Non linear static analysis of multi storey steel structure with different re-entrant ratios

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Abstract— Structures with re-entrant corner are commonly encountered when there is a scope for maximum utilization of the minimum available space. Also, these structures respond differently when built with different re-entrant ratios.One of the major problems associated with re-entrant corner is torsion. It also leads to difference in the stress induced in different wings of the structure leading to stress concentration at the re-entrant corner. This study focuses on the response of steel structures with re-entrant corner to a monotonically increasing pattern of lateral loads. The major objective is to generalise these responses of the structures, when different re-entrant ratios are considered by conducting a non-linear static pushover analysis in-SAP2000. The results obtained for structures with different re-entrant ratios are compared in terms of lateral displacement, inter storey drift and torsional irregularity.This study also includes dissipative capacity improvement of these structures (with different re-entrant ratios and number of bays) without increasing its stiffness in a significant way with supplemental fluid viscous dampers.

Index Terms— Non linear aanalysis, Steel structure, Multistorey, Re entrant ratios, Viscous damper, Lateral displacement, Inter storey drift, Torsional irregularity.

1 INTRODUCTION

Major factors contributing to lateral displacement, inter storey drift and torsional irregularity and there by leading to collapse of a steel structure include:
• Magnitude of force acting on it.
• The height of the structure.
• Plan symmetry of the structure.
It is known and established that the height of the structure and magnitude of force acting on it will be directly proportional to lateral displacement, inter storeydrift and torsional irregularity. This study is focussed on the behaviour of steel structures with planar asymmetry, there by generalising the effect of planar dimension on lateral displacement, inter storey drift and torsional irregularity. The Planar dimensional changes include plan setback of the structure (Forming a re-entrant corner) and increase or decrease in the plan dimensions (Number of bays).

1.1 GENERAL BACKGROUND

Building plans with re-entrant corners are a most useful set of shapes for urban sites, particularly for residential apartments and hotels, which enable large plan areas to be accommodated in relatively compact form, yet still provide a high percentage of perimeter rooms with access to air and light. But these configurations pose a great deficiency in the seismic behaviour of the structure. Most of the building codes recognize re-entrant corners as one of the serious irregularities in buildings and recommends proper evaluation of such structures and incorporation of retrofit strategies. Basically, any irregularity causes an abrupt change in strength or stiffness of the structure which is not desirable in an earthquake resistant system.
Buildings with simple and regular configurations are likely to perform better in the event of an earthquake. Presence of re-entrant corners are one the serious plan irregulars that results in poor seismic performance of buildings. This study is conducted on L-shape\d steel structures by a non-linear static pushover analysis in SAP2000, when different re-entrant ratios are considered.

1.2 RE ENTRANT RATIO AND NUMBER OF BAY

For a building with re-entrant corner, if the plan setback is at least 15% of both plan dimensions, then the setback is considered to form a re-entrant corner. Reentrant corners can form any angle below 180. In structures subjected to internal or external loads, re-entrant corners create high stress concentrations. In the case of structural plans with two wings, they may oscillate out-of-phase and lead to large shear stresses in floor and/or roof diaphragms during earthquakes. This study is conducted on steel structures with re-entrant angle 90, i.e, L-shaped building with different plan setback of both plan dimensions. Movement of the wings of an Lshaped building during an earthquake results in high shear stresses combined with a stress concentration at the re-entrant corner; this is aggravated by torsional effects which develop since the center of mass and the center of rigidity cannot coincide in this form.

For generalizing the effect of plan setback of the L-shaped structure (Reentrant ratio) and increase or decrease in the plan dimensions (Number of bays) on lateral displacement, inter storey drift and torsional irregularity, a non-linear static push-over analysis in SAP2000 is done on six different re-entrant ratios with three different number of bays thereby analysing a total of 18 different models.

1.3 SEISMIC ANALYSIS

Seismic analysis is a subset of structural analysis and it is the calculation of the response of a structure subjected to earthquakes. It is a part of the process of structural design, earthquake engineering or structural assessment, retrofit in regions Where earthquakes are prevalent and the vulnerability of structures. There are four different analysis procedures for a performance-based evaluation of a structure as per FEMA 356 (ASCE 2000) outlines.
• Linear static procedure (Equivalent static analysis)
• Linear dynamic procedure (Response spectrum analysis)
• Non-linear static procedure (Push-over analysis)
• Non-linear dynamic procedure (Time history analysis)
In this study, a non-linear static analysis (Push-over analysis)

was conducted to assess the ductility of the steel frames.

1.3.1 NON LINEAR STATIC ANALYSIS

A structure is subjected to a monotonically increasing pattern of lateral loads which represents the inertial forces which would be experienced by the structurewhen subjected to ground shaking in a pushover analysis. Various structural elementsmay yield sequentially under incrementally increasing loads. The structureexperiences a loss in stiffness consequently at each event. Using a pushover analysis,a characteristic non-linear force-displacement relationship can be determined. It is necessary for the following considerations:

• Pushover analysis is a non-linear static analysis used mainly for seismic evaluation of framed building

• Seismic demands are compared by non-linear static analysis of the structure, which is subjected to monotonically increasing lateral forces with an invariant height wise distribution until a target displacement is reached.

• It is also necessary for evaluating the seismic adequacy of existing buildings.

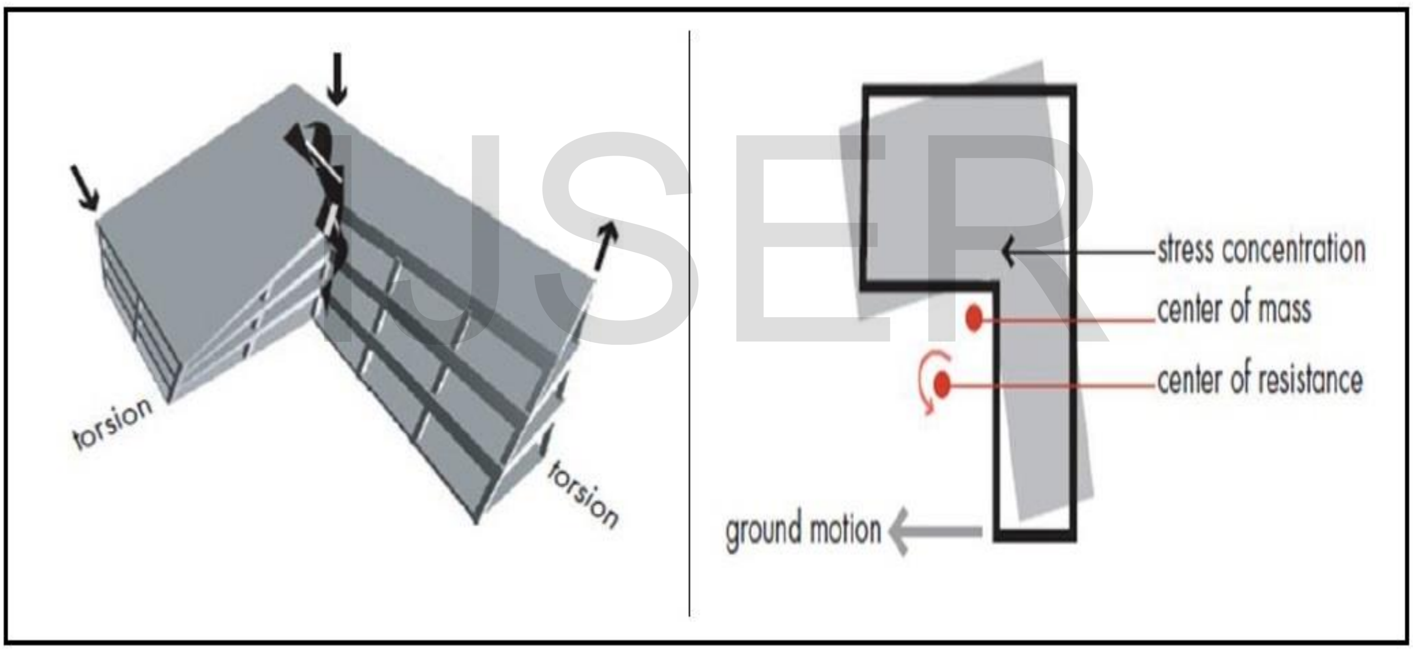
• Comparative study of storey drift for different re-entrant ratios and number of bays.

• Comparative study of torsional irregularity for different re-entrant ratios and number of bays.

• Mitigation of the irregularities based on the study without increasing its stiffness in a significant way by supplemental fluid viscous dampers.

1.5 SCOPE

Structures are often subjected to lateral loads like the earthquake, wind etc.Structures with re-entrant corners are likely to provide a poor seismic performance than regular structures. In the present study, the performance of irregular structures with different re-entrant ratios are compared by conducting non-linear static analysis in SAP2000 v20. The study will also give an idea about the suitability of supplemental fluid viscous dampers to improve the seismic performance of structures.



Non-linear static pushover analysis can provide an insight into the structural aspects, which control performance during severe earthquakes. The analysis provides data on the strength and ductility of the structure, which cannot be obtained by elasticanalysis. By pushover analysis, the base shear versus top displacement curve of the structure, usually called the capacity curve is obtained.

1.4 OBJECTIVES

The primary objective of the study is,

• To study the behaviour of steel structures with different re-entrant ratios and number of bays.

• Comparative study of lateral displacement for different re-entrant ratios and number of bays.

2 LITERATURE REVIEW

The following papers are surveyed through for conduting the study.

2.1 RE-ENTRANT CORNER

Anis S. Shatnawi, Mazen Musmar, Laith I. Gharaibeh,(2013) studied the use of codal provisions using different seismic analysis procedures for buildings having horizontal re-entrant corner irregularity.This study aims to quantify the lim- its on building height and on the percentage of the re-entrant corner of the build- ing.It has been found that the maximum underestimation of column shear forces for buildings without re-

entrant corner is 0% less than those with re-entrant corners.It is also noted that the column at the re-entrant corner is not effectively affected until a re-entrant corner of 25% exists in buildings.
Bethany Marie Brown, (2014) detailed about the effect of lateral loads on the forces in the re entrant corner of structures was examined so as to better un- derstand why damage occurs in this location after major wind or seismic events. Thirty models were analysed using finite element analysis in SAP2000 with vary- ing dimensions and wall locations.Finally it was also found that the addition of walls, both exterior shear walls and interior shear walls, greatly decreases the axial forces for both the interior and exterior strut and interior and exterior chords in the re entrant corner.
Shreyasvi C, dr B. Shivakumaraswamy, (2015) focused on the response of the building with a re - entrant corner located in various seismic zones. The major objective is to study the response of a building in different seismic zones and also to compare a building containing re - entrant corners with a building of regular plan configuration by performing linear dynamic analysis.The re-entrant building was compared with regular building, it was observed that the former undergoes larger storey displacement and drift than the latter.The storey drift experienced by the building is highest in zone V and least in zone III.
Anushri C, Dr B Shivakumara Swamy,(2016)discussed a paper which per- form equivalent static analysis and time history analysis for a G+7 storey plan regu- lar and plan irregular building. L-shape, C-shape and T-shape pal irregular buildings are considered for the analysis.The results obtained are then compared for storey displacement, storey drift, storey stiffness and time period.There was reduction in the values of displacement and drift and an increase in the stiffness of the building.
Kazi Muhammed Mustaqeem,Md. Mansoor Ahmed,(2016)studied on two sorts of arrangement namely diaphragm discontinuity and re-entrant corners in the structure.The models were investigated utilizing static, dynamic and pushover analysis and parameters considered being displacement, maximum drift, base shear, and time period.Pushover analysis gives higher value as compared to static and re- sponse spectrum method.The influence of diaphragm opening played a major role in reducing the base shear hence attracting less seismic forces.

2.2 TORSIONAL IRREGULARITY

S. A. Powale, N. J. Pathak,(2019)focused on asymmetric structures have irregular distribution of mass and stiffness and its centre of mass and centre of rigidity do not coincide and hence causes the torsional effect on the structures which is one of the most important factor influencing the seismic damage of the structure. In this paper, seismic performance of two buildings irregular in plan are analysed and compared. Two 33 storey buildings with ‘S’ and ‘L’ plan shapes are modelled in ETABS 2016 using Time History Analysis.it is observed that ’S’ shaped plan buildings show better earthquake resistance than ‘L’ shaped plan buildings when torsional irregularity is the primary point of consideration.
S.N.Suryawanshi, S.B.Kadam and S.N.Tande (2014) studied on the twist- ing moment impacts on the structure with response spectrum analysis.Response

spectrum technique is used to calculate twisting moments, shear at base, disloca- tions and time period and their ability and demand is measured using pushover analysis.It is concluded that, for asymmetric building, twisting moment is more than symmetrical building. For asymmetrical building, shear at base and roof dislo- cation is more than a symmetrical building. Symmetrical building performance in a seismic event is better than asymmetrical building.
R.Thaskeen and S.Shajee (2016)focussed on both symmetric and asym- metric buildings are compared with horizontal irregularity in this study.Four types of structures with the unchanged outside perimeter area are considered and reinforced by the application of shear cores to evaluate the twisting impact on the build- ings. A straightforward linear comparison is also performed for G+12 and G+17 buildings based on.
M.Tripathi, M.Williams.P. And Dr.R.K.Tripathi (2016) studied on the static linear, linear dynamic and non linear static behaviour, and a G+14 RCC frame was used.Three sets of models were analysed, one with an eccentric mass of magnitude twice the mass on the remaining part, one with four foldmass and one with six-fold mass magnitude. It was found that shear wall provision decreases the building’s torsion. Shear wall structures have less displacement on the top floor than those without shear wall. When shear walls are given, base shear increases, resulting in the reduced time period as well.
Lohith Kumar B C, Batu Abera Areda, Dereje Tolosa, Gangadhar N,
(2017)
In the present study, seismic analysis has been performed by Equivalent Lat-
eral Force Method (ELF) ie the codal method, for all zones and for all soil types irregularities such as Re-entrant irregularity and Torsional irregularity for 10, 15, 20 storey buildings. The torsional moments, fundamental period and base shear increases with the increase in the height of a regular building.Torsional moments are high in a 20 storied building compared to a 10 or 15 storied building. The effect of variation in the Base shear is high in 15 storied building compared to a 10 or a 20 storied building in soil type 2 in all zones.

2.3 FLUID VISCOUS DAMPER

K. Sudheer kumar, Y.Vinod, (2019) conducted studies on different dampers which are the energy dissipating devices which are used to resist lateral forces act- ing on the structure. This study deals with the performance evaluation of various type of passive control devices for the selected RC frame structure. Time his- tory analysis is carried out on a G+9 story RC framed structure with and without dampers by using sap 2000. Result of the analysis revealed that maximum absolute displacement, storey shear, storey drift values are more in case of RC framed struc- ture without damper as compared to RC framed structure with dampers. The result carried out by using sap 2000 software for RC framed structure find out the vari- ous parameters such as absolute displacement, storey drift, storey shear are com- pared.As a conclusion viscous damper perform effectively reduce and control the seismic response of the selected RC framed structure.

3 VALIDATION

3.1 GENERAL

Before starting the study, as a first phase of the work, valida- tion of a rec- ognized journal is necessary to understand the concepts. This section explains the details of the validation.

3.2 VALIDATION

For the validation of the model, the journal paper selected is *Study of non- linear fluid viscous damper's behaviour in seismic steel structures*. The model is analysed by the software SAP2000 by non linear dynamic analysis. The details of the journal is given in Table 3.1.

Table 3.1: Details of Journal

JOURNAL NAME	:	STUDY OF NONLINEAR FLUID VISCOUS DAMPERS BEHAV- IOR IN SEISMIC STEEL STRUC- TURES
PUBLICATION	:	SPRINGER JOURNAL 2014
SOFTWARE	:	SAP2000
AUTHORS	:	ABDELOUAHAB RAS, NADIR BOUMECHRA

3.2.1 DETAILS OF MODEL

A G+12 building of following dimensions are tabulated in Ta- ble 3.2 is considered.The analysis is done by considering Zone III importance factor 1.2 and for third type of soil according to Egyptian Code for calculation of loads for structures ECP-201.

Table 3.2: Details of Model

Total length	:	23.70m
Total width	:	22.92m
Total height	:	45.82m
Height of floors	:	3.40m
Height of third floor	:	4.42m
Modulus of elasticity	:	200GPa
Weight per unit volume	:	7698kN/m3

3.2.2 DETAILS OF SECTION

The cross sectional properties of the steel beams taken into account for analysing are tabulated in 3.3

Table 3.3: Details of Beam section

BAY	X DIRECTION	Y DIRECTION
First Bay	IPE200	1PE330
Second bay	IPE240	IPE330
Third bay	IPE240	IPE330
Fourth bay	IPE240	IPE500

The cross sectional properties of the steel columns are tabulat- ed in Table 3.4.The damper stiffness inserted into the SAP2000 model is equivalent to that of brace with L120x13 profile.

Table 3.4: Details of Column section

STOREY	X DIRECTION	Y DIRECTION
STOREY 12	HE200M	HE200M
STOREY 11	HE200M	HE200M
STOREY 10	HE200M	HE200M
STOREY 9	HE200M	HE200M
STOREY 8	HE200M	HE200M
STOREY 7	HE240M	HE240M
STOREY 6	HE240M	HE240M
STOREY 5	HE300M	HE300M
STOREY 4	HE300M	HE300M
STOREY 3	HE300M	HE300M
STOREY 2	HE320M	HE320M
STOREY 1	HE320M	HE320M

3.2.3 TIME HISTORY ANALYSIS

The lateral dynamic load applied to the structure was simulat- ed by (FNA) of the Boumerdes earthquake (Algeria May 2003) with a magnitude of 6.69 on the Richter scale. This accelero- gram is recorded at the station of Keddara (East–west). Fluid viscous damper is connected as shown in figure 3.1.

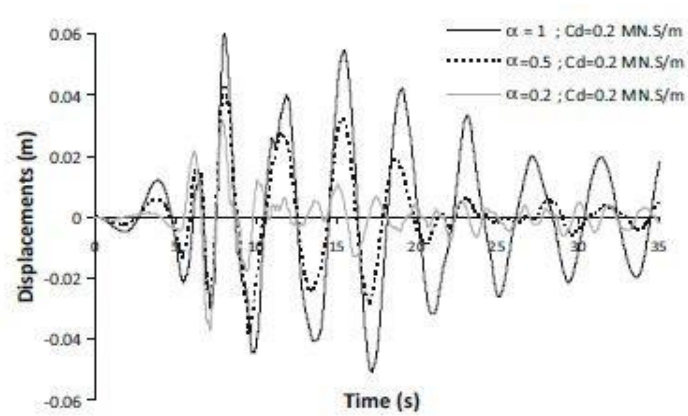


Figure 3.2: Time history displacement graph

3.2.4 RESULT COMPARISON

The maximum displacement for building with FVD in the journal is 0.025m- 0.028m around for α = 0.2 where as from the software is 0.0208 m shown in figure 3.3 implies the error percentage is limited to 15%. The obtained time history displacement graph have been plotted in figure 3.3

3.3 CONCLUSION

This study permitted to analyse the difference in steel structure behaviour, with linear and non linear fluid viscous damper for a seismic load. Numerical cal- culation with SAP2000 software was used for the analysis of a 12-storey building. The results show that the use of non linear device in buildings generates a very significant reduction in the structural response compared to the linear one.There is around 64 percent reduction in the maximum displacement in a structure with dampers than unbraced structure.

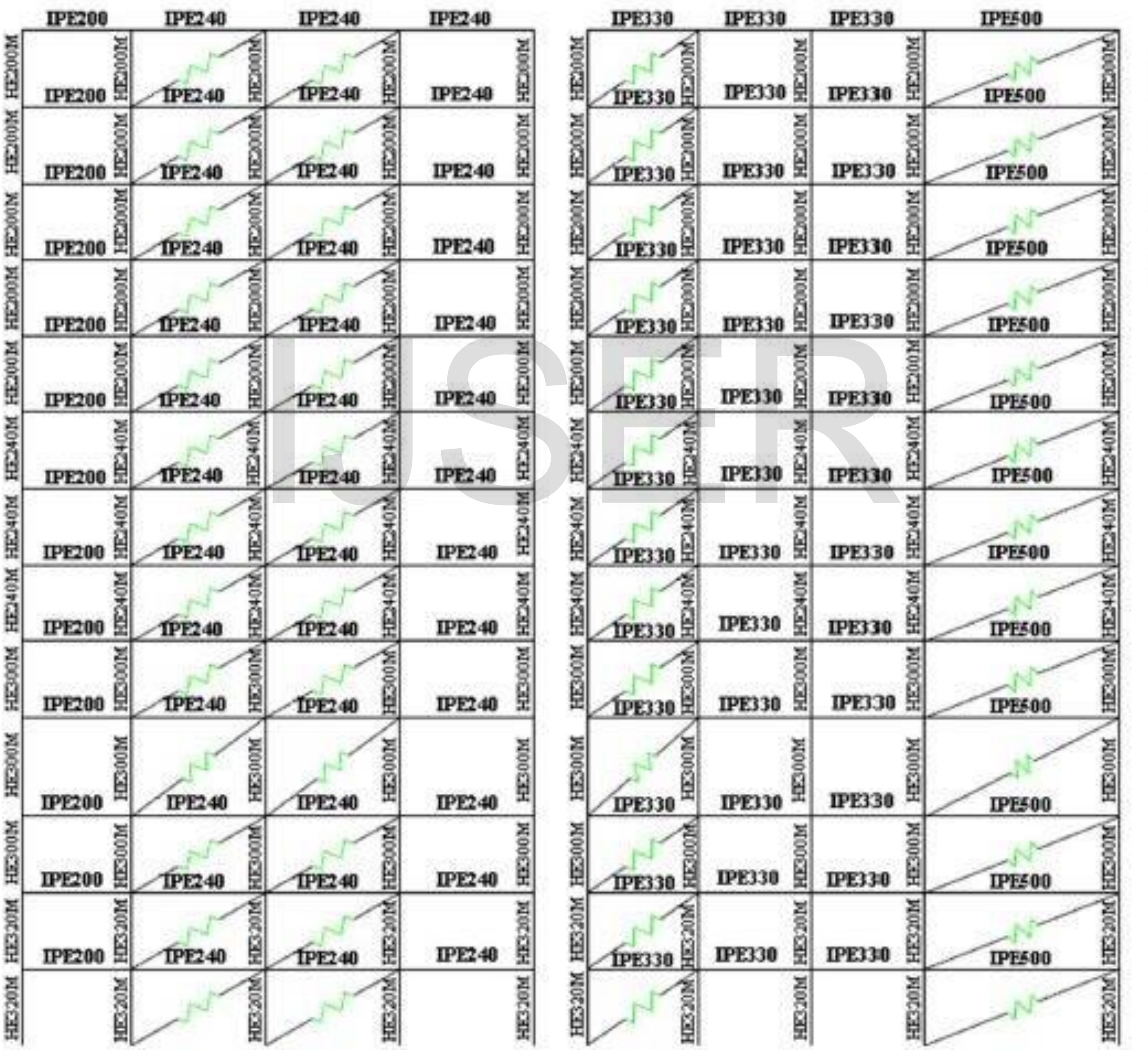


Figure 3.1: Modelling of twe lve storey building connected to FVD

4 ANALYSIS AND MODELLING

4.1 GENERAL

This section covers the analysis of models in SAP2000 and details of com- puter model preparations for this study.

4.2 ANALYSIS OF MODELS IN SAP2000

The steps followed in the pushover analysis are explained below. In the be- low described steps, the first three steps are about the computer model preparation, fourth step is about run analysis and finally step five is about review of pushover analysis results.

Step 1: Create the model. Define and assign the material properties, section proper- ties, loads and supports.

Step 2: Define hinges for the members. For beams, M3 hinges are defined at 0.05% distance on both the ends. For columns, P-M-M hinges are defined at 0.05% distance on both the ends. These hinges are assigned to corresponding mem- bers.

Step 3: Define the pushover load case in load patterns. Then go to the load cases and change the load case type as non-linear static with geometric non-linearity as P Delta. Change the load application control to displacement control and then enter the details regarding the amount of push, no. of steps, etc.

Step 4: Set the load cases to run and and attain the results.

Step 5: The results will be in the form of tabulated displacement values, pushover curves or capacity curves.

4.3 MODELLING

For comparative study of the effect of plan setback (Re-entrant ratio) and increase or decrease in the plan dimensions (Number of bays) on lateral displace- ment on steel structures, a non-linear static pushover analysis in SAP2000 is done on structures with six different re-entrant ratios having three different number of bays, thereby analysing a total of 18 different models.

For columns, Interacting (P-M2-M3) hinges, which yields based on the interaction of axial force and bi-axial bending moments at the hinge location, are used. M3 (moment) hinges are assigned for the beam elements. Other common details of the models are given in Table 4.1

Table 4.1: Common details of the models

Columns	:	ISHB 250
Beams	:	ISMB 250
Dimension of a single bay	:	5m X 5m
Slab concrete	:	M25
Number of storeys	:	12
Height of each storey	:	3m

Model preparations are based on two different planar dimensions variation:

- Re-entrant ratio
- Number of bays

4.3.1 Variation in Re-entrant ratio

The six different re-entrant ratios selected for the models are as below:

- a/A = 0.8, b/B = 0.8
- a/A = 0.2, b/B = 0.8
- a/A = 0.6, b/B = 0.4
- a/A = 0.4, b/B = 0.6
- a/A = 0.8, b/B = 0.2
- Regular Structure

4.3.2 Variation in Number of bays

The number of bays is varied in three steps with the addition of 5 bays in each step starting from 5 initial bays. The addition is made simultaneously in both planar axis. The planar dimension of the three models are:

- 25m X 25m (5 Bay)
- 50m X 50m (10 Bay)
- 75m X 75m (15 Bay)

The configurations of 5 bay, 10 bay and 15 bay models are represented in figures 4.1, 4.2 and 4.3 respectively.

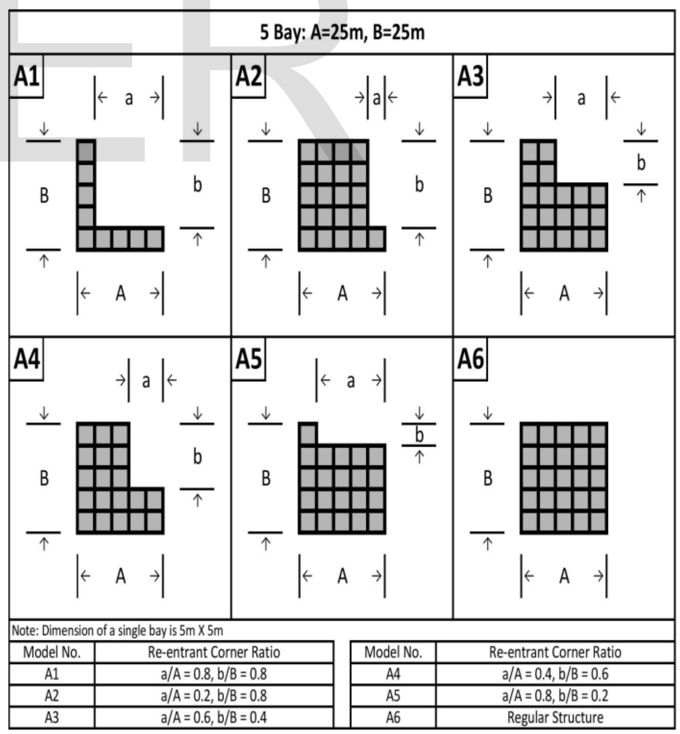
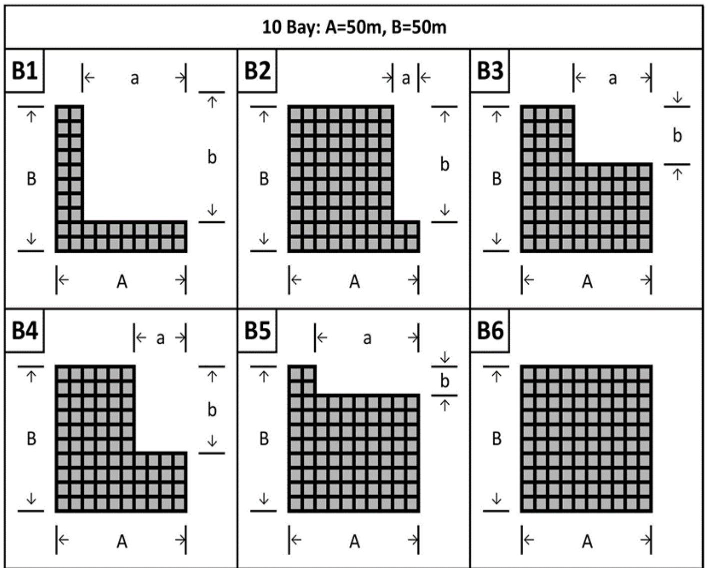


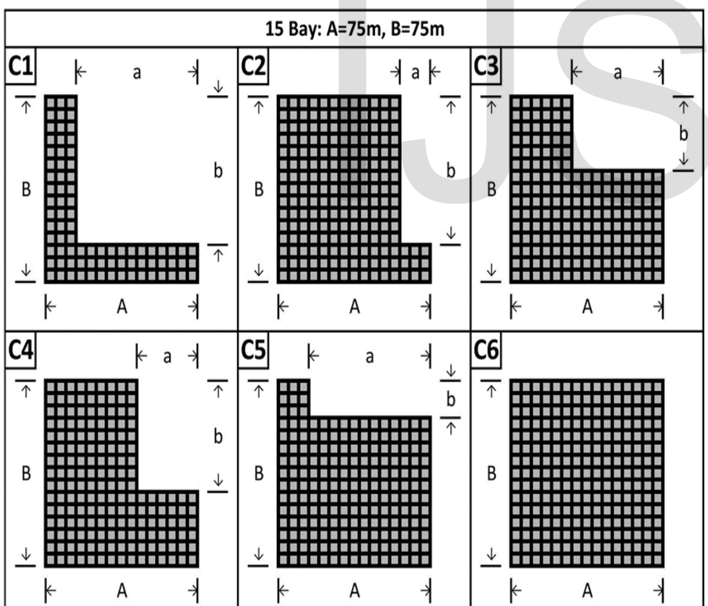
Figure 4.1



Note: Dimension of a single bay is 5m X 5m

Model No.	Re-entrant Corner Ratio	Model No.	Re-entrant Corner Ratio
B1	a/A = 0.8, b/B = 0.8	B4	a/A = 0.4, b/B = 0.6
B2	a/A = 0.2, b/B = 0.8	B5	a/A = 0.8, b/B = 0.2
B3	a/A = 0.6, b/B = 0.4	B6	Regular Structure

Figure 4.2



Note: Dimension of a single bay is 5m X 5m

Model No.	Re-entrant Corner Ratio	Model No.	Re-entrant Corner Ratio	Model No.	Re-entrant Corner Ratio
C1	a/A = 0.8, b/B = 0.8	C3	a/A = 0.6, b/B = 0.4	C5	a/A = 0.8, b/B = 0.2
C2	a/A = 0.2, b/B = 0.8	C4	a/A = 0.4, b/B = 0.6	C6	Regular Structure

Figure 4.3

5 LATERAL DISPLACEMENT

5.1 GENERAL

Lateral displacement of a structure is a critical parameter for its evaluation or design. The magnitude of lateral displacement indicates the damage state and the vulnerability of the building.This section is a comparative study of lateral displacement for different re-entrant ratios and number of bays.

5.2 DETAILS OF ANALYSIS

There will be two sets of results in a pushover analysis:

- When pushover force is acting along X axis (PX)
- When pushover force is acting along Y axis (PY)

The displacement occurs X axis is notated as U1 and the displacement occurs in Y axis is notated as U2. Also, there will be two types of displacements for each cases (pushover force PX and PY):

Displacement occurring in the same direction of pushover force applied (U1 for PX and U2 for PY)

Displacement occurring in the perpendicular axis of pushover force applied (U2 for PX and U1 for PY)

The displacement occurring in the same direction of pushover force applied (U1 for PX and U2 for PY) is discussed in this section. Displacement occurring perpendic- ular to the pushover force applied (U2 for PX and U1 for PY) will be discussed in section 7. The corner of the structure showing maximum displacement is selected for the floor wise values. All values are taken in collapse prevention step (CP) just before collapse (C) in SAP2000.

Also, when comparing PX and PY, it is to be noted that there is a reduction in base shear force around 75% during pushover PY. Table 5.1 shows the average base shear for the selected models. Direction of the pushover forces are represented in Figure 5.1.

Table 5.1: Average base shear force (KN)

	5 Bay	10 Bay	15 Bay
PX	2230	7380	15700
PY	530	1730	3600

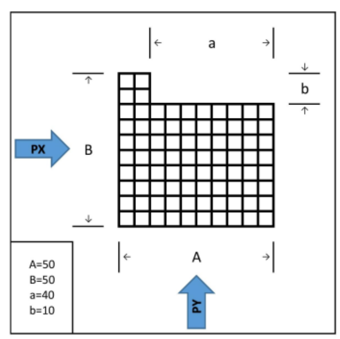


Figure 5.1: Direction of pushover force

5.3 RESULTS AND INTERPRETATIONS

Equally important to the analysis is the post processing of the resulting data. The tabulated data and displacement curves after analysis are interpreted in two parts:

- Re-entrant ratio
- Number of bays

5.3.1 VARIATION IN RE-ENTRANT RATIO

As it was stated, there are 6 different re-entrant corner ratios selected for this study. These 6 ratios are compared across 3 different number of bays, i.e, 5 bay, 10 bay and 15 bay.

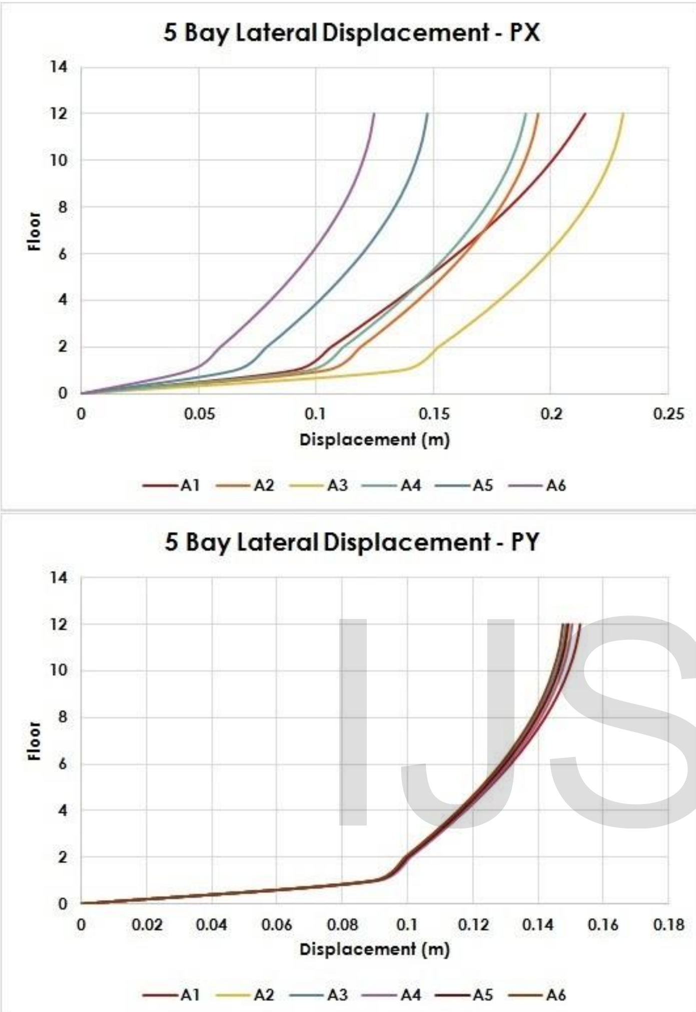


Figure 5.2: Displacement Curve - 5 Bay

5.3.1.1 FIVE BAY

Figure 5.2 is the graphical representation of displacement of 5 bay structures with PX and PY pushover forces. For push in X direction (PX), model A6 (Regular structure) shows the least displacement while model A3 (a/A=0.6, b/B=0.4) shows maximum displacement. There is no significant difference of displacement between the models when pushover force is PY.

5.3.1.2 TEN BAY

Figure 5.3 represents 10 bay structures with PX and PY push-over forces. For push in X direction (PX), model B6 (Regular structure) shows the least displace- ment while model B3 (a/A=0.6, b/B=0.4) shows maximum displacement. When pushover force is PY, curves of models B3 and B5 are super-imposed and shows maximum displacement than the other models.

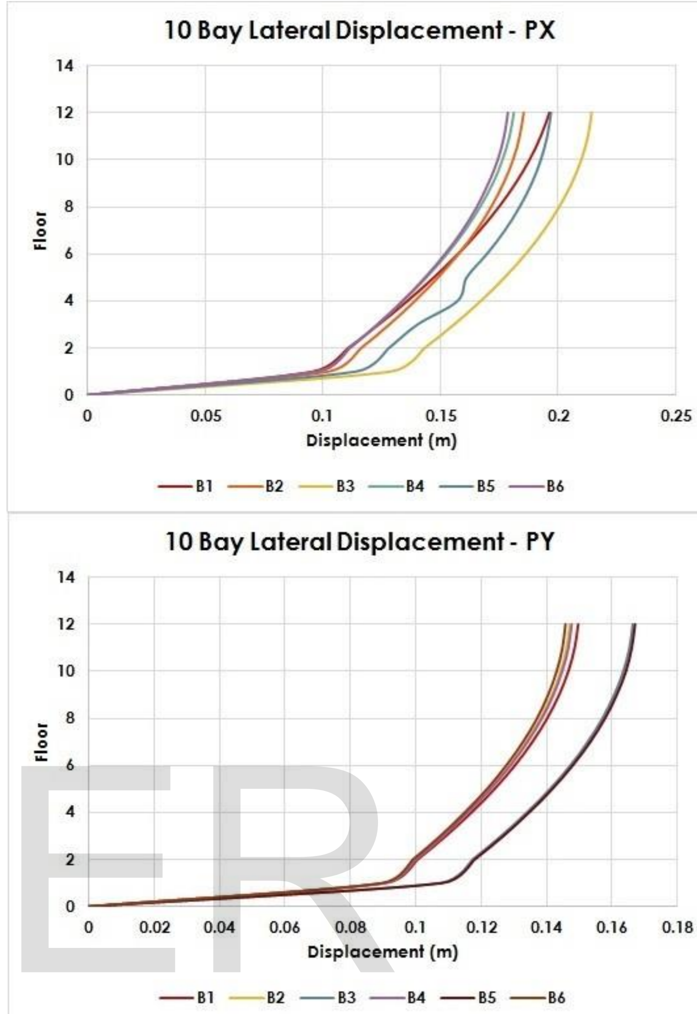


Figure 5.3: Displacement Curve - 10 Bay

5.3.1.3 FIFTEEN BAY

Figure 5.4 represents 15 bay structures with PX and PY push-over forces. For push in X direction (PX), model C6 (Regular structure) shows the least displace- ment while model C3 (a/A=0.6, b/B=0.4) shows maximum displacement. There is no significant difference of displacement between the models when pushover force is PY.

5.3.2 VARIATION IN NUMBER OF BAYS

This section compares the behaviour of structures if the number of bays are changed keeping the same re-entrant corner ratio. It can noted from figures 5.2, and 5.4 that the variation of displacement along the floors are proportional for all the selected models and hence maximum displacements of models are selected for the comparative study. It can also be noted that here is no significant difference of displacement between the models when pushover force is PY. Figure 5.5 is the graphical representation of effect of variation in number of bays on linear displace- ment.

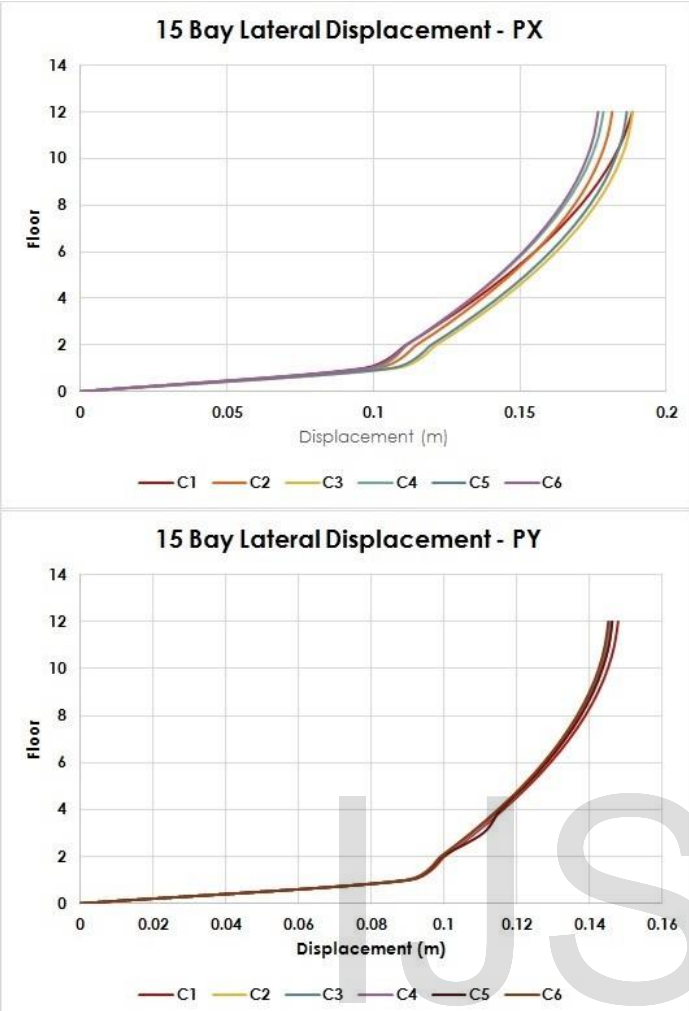


Figure 5.4: Displacement Curve - 15 Bay

The linear displacement of 5 bay structures are maximum and that of 15 bay are minimum for A1, B1, C1 (a/A=0.8, b/B=0.8); A2, B2, C2 (a/A=0.2, b/B=0.8); A3, B3, C3 (a/A=0.6, b/B=0.4) and A4, B4, C4 (a/A=0.4, b/B=0.6).

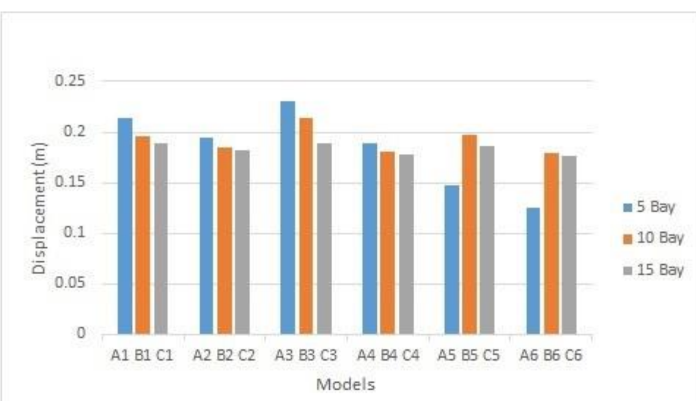


Figure 5.5: Variation in Number of bays

For A6, B6, C6 (regular structures) and A5, B5, C5 (a/A=0.8, b/B=0.2) 10 bay models shows maximum displacement while 5 bay models shows the least.

6 STOREY DRIFT

6.1 GENERAL

The accurate prediction of story drift and its distribution along the height of the structure is very critical for seismic performance evaluation of a structure.

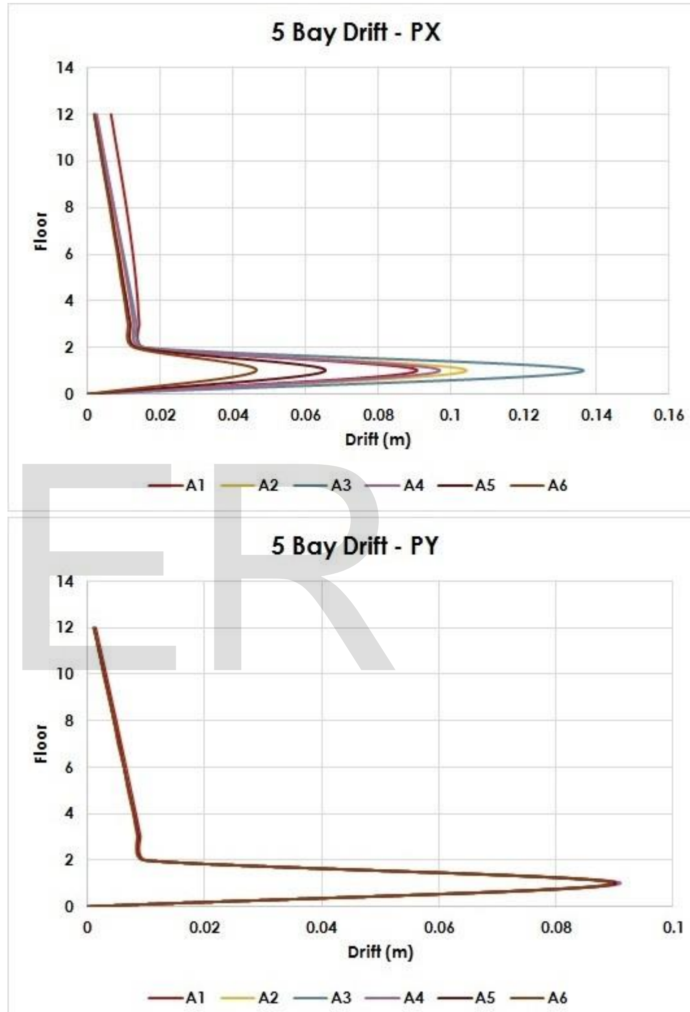


Figure 6.1: Storey drift Curve - 5 Bay

This section investigates effect of plan setback (Forming a re-entrant corner) and increase or decrease in the plan dimensions (Number of bays) on the story drift of a structure. For this purpose, structures with different planar configurations were analysed using non-linear static pushover analysis in SAP2000 and obtained results are compared to evaluate the effect of change in configurations on the storey drift generated. The details of analysis required for calculation of storey drift remains the same as mentioned in Section 5.

6.2 RESULTS AND INTERPRETATIONS

The tabulated data and storey drift curves after analysis are interpreted in two parts:

- Re-entrant ratio
- Number of bays

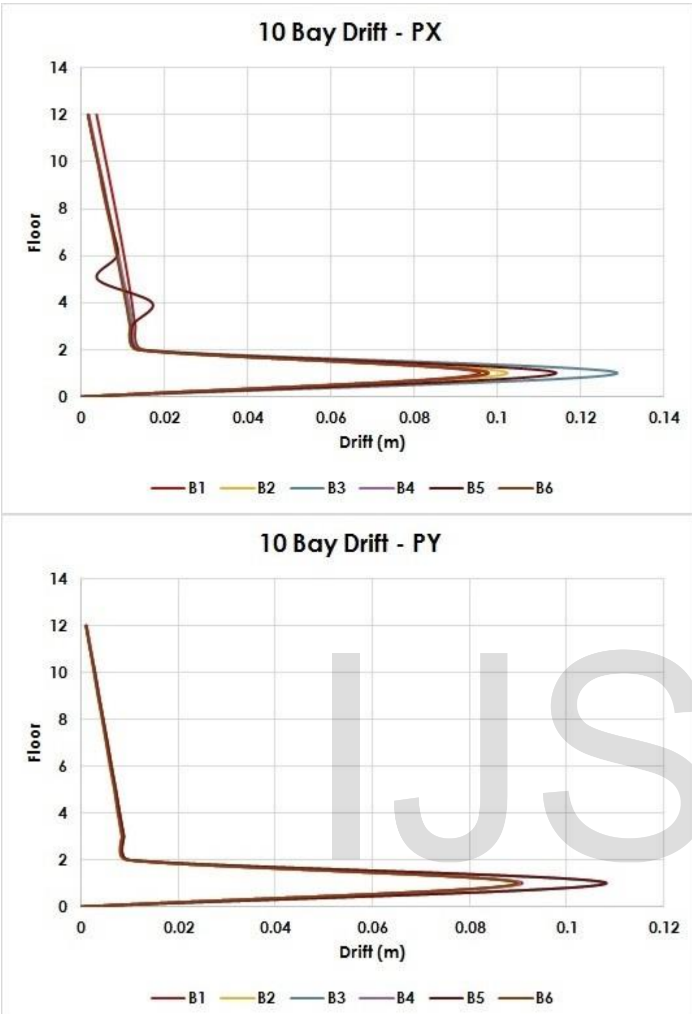


Figure 6.3: Storey drift Curve - 10 Bay

6.2.1 VARIATION IN RE-ENTRANT RATIO

As it was stated, there are 6 different re-entrant corner ratios selected for this study. These 6 ratios are compared across 3 different number of bays, i.e, 5 bay, 10 bay and 15 bay.

6.2.1.1 FIVE BAY

Figure 6.1 is the graphical representation of storey drift of 5 bay structures with PX and PY pushover forces. For push in X direction (PX), model A6 (Regular structure) shows the least storey drift while model A3 (a/A=0.6, b/B=0.4) shows maximum storey drift. There is no significant difference of storey drift between the models when pushover force is PY.

6.2.1.2 TEN BAY

Figure 6.2 represents 10 bay structures with PX and PY push-over forces. For push in X direction (PX), model B6 (Regular structure) shows the least storey drift while model B3 (a/A=0.6, b/B=0.4) shows maximum storey drift. When push-over force is PY, curves of models B3 and B5 are superimposed and shows maximum storey drift than the other models.

6.2.1.3 FIFTEEN BAY

Figure 6.3 represents 15 bay structures with PX and PY push-over forces. For push in X direction (PX), model C6 (Regular structure) shows the least storeydrift while model C3 (a/A=0.6, b/B=0.4) shows maximum storey drift. There is no significant difference of storey drift between the models when pushover force is PY.

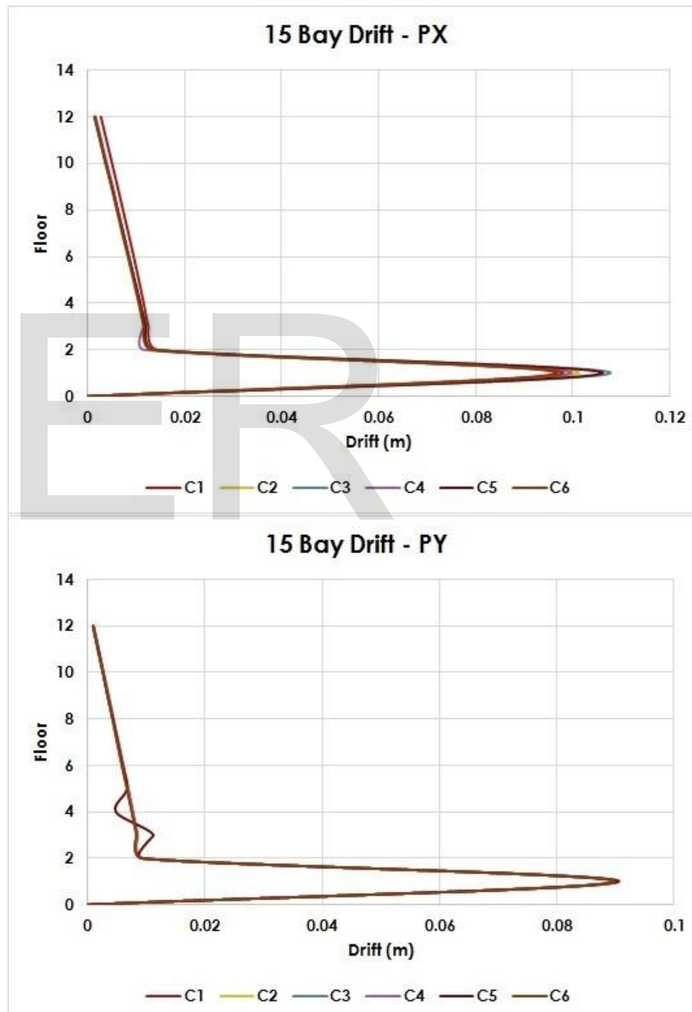


Figure 6.3: Storey drift Curve - 15 Bay

6.2.2 VARIATION IN NUMBER OF BAYS

This section compares the behaviour of structures if the number of bays are changed keeping the same re-entrant corner ratio. It can noted from figures 6.1, and 6.3 that the variation of storey drift along the floors are proportional for all the selected models and hence maximum storey drifts of models are selected for the comparative study. It can also be noted that here is no significant difference of storey drift between the models when pushover force is PY. Figure 6.4 is the graphical representation of effect of variation in number of bays on storey drift.

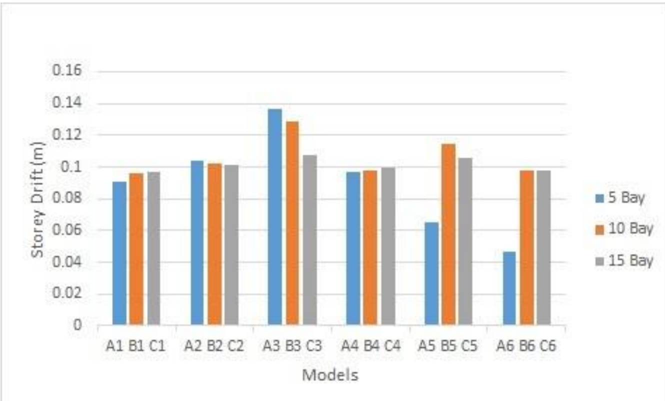


Figure 6.4: Variation in Number of bays

The storey drift of 5 bay structures are maximum and that of 15 bay are minimum for models A3, B3, C3 (a/A=0.6, b/B=0.4). For A6, B6, C6 (regular structures) and A5, B5, C5 (a/A=0.8, b/B=0.2) 10 bay models shows maximum storey drift while 5 bay models shows the least. Other models are not showing any significant change in drift if the number of bays are changed.

7 TORSIONAL DISPLACEMENT

7.1 GENERAL

Torsional irregularity is one of the major causes of severe damage and col- lapse of structures during an earthquake. Torsional irregularity can be simply de- fined as the twisting of a structure on its vertical axis. A well proportioned structure will generate least twisting effect under any load conditions. Irregular structures generate maximum torsional effects. In this section, the effect of planar dimen- sional change on torsion generated is reviewed by a non-linear static pushover anal- ysis using SAP2000.

The modelling and analysis remains the same as in the previous sections. The de- tails of selected models are given in Table 6.1. The configurations of these models are represented in figure 4.1, 4.2 and 4.3

7.2 DETAILS OF ANALYSIS

There will be two sets of results in a pushover analysis:

- When pushover force is acting along X axis (PX)
- When pushover force is acting along Y axis (PY)

The displacement occurs X axis is notated as U1 and the displacement occurs in Y axis is notated as U2. Also, There will be two types of displacements for each cases (pushover force PX and PY):

Displacement occurring in the same direction of pushover force applied (U1 for PX and U2 for PY). Displacement occurring in the perpendicular axis of pushover force applied (U2 for PX and U1 for PY). The displacement occurring in the same direction of pushover force applied (U1 for PX and U2 for PY) is discussed in this section 5 (Linear displacement). Displacement occurring perpendicular to the pushover force applied (U2 for PX and U1 for PY) will be because of the torsional effect generated on the structure. This torsional displacement is reviewed for comparative study in this section.

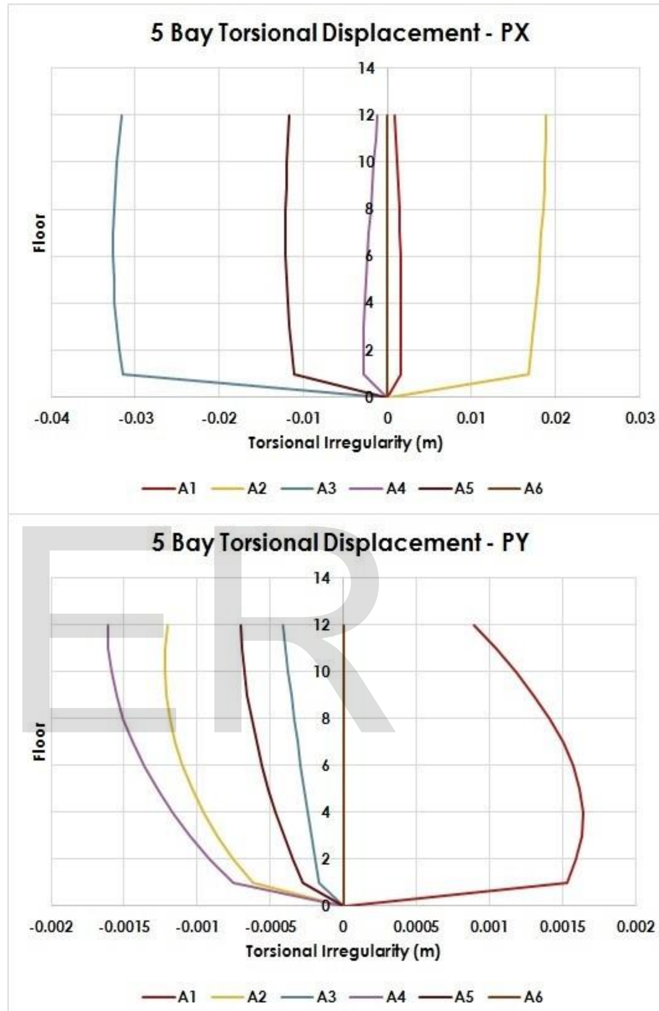


Figure 7.1: Torsional irregularity - 5 Bay

The corner of the structure showing maximum displacement is selected for the floor wise values. All values are taken in collapse prevention step (CP) just before col- lapse (C) in SAP2000.

7.3 RESULTS AND INTERPRETATIONS

The tabulated data and curves after analysis are interpreted in two parts:

- Re-entrant ratio
- Number of bays

7.3.1 VARIATION IN RE-ENTRANT RATIO

As it was stated, there are 6 different re-entrant corner ratios selected for this study. These 6 ratios are compared across 3 different number of bays, i.e, 5 bay, 10 bay and 15 bay.

7.3.1.1 FIVE BAY

Figure 7.1 is the graphical representation of torsional displacement (TD) of 5 bay structures with PX and PY pushover forces. For push in X direction (PX), model A6 (Regular structure) shows the least TD while model A3 (a/A=0.6, b/B=0.4) shows maximum TD. When pushover force is PY, model A6 (Regular structure) shows the least TD while model A1 (a/A=0.8, b/B=0.8) shows maximum TD.

7.3.1.2 TEN BAY

Figure 7.2 represents 10 bay structures with PX and PY pushover forces. For push in X direction (PX), model B6 (Regular structure) shows the least TD while model B3 (a/A=0.6, b/B=0.4) shows maximum TD. When pushover force is PY, model B6 (Regular structure) shows the least TD while model B1 (a/A=0.8, b/B=0.8) shows maximum TD.

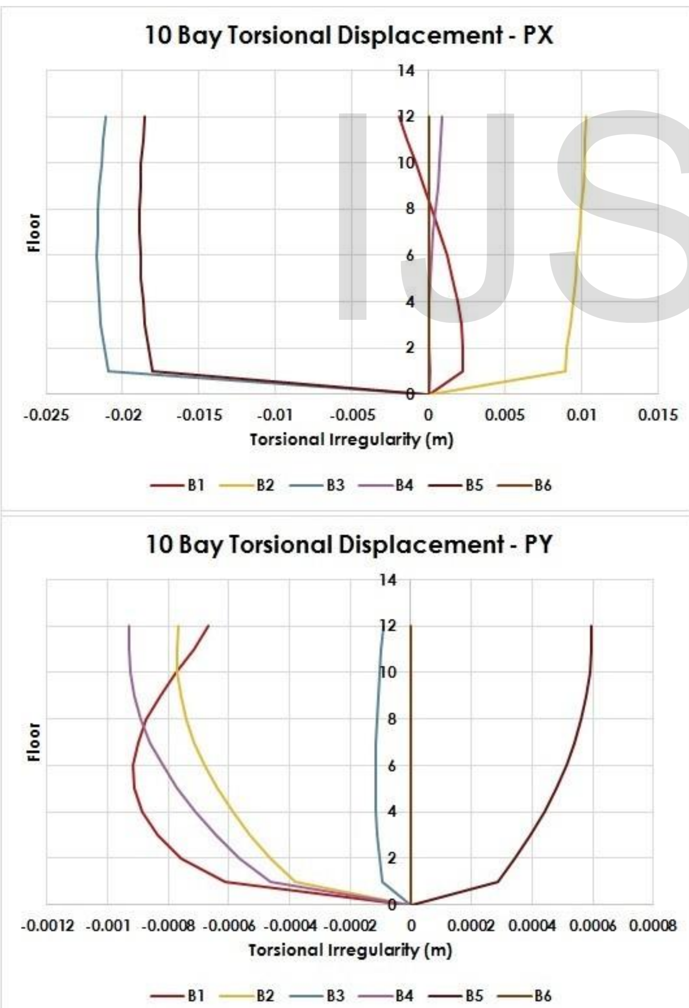


Figure 7.2: Torsional irregularity - 10 Bay

7.3.1.3 FIFTEEN BAY

Figure 7.3 represents 15 bay structures with PX and PY pushover forces. For push in X direction (PX), model C6 (Regular structure) shows the least TD while model C3 (a/A=0.6, b/B=0.4) shows maximum TD. When pushover force is PY, model C6 (Regular structure) shows the least TD while model C1 (a/A=0.8, b/B=0.8) shows maximum TD.

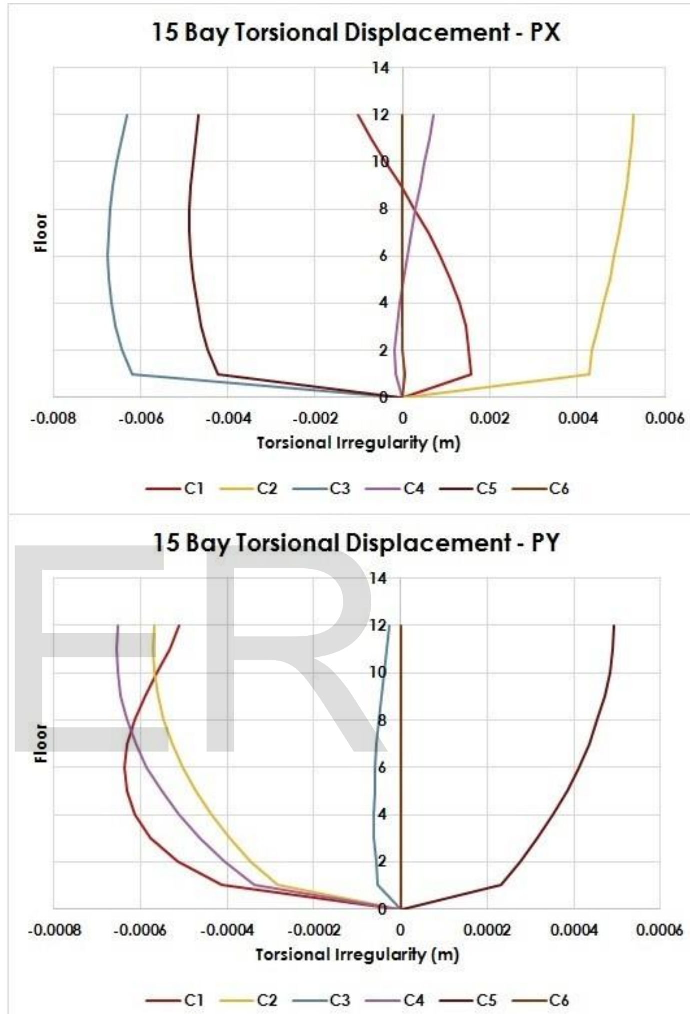


Figure 7.3: Torsional irregularity - 15 Bay

7.3.2 VARIATION IN NUMBER OF BAYS

This section compares the behaviour of structures if the number of bays are changed keeping the same re-entrant corner ratio. The maximum torsional dis- placements of each models are selected for this comparative study. Figure 7.4 is the graphical representation of effect of variation in number of bays on TD for pushover PX. The torsional displacement of 5 bay structures are maximum and that of 15 bay are minimum for A2, B2, C2 (a/A=0.2, b/B=0.8); A3, B3, C3 (a/A=0.6, b/B=0.4) and A4, B4, C4 (a/A=0.4, b/B=0.6). For A1, B1, C1 (a/A=0.8, b/B=0.8) and A5, B5, C5 (a/A=0.8, b/B=0.2) 10 bay models shows maximum displacement while 15 bay models shows the least. Regular models A6, B6, C6 have their TD nullified when compared with the other models.

Figure 7.4 is the graphical representation of effect of variation in number of bays on TD for pushover PY. When pushover force is PY, The torsional displacement of 5 bay structures are maximum and that of 15 bay are minimum for all re-entrant ratios. Regular models A6, B6, C6 have their TD nullified when compared with the other models.

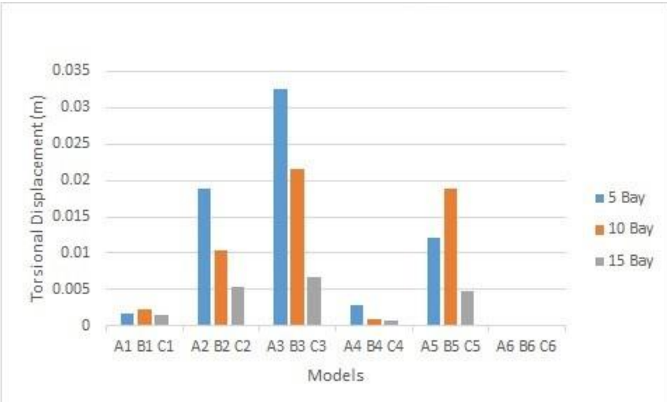


Figure 7.4: Variation in Number of bays for pushover PX

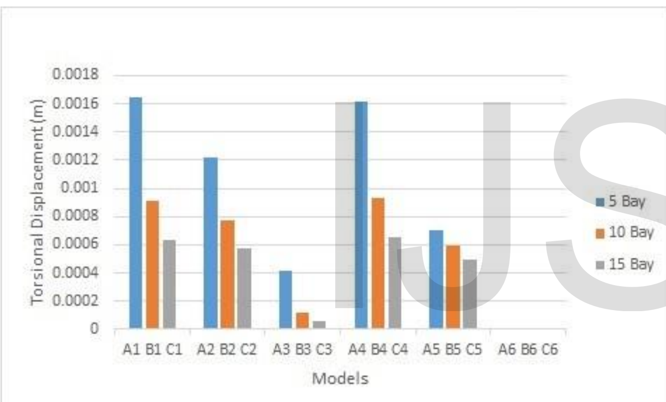


Figure 7.5: Variation in Number of bays for pushover PY

8 MITIGATION OF THE IRREGULARITIES USING FVD

8.1 GENERAL

The integrity and serviceability of the steel multi-storey buildings structures against natural hazard such as earthquake were a challenge among structural en- gineers and researches. The major concern in the design of theses structures is to have enough lateral stability to resist wind and seismic forces. There are different systems to limit the lateral drift.Among these systems, there is the combination of structural steel frames with passive energy dissipation provided by fluid viscous dampers (FVD). The use of this device is now becoming cost-effective solution to improve seismic performance of existing as well as new buildings.

This section is an attempt for mitigation of the irregularities (Lateral displacement, Storey drift and torsional displacement) based on the study without increasing its stiffness in a significant way by supplemental fluid viscous dampers.

8.2 MODELLING AND ANALYSIS

From the literature review it is understood that fluid viscous damper provides substantial reductions in displacements, drifts, and torsion greatly enhanced damping and lowers both stress and deflection throughout a structure. This allows the structure to remain elastic. Table 8.1 provides the details of the damper used for this study.

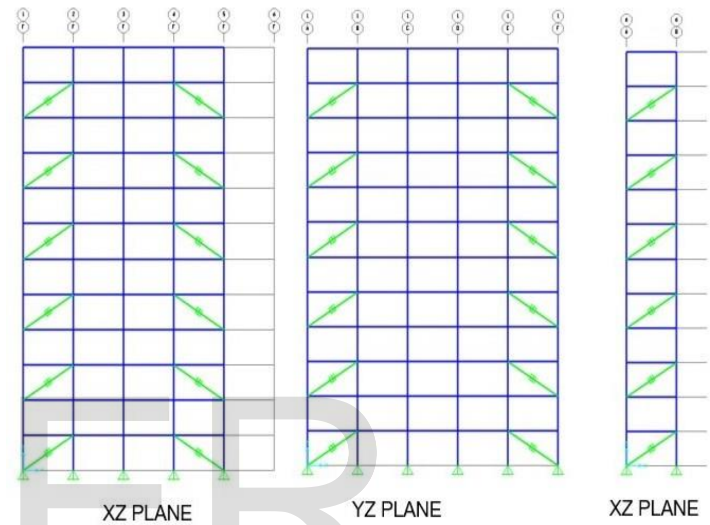


Figure 8.1: FVD connection details on model A2

After defining the properties of damper in both U1 and U2, it is set to draw with 2 joint link and assigned as shown in Figure 8.1 the model is set to run and the obtained results are tabulated and compared. Table 8.2 shows a sample tabulated results of model A2.

Table 8.1: Details of FVD

Type	Non linear FVD
Mass	98 kg
Weight	500 kN
Stiffness	2000000 kN/m
Damper coefficient	200 kN.s/m
Damper exponent	0.5

8.3 EVALUATION

By the installation of a fluid viscous damper, the below mentioned conclusions were derived from the results generated

- 40-65% reduction in lateral displacements in 5 bay building in all the models.

9 CONCLUSIONS AND FUTURE SCOPE

9.1 GENERAL

The primary objective of the project is to propose the best and worst re- entrant configuration from a selected range of structures across 3 different bay lengths. To achieve this primary objective, several secondary objectives were con- sidered. Initially, a literature study has been conducted regarding the irregularities. And then a further study is conducted for identifying the most suitable mitigation plan. Finally the modelling and analysis was done in SAP2000 to compare the models for their seismic behaviours.

9.2 CONCLUSIONS

The seismic behaviour of models are observed to be mostly similar in the case of storey drift and lateral displacements. As to the torsional displacement, some variations were observed in behaviour of models.

9.2.1 LATERAL DISPLACEMENT

Re-entrant structure with ratio a/A=0.6 and b/B=0.4 is the worst case in terms of lateral displacement generated in the structure. This stays true across all bay lengths and both pushover cases (PX and PY). Regular structure is the safest in all bay cases in terms of all irregularities generated.
Figure 9.1 is a representation of the models compared for their lateral displace- ment. It is evident from the figure that lateral displacement of 10 bay and 15 bay structures are identical. Maximum and minimum values of lateral displacement for5 bay structures shows identical behaviour with 10 bay and 15 bay structures.

9.2.2 STOREY DRIFT

Re-entrant structure with ratio a/A=0.6 and b/B=0.4 is the worst case in terms of storey drift generated in the structure. This stays true across all bay lengths and both pushover cases (PX and PY). Regular structure is the safest in all bay cases in terms of all irregularities generated.
Figure 9.2 is a representation of the models compared for their storey drift. It isevident from the figure that storey drift of 10 bay and 15 bay structures are identical. Maximum and minimum values of storey drift for 5 bay structures shows identical behaviour with 10 bay and 15 bay structures.

9.2.3 TORSIONAL DISPLACEMENT

The torsional displacement of 5 bay structures are maximum and that of 15 bay are minimum for A2, B2, C2 (a/A=0.2, b/B=0.8); A3, B3, C3 (a/A=0.6, b/B=0.4) and A4, B4, C4 (a/A=0.4, b/B=0.6).
For A1, B1, C1 (a/A=0.8, b/B=0.8) and A5, B5, C5 (a/A=0.8, b/B=0.2) 10 bay models shows maximum displacement while 15 bay models shows the least.
When pushover force is PY, The torsional displacement of 5 bay structures are max- imum and that of 15 bay are minimum for all re-entrant ratios. In both PX and PY cases, regular models A6, B6, C6 have their TD nullified when compared with the other models.

9.3 FUTURE SCOPE

This study is conducted on square plot plans of 25m, 50m and 75m. How- ever, future studies should consider irregular plot plans. Also, effect of variation in bay lengths and storey heights can be studied.
Reduction of torsional displacement using FVD is around 15%. Other mitigation plans can be considered for better reduction of irregularities.

REFERENCES

[1] Divyashree M, Gopi Siddappa (2015) Seismic Behaviour of RC Buildings with Re-entrant Corners and Strengthening. IOSR Journal of Mechanial and civil enginerin IOSR-JMCE.
[2] Swaminathan Krishnan (2006) Case studies of damage to 19-storey irregular steel moment-frame buildings under near-source ground motion. Earthquake Engineering and structural dynamics, Wiley Interscience, Cali- fornia.
[3] Anis S. Shatnawi, Mazen Musmar, Laith I. Gharaibeh (2019) Evaluation of Seismic Analysis Procedures for Concrete Moment-Resistant Frames with Horizontal Re-entrant Corners Irregularity. International journal of advanced science engineering information technology, Jordan.
[4] Anushri C, Dr B Shivakumara Swamy (2016) Study on Performance of Regular and L-Shape Plan Irregular Building with Dampers, Shear Wall and Infill Wall IRJET Vol 3, Issue 10.
[5] Dubey, S.K and Sangamnerkar (2011) Seismic Behavior of Asymmetric RC Buildings. International journal of advanced engineering technolo]gy, 2(4): 296-301.
[6] Ravi Kanth Mittal, P.Prashanth (2012) Response Spectrum Modal Analysis Of Buildings Using Spreadsheets International Journal Of Modern
[7] Engineering Research (IJMER)., volume 2, issue 6, pg – 4207 to 4210, 2012.
[8] Heysami, Alireza (2015) Types of dampers and their seismic performance during an earthquake. Current world environment, Vol. 10, pp. 1002-1015.
[9] Bhaskararao, A. V,and R. S. Jangid (2006) Seismic analysis of structures connected with friction dampers. Engineering Structures, Vol. 28, Issue 5, pp. 690-703.
[10] Mualla, I. H, L. O. Nielsen, M. Sugisawa, and Y. Suzuki (2012) Large capacity dampers for buildings and structures. 15h World Conference on Earthquake Engineering, Lisbon, Portugal.
[11] Min, Kyung-Won, Ji-Young Seong, and Jinkoo Kim (2010) Simple design procedure of a friction damper for reducing seismic responses of a single- story structure. Engineering Structures, Vol. 32, Issue 11, pp. 3539-3547.
[12] Cheng, Xuansheng, Chuansheng Jia, and Yue Zhang (2014) Seismic responses of an added-story frame structure with viscous dampers. Mathematical Problems in Engineering.
[13] Anil K Chopra Dynamics of structures, PEARSON publications, Third edition.
[14] Esmaeel Asadi and Hojjat Adeli (2018) Nonlinear Behavior and Design of Mid-To-High-rise Diagrid Structures in Seismic Regions, Research Thesis Report.
[15] IS 1893 (Part 1) (2016) Indian Standard Criteria for Earthquake Resistant Design of Structures (Sixth Revision).
[16] Mario Paz Structural dynamics. CBS publishers, Second edition.

[17] Newmark N and Hall W (1982) Earthquake spectra and design Engineering monograph, Research Thesis, Earthquake Engineering Research Institute, Berkeley, California.
[18] Pankaj Agarwal and Manish Shrikhande (2014) Earthquake resistant design of structures PHI Learning private limited, Thirteenth printing.
[19] S.R Damodarasamy and S.Kavitha (2014) Basics of structural dynamics and a seismic design PHI Learning private limited, Tenth printing.
[20] L. Hubert and P. Arabie, "Comparing Partitions," *J. Classification,* vol. 2, no. 4, pp. 193-218, Apr. 1985. (Journal or magazine citation)
[21] R.J. Vidmar, "On the Use of Atmospheric Plasmas as Electromagnetic Reflectors," *IEEE Trans. Plasma Science*, vol. 21, no. 3, pp. 876-880, available at http://www.halcyon.com/pub/journals/21ps03-vidmar, Aug. 1992. (URL for Transaction, journal, or magzine)
[22] J.M.P. Martinez, R.B. Llavori, M.J.A. Cabo, and T.B. Pedersen, "Integrating Data Warehouses with Web Data: A Survey," *IEEE Trans. Knowledge and Data Eng.*, preprint, 21 Dec. 2007, doi:10.1109/TKDE.2007.190746.(PrePrint)