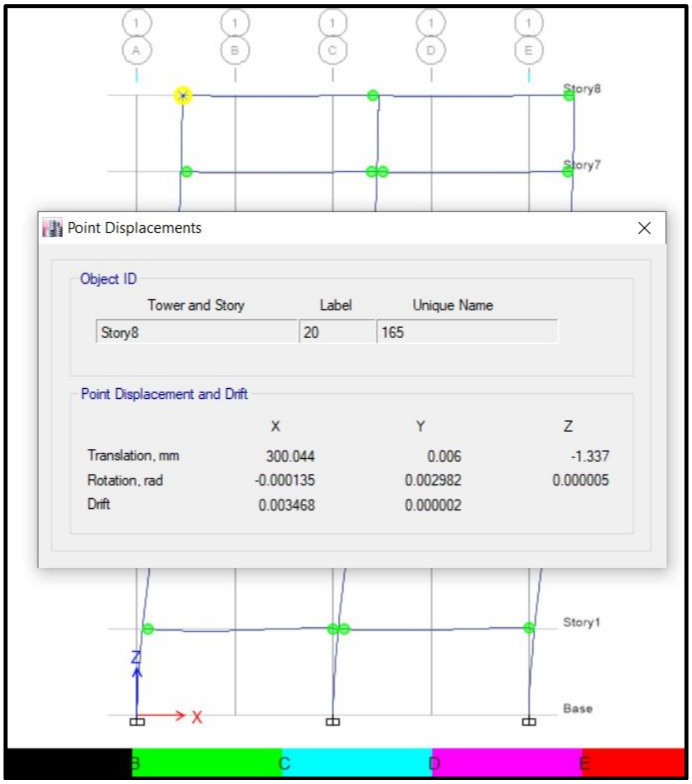
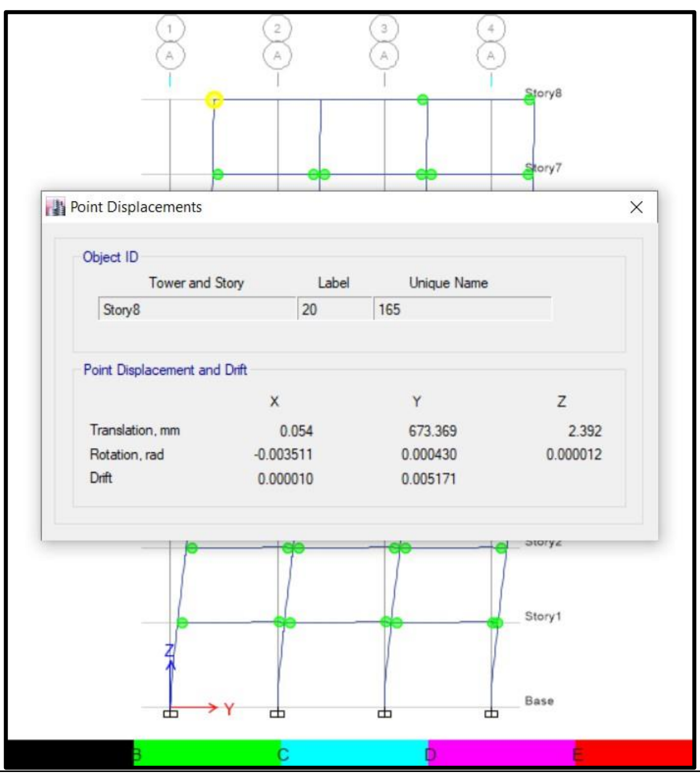


Hinge Formation for SRC Rectangular Building Double Span (X direction)



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Hinge Formation for RCC Rectangular Building Double Span (Y direction)

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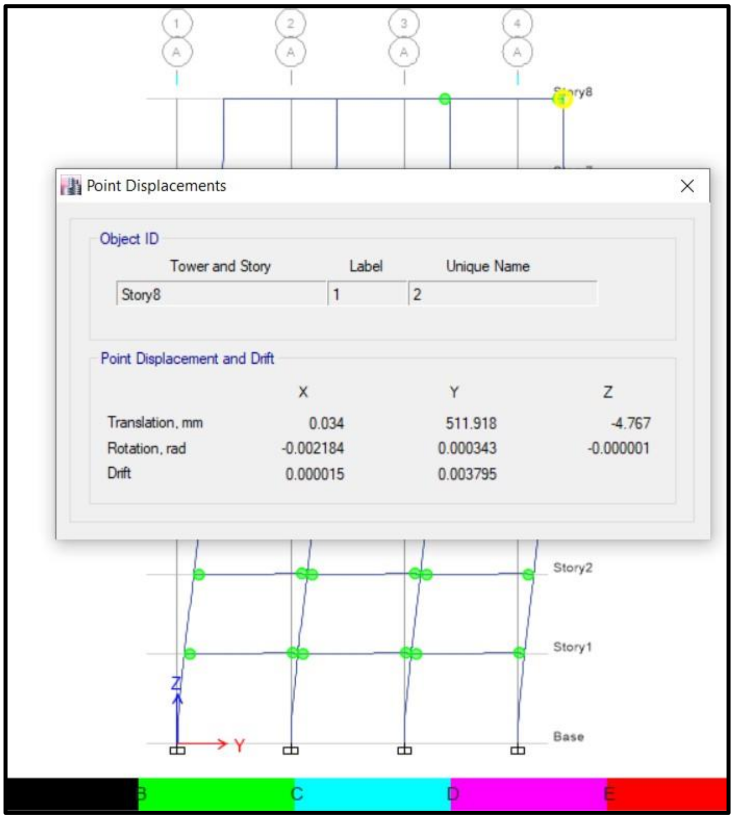
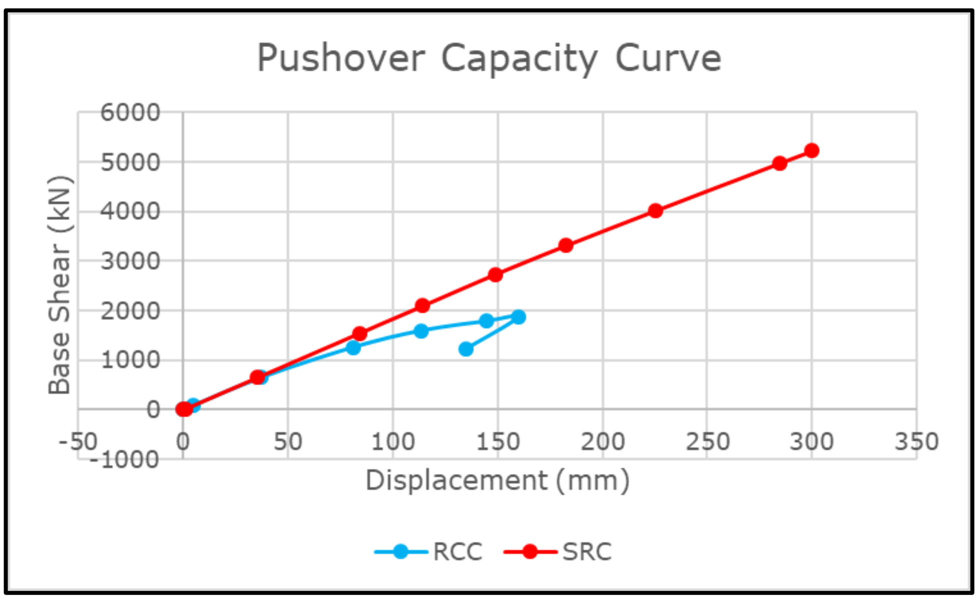


Hinge Formation for SRC Rectangular Building Double Span (Y direction)

Pushover Capacity Curve



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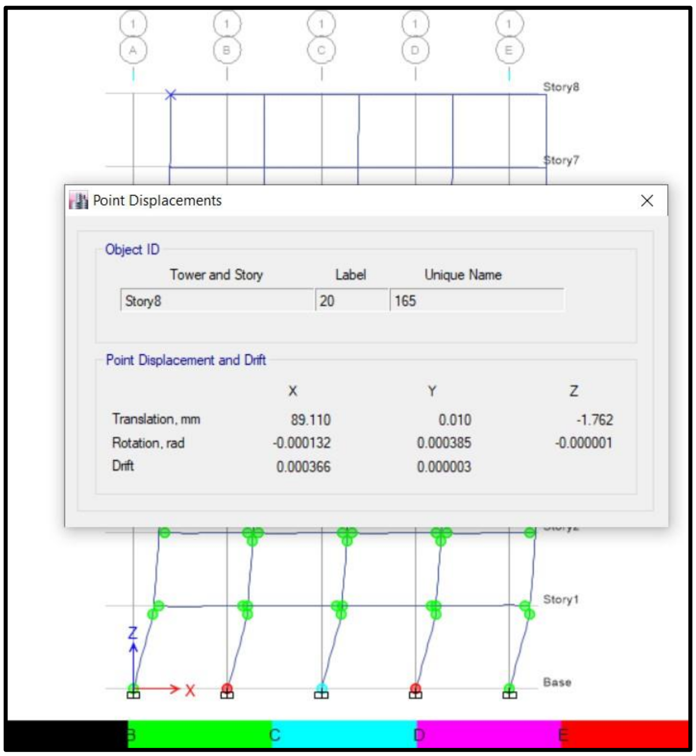
G+7 Rectangular Building with Opening

Figures ahead show the hinge formation in the RCC & SRC buildings for both X & Y directions along with the comparison of pushover capacity of the RCC & SRC columns.

The RCC columns show hinge formation and collapse at a much smaller deformation i.e. 89mm whereas the SRC column buildings the hinge formation is only present in beams & hence, the building is overall safer as it shows strong column weak beam behaviour unlike the RCC building. It is also seen that the pushover capacity of RCC columns is significantly less than that of SRC columns.



Hinge Formation for RCC Rectangular Building with opening (X direction)

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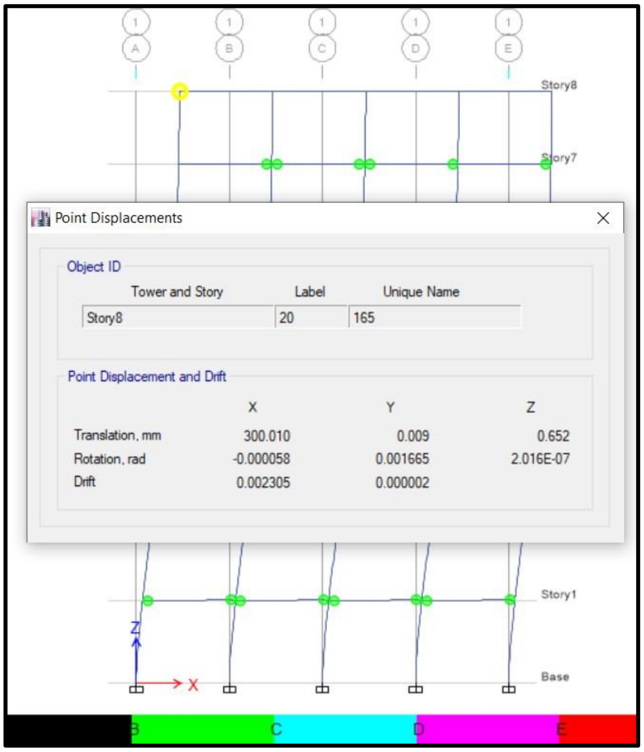
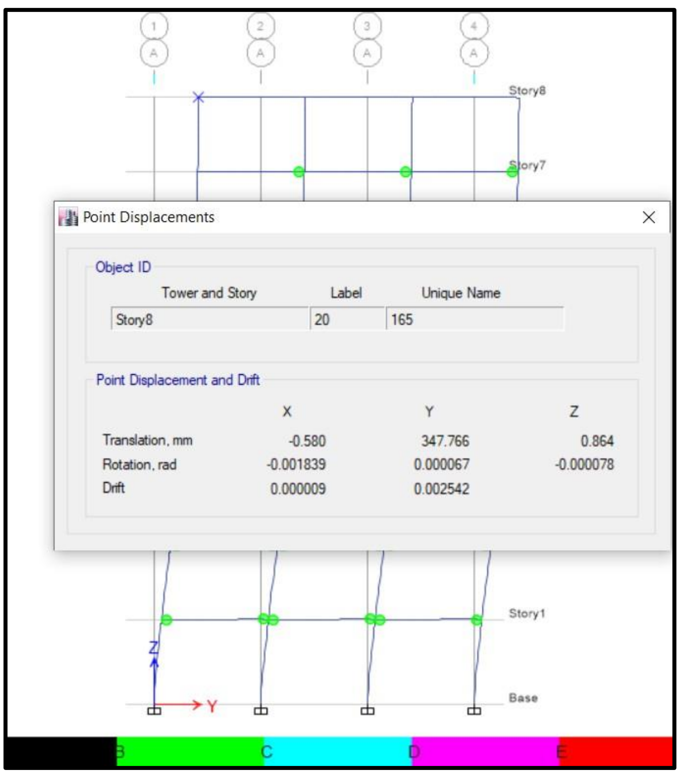


Hinge Formation for SRC Rectangular Building with opening (X direction)

Hinge Formation for RCC Rectangular Building with opening (Y direction)



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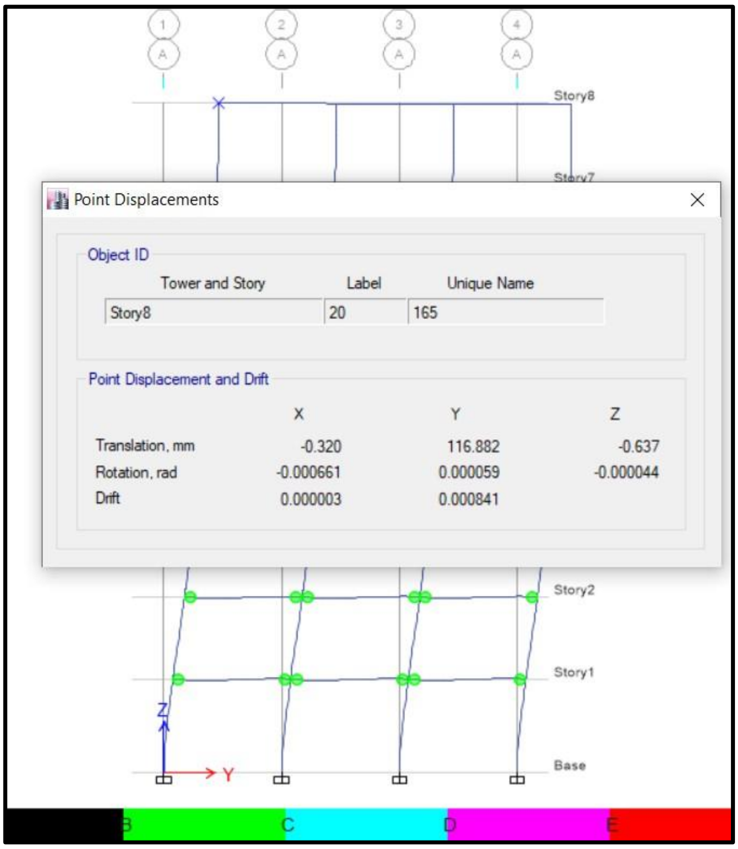
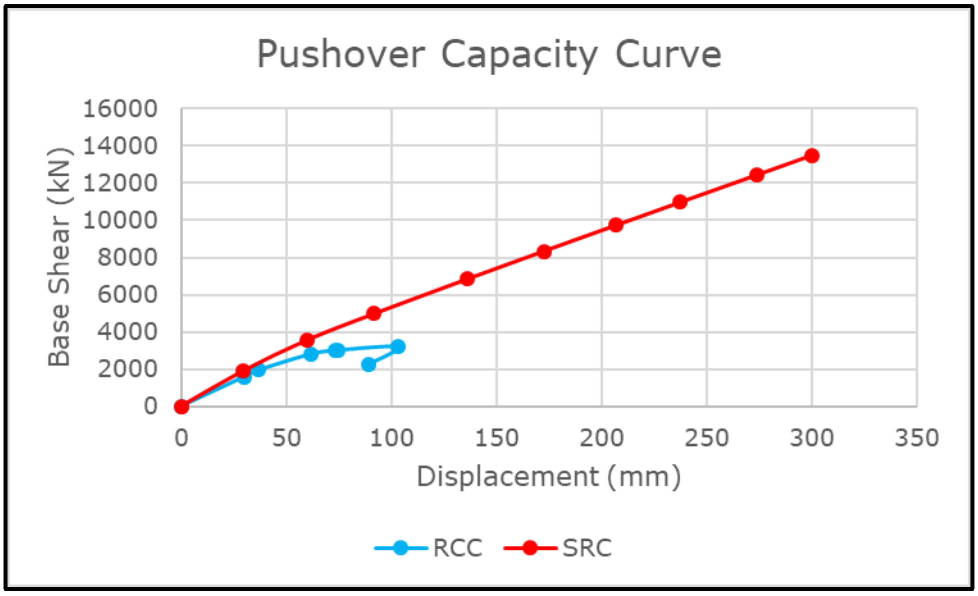


Hinge Formation for SRC Rectangular Building with opening (Y direction)



Pushover Capacity Curve

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7.Conclusion

Based on the analytical study, it can be concluded that

1. For different column arrangement/ building shapes the SRC columns have better design capacity. The lesser size & lower number of column requirement in SRC results in better space utilization.
2. Similar size RCC columns show a much higher reinforcement demand even for lower earthquake forces as compared to SRC columns. 3.8% reinforcement is required in Double Span building while the SRC Columns are only utilised 45%. Considering practical challenges, the 3.8% reinforced section should be increased in size.
3. The SRC buildings are stiffer than RCC buildings. The SRC buildings show present a ~5% less time period than RCC buildings for a higher base shear.
4. SRC columns reduce the story drifts by ~50% and thus reduce the soft story effect.
5. SRC columns reduce the story displacements by ~10%.
6. RCC columns have a much less earthquake capacity as confirmed by pushover analysis. Hinge formation is observed in columns for a much smaller induced deformation. Failure is observed in RCC columns at ~90mm deformation. SRC columns have a much higher capacity, no hinge formation is observed even at 300mm deformation.
7. For a generic Pushover analysis performed by imposing deflection and definition of hinges, the RCC buildings show hinge formation first in columns. Hence, strong beam weak column scenario i.e. possible global failure. While for SRC building hinge formation is observed in beams only. Hence, weak beam and strong column scenario i.e. local failure.

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