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''APPLICATION OF PUSH OVER ANALYSIS FOR STRUCTURAL ASSESSMENT OF RCC BUILDING''

Mr. Suraj S. Shinde[1], Dr. Nagesh L. Shelke[2], Prof. Manoj Deosarkar[3]
Prof. Vishwajeet Kadlag [4]

1. *PG Student, DYPSOET Pune, Department of Civil Engineering, India*
2. *Asso. Professor, Guide (HoD) DYPSOET Pune, Department of Civil Engineering, India*
3. *Asst. Prof. (Co guide) DYPSOET Pune, Department of Civil Engineering, India*
4. *Asst. Prof. DYPSOET Pune, Department of Civil Engineering, India*

Abstract: Shear wall is one of lateral resisting structure which is used commonly. Shear wall gives high stiffness to the structure so as the structure will be stable. This will reduce the destruction comes from lateral loads such as an earthquake. Earlier studies showed that shear wall gives different performance based on its position in structures. The study focuses to see the effect of shear wall location in multi-storied building. A residential building of G+12 Storey structure having base dimension of plan 13.5m X 10.5m with typical floor height of 3m is considered. In this study G+12 storied building was modeled using software and four different cases were studied with different location of shear wall in building frame for critical parameters like displacement and base shear under lateral loading. The analysis has been carried out using the software SAP2000 for analysis equivalent static method and non-linear static analysis method is used here. Four types of models have been analyzed. It is found from this study that Model 3 shows best performance.

Keywords: Linear analysis, Non-linear analysis, Pushover analysis, Shear wall.

1. INTRODUCTION

A pushover analysis is performed by subjecting a structure to a monotonically increasing pattern of lateral loads, representing the inertial forces which would be experienced by the structure when subjected to ground shaking. Under incrementally increasing loads various structural elements may yield sequentially. Consequently, at each event, the structure experiences a loss in stiffness. Using a pushover analysis, a characteristic non-linear force displacement relationship can be determined. It is necessary for the following considerations: Pushover analysis is a nonlinear static analysis used mainly for seismic evaluation of framed building. Seismic demands are computed by nonlinear 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.

Nonlinear 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 elastic analysis. By pushover analysis, the base shear versus top displacement curve of the structure, usually called capacity curve, is obtained. Based on the capacity curve, a target displacement which is an estimate of the displacement that the design earthquake will produce on the building is determined. The extent of damage experienced by the structure at this target displacement is considered representative of the damage experienced by the building when subjected to design level ground shaking.

1.1 METHODOLOGY

1.1.1 General:-

The Seismic vulnerability assessment of multistoried buildings will be carried out using pushover analysis. The different methods to be used are as follows*:*

i. Standard pushover analysis method (FEMA 356)
ii. Capacity spectrum Method (ATC 40)
iii. Modal pushover analysis method.
iv. Non-linear Time history analysis method.

1.1.2 Standard Pushover Analysis -

The pushover analysis consists of the application of gravity loads and a representative lateral load pattern. The lateral loads were applied monotonically in a step-by-step nonlinear static analysis. The applied lateral loads were accelerations in the x direction representing the forces that would be experienced by the structures when subjected to ground shaking. A two or three dimensional model diagrams of all lateral force and gravity forces are first created and gravity loads are applied initially. A predefined lateral load pattern which is distributed along the building height is then applied. The lateral forces are increased until some members yield. The capacity of the structure is represented by the base shear versus roof- displacement graph as shown in Figure 1.

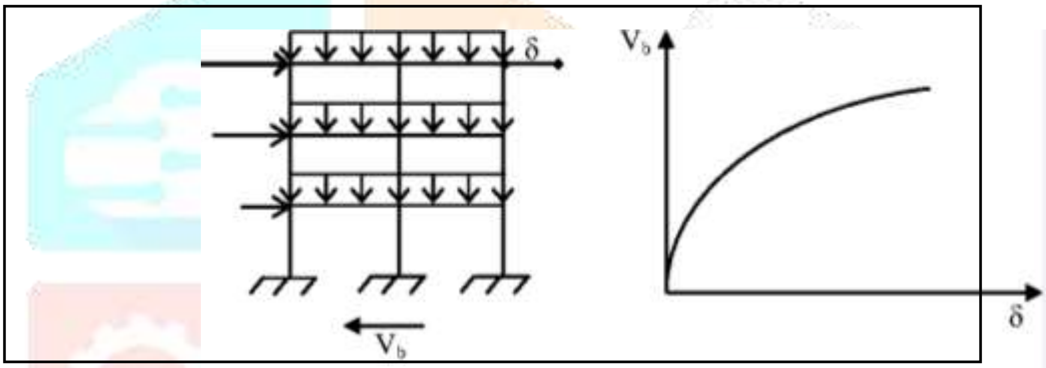


Figure 1: Construction of Pushover Curve

1.1.3 Key Elements of Pushover Analysis -

1. Definition of plastic hinges: In SAP2000, nonlinear behavior is assumed to occur within a structure at concentrated plastic hinges. The default types include an uncoupled moment hinges, an uncoupled axial hinges, an uncoupled shear hinges and a coupled axial force and biaxial bending moment hinges.
2. Definition of the control node: control node is the node used to monitor displacements of the structure. Its displacement versus the base-shear forms the capacity (pushover) curve of the structure.
3. Developing the pushover curve which includes the evaluation of the force distributions. To have a displacement similar or close to the actual displacement due to earthquake, it is important to consider a force displacement equivalent to the expected distribution of the inertial forces.
4. Estimation of the displacement demand: This is a difficult step when using pushover analysis. The control is pushed to reach the demand displacement which represents the maximum expected displacement resulting from the earthquake intensity under consideration, which is calculated in Response spectrum analysis.

The main output of a pushover analysis is in terms of response demand versus capacity. If the demand curve intersects the capacity envelope near the elastic range, Fig.2 (a), then the structure has a good resistance. If the demand curve intersects the capacity curve with little reserve of strength and deformation capacity, Fig.2 (b), then it can be concluded that the structure will behave poorly during the imposed seismic excitation and need to be retrofitted to avoid future major damage or collapse. Depending on the weak zones that are obtained in the pushover analysis, we have to decide whether to do perform seismic retrofitting or rehabilitation.

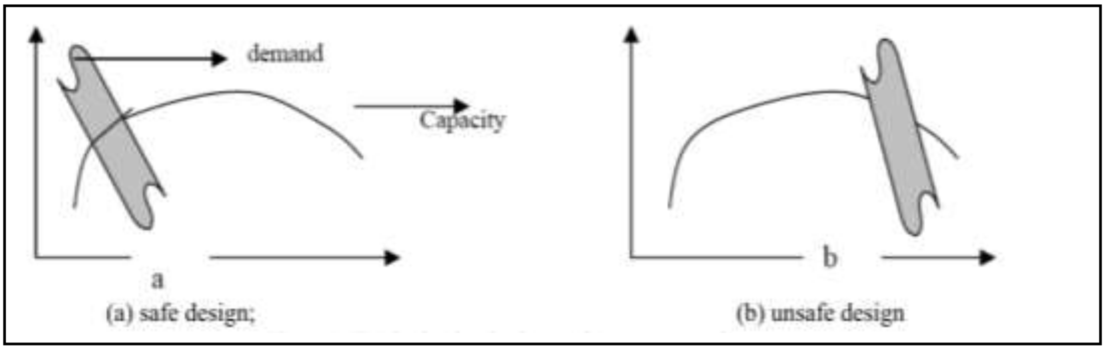


Figure 2: Typical seismic demand versus capacity

Under incrementally increasing loads some elements may yield sequentially. Consequently, at each event, the structures experiences a stiffness change as shown in Figure 3, where IO,LS and CP stand for immediate occupancy, life safety and collapse prevention respectively.

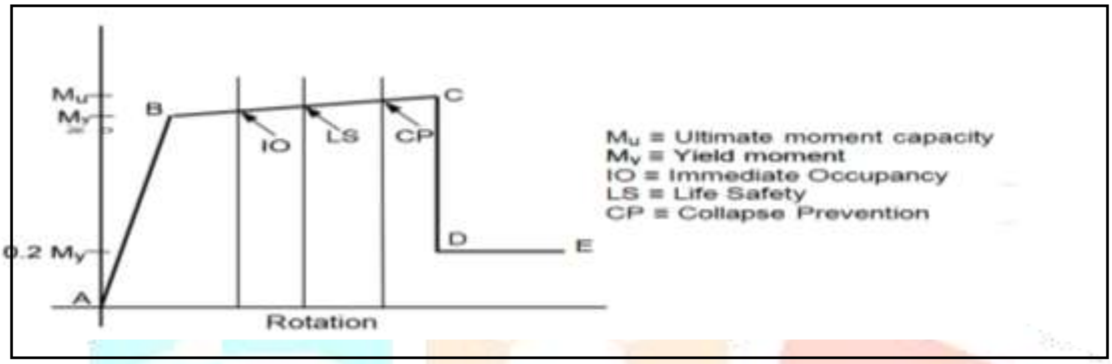


Figure 3: Typical moment-rotation relations for plastic hinges

Where,

Figure 3 present graphical representation of the hinge definition for the beams. No plastic deformation occurs until point B, Where the hinge yields. Point C represents ultimate capacity of hinge and point D corresponds to residual strength of it. Point E represents the ultimate displacement capacity of hinge after reaching to total failure.

Immediate occupancy IO: Damage is relatively limited; the structure retains a significant portion of its original stiffness.

Life safety level LS: Substantial damage has occurred to the structure, and it may have lost a significant amount of its original stiffness. However, a substantial margin remains for additional lateral deformation before collapse would occur.

Collapse prevention CP: At this level the building has experienced extreme damage, if laterally deformed beyond this point; the structure can experience instability and collapse.

2. SHEAR WALL

2.1 Introduction to shear wall:

Tall buildings are the most complex built structures since there are many conflicting requirements and complex building systems to integrate. Today’s tall buildings are becoming more and more slender, leading to the possibility of more sway in comparison with earlier high-rise buildings. Thus the impact of wind and seismic forces acting on them becomes an important aspect for the design. Reinforced concrete framed buildings are adequate for resisting both vertical and horizontal loads acting on them. Lateral forces like wind and seismic forces can be resisted by the use of a shear wall system which is one of the most efficient methods of ensuring the lateral stability of tall buildings.

Generally shear wall can be defined as structural vertical member that is able to resist combination of shear, moment and axial load induced by lateral load and gravity load transfer to the wall from other structural member. An introduction of shear wall represents a structurally efficient solution to stiffen a structural system because the main function of a shear wall is to increase the rigidity against lateral load.

2.2 Reinforced Concrete (RC) Shear Wall:

Reinforced concrete (RC) shear walls are specially designed structural walls included in the buildings to resist horizontal forces which are induced in the plane of the wall due to wind, earthquake and other forces. Shear walls have very high in-plane stiffness and strength, which can be used to simultaneously resist large horizontal loads and support gravity loads. Reinforced concrete wall thickness varies from 150 mm to 500 mm, depending on horizontal forces due to wind, earthquake etc, building age, and thermal insulation requirements. In general, these walls are continuous throughout the building height; however, some walls are discontinued at the street front or basement level to allow for commercial or parking spaces. Usually the wall layout is symmetrical with respect to at least one axis of symmetry in the plan. Shear walls provide lateral load resistance by transferring the wind or earthquake load to foundation. Besides, they impart lateral stiffness to the system and also carry gravity loads. Figure 4 gives the general configuration of the shear wall. When shear walls are situated in advantageous positions in the building, they can form an efficient lateral force resisting system.

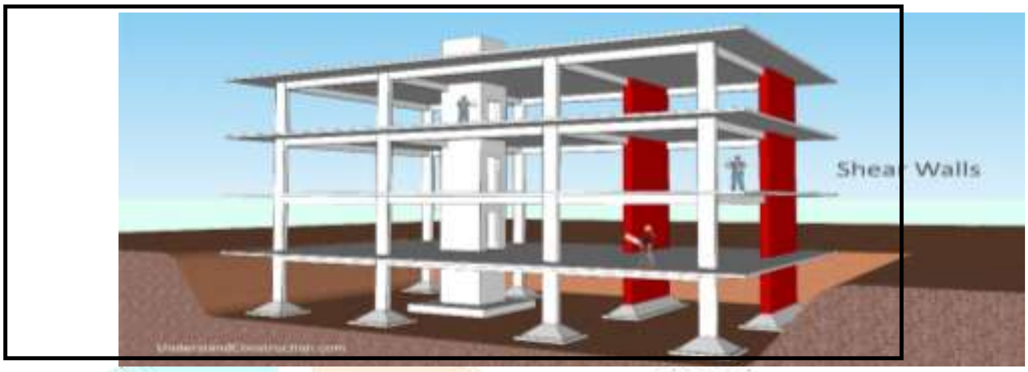


Figure 4: General Configuration of a Shear Wall
(Courtesy: http://www.nicee.org)

2.3 Functions of a Shear Wall:

Shear wall are one of the excellent means of providing earthquake resistance to multistoried reinforced concrete buildings. When RC Multi-Storey building is designed without shear walls then column sizes are quite heavy and steel required is large. So there is lot of congestion at these joints and it is difficult to place and vibrate concrete at these places and displacement is quite heavy which induces heavy forces in member. Shear walls may become essential from the point of view of economy and control of horizontal displacement. The structure is still damaged due to some or the other reason during earthquakes. Behavior of structure during earthquake motion depends on distribution of weight, lateral stiffness and strength in both horizontal and planes of building. To reduce the effect of earthquake, reinforced concrete shear walls are used in the building. These can be used for improving seismic response of buildings. Structural design of buildings for seismic loading is primarily concerned with structural safety during major Earthquakes. In tall buildings, it is very important to ensure adequate lateral stiffness to resist lateral load. The provision of shear walls in building to achieve lateral stiffness has been found to be effective and economical.

Properly designed and detailed buildings with shear walls have shown very good performance in past earthquakes. The overwhelming success of buildings with shear walls in resisting strong earthquakes is summarized in the quote: "We cannot afford to build concrete buildings meant to resist severe earthquakes without shear walls." Mark Fintel, a noted consulting engineer in USA. Shear walls in high seismic regions require special detailing. However, in past earthquakes, even buildings with sufficient amount of walls that were not specially detailed for seismic performance (but had enough well-distributed reinforcement) were saved from collapse. Shear wall buildings are a popular choice in many earthquake prone countries, like Chile, New Zealand and USA. Shear walls are easy to construct, because reinforcement detailing of walls is relatively straight-forward and therefore easily implemented at site.

2.4 External Forces Acting on Shear Wall

Shear walls resist two types of forces: shear forces and uplift forces. Shear forces are generated in stationary buildings by accelerations resulting from ground motion and by external forces like wind and P-waves. This action creates shear forces throughout the height of the wall and the top and bottom shear wall connections. Uplift forces exist on shear walls because the horizontal forces are also applied to the top of the wall. These uplift forces try to lift up one end of the wall and push the other end down. In some cases, the uplift force is large enough to topple the wall over. Uplift forces are greater on tall short walls and less on low long walls. Bearing walls have less uplift than non-bearing walls/shear walls because gravity loads on shear walls help them to resist the uplift. Shear walls should be located on each level of the structure including the crawl space. Figure 5 shows the various forces acting on a shear wall. To form an effective box structure, equal length shear walls should be placed symmetrically on all four exterior walls of the building. Shear walls should be added to the building internally when the exterior walls cannot provide sufficient strength and lateral stiffness. Shear walls are most efficient when tile are aligned vertically and are supported on foundation walls or footing. When exterior shear walls do not provide sufficient strength, other parts of the building need additional strength.

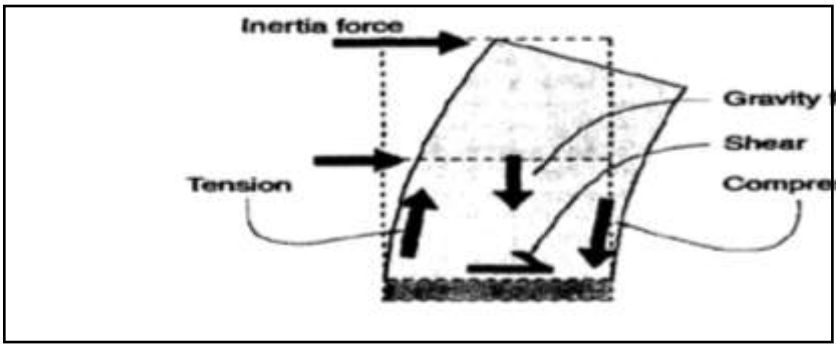


Figure 5: Forces Acting on a Shear Wall
(Courtesy: https://civildigital.com**)**

3. OBJECTIVES

The Major objective of the paper is to study the performance of building for different location of shear walls in multiple models. Different models are being made in this study and the decision of selecting a best model is based on the seismic parameters like storey displacement and formation of plastic hinges.

Steps followed to achieve major objective are:

- To know the lateral displacement pattern in various types of frames.
- To find out the configuration which has least lateral displacement and plastic hinges i.e. best location of shear walls in a building for earthquake prone area.
- To compare the plane frame and the frames with shear walls and find out the best model.

4. METHODOLOGY

4.1 General:

This chapter covers the methodology adopted in the study for the present research work. The present study was carried out to check parameters like lateral displacement, storey drift to find out the effect of location of shear walls on performance of building. Following four types of models have been prepared in the present study and equivalent linear static and non-linear static analysis (push over analysis) has been done on the same.
Model 1: Building without Shear Wall
Model 2: Shear Wall at 3 periphery sides of lift
Model 3: Shear Wall at middle along periphery of structure
Model 4: Shear Wall at Corner along periphery of structure in L shape

4.2 Equivalent Linear Static Analysis:

All design against earthquake effects must consider the dynamic nature of the load. However, for simple regular structures analysis by equivalent linear static methods is often sufficient. This is permitted in most codes of practice for regular, low- to medium rise buildings.

In this method of analyzing multi storey buildings recommended in the code, the structure is treated as discrete system having concentrated masses at floor levels which include that weight of columns and walls in any storey should be equally distributed to the floors above and below the storey. In addition, the appropriate amount of imposed load at the floor is also lumped with it. First, the design base shear is computed for the whole building, and then it is distributed along the height of the building. The lateral forces at each floor thus obtained are distributed to individual lateral load resisting elements. It assumes that the building responds in its fundamental mode. For this to be true, the building must be low-rise and must not twist significantly when the around moves.

4.2.1 Seismic Base Shear -

According to IS: 1893 (Part l)-2016, the base shear (V_B) is given by the following formula:

$$V_B = A_h \text{ x } W \qquad \text{(Clause 7.6.1, IS: 1893 (Part l)-2016)}$$

Where,
A_h = Design horizontal acceleration spectrum value using the fundamental natural period T_a in the considered direction of vibration
W = seismic weight of the building
The A_h shall be determined by the following expression

$$\frac{Z\,I\,S}{2\,R\,g} = Ah \quad \text{(Clause 6.4.2, IS: 1893 (Part l)-2016)}$$

where,
Z = Zone factor as per Table 3 of IS: 1893
R = Response Reduction factor as per Table 9 of IS: 1893
I = Importance factor as per Table 8 of IS: 1893
S_a/g = Average response acceleration coefficient as per Figure 2 of the IS: 1893 (Part l)-2016.

4.2.2 Seismic Weight -

The seismic weight of the whole building is the sum of the seismic weights of all the floors. As per (Clause 7.4.1, IS: 1893 (Part l)-2016) the seismic weight of each floor is sum of its full dead load and the appropriate amount of imposed load, the latter being that part of the imposed loads that may reasonably be expected to be attached to the structure at the time of earthquake shaking. It includes the weight of permanent and movable partitions, permanent equipment, a part of the live load, etc. While Any weight supported in between storeys should be distributed to the floors above and below in inverse proportion to its distance from the floors. As per IS: 1893 (Part l)-2016, the percentage of imposed load as given in code should be used. For calculating the design seismic forces of the structure, the imposed load on the roof need not be considered.

4.2.3 Distribution of Design Force -

Vertical distribution of base shear to different floor levels, the design base shear (V_B) is distributed along the height of the building as per the following expression:-

$$Qi = VB\,\frac{Wihi2}{\sum_{j=1}^{n} \quad Wj\,hj2} \qquad \text{(Clause 7.6.3(a), IS: 1893 (Part 1)-2016)}$$

Where,
Q_i is the design lateral force at floor i,
W_i is the seismic weight of floor i,
h_i, is the height of floor i measured above the base, and
n is the number of storeys in the building i.e., the number of levels at which the masses are located.

5. STRUCTURAL MODELLING

The buildings are modeled and analyzed for static and pushover analyses, using the finite element package SAP2000. The analytical models of the buildings include all components that influence the mass, strength and stiffness. The non-structural elements and components that do not significantly influence the building behavior were not modeled. The floor slabs are assumed to act as diaphragms, which ensure integral action of all the vertical lateral load-resisting elements. Beams and columns were modeled as frame elements with the centerlines joined at nodes. Rigid offsets were provided from the nodes to the faces of the columns or beams.

The weight of the slab was distributed to the surrounding beams as per IS 456: 2000, Clause 24.5. The mass of the slab was lumped at the center of mass location at each floor level. This was located at the design eccentricity (based on IS 1893:2016) from the calculated center of stiffness. Design lateral forces at each storey level were applied at the center of mass locations independently in two horizontal directions (*X*- and *Y*- directions).

5.1 Building Description:

Number of storeys: 13
Type of frame: Special RC moment resisting frame hinged at base.
Floor height: 3.0 m
Slab: S1 (125 mm thick)
Beam: B1 (300 x 300) mm
Cover = 25mm
Column: A) C1 (300 x 600) mm
  Cover = 40mm
  Longitudinal steel = 12 no's 25mm of Fe500
  Transverse steel = 3 legged stirrups of 8mm @ 150mm
 B) C2 (300 x 300) mm
  Cover = 40mm
  Longitudinal steel = 8 no's 25mm of Fe500
  Transverse steel = 3 legged stirrups of 8mm @ 150mm

Thickness of masonry wall: 230 mm
Thickness of shear wall: 300 mm
Materials: Slab M 25, Beam and Shear Wall M30, Column M40 concrete,
Rebar: Fe 500 steel Material

Density of concrete: 25 KN/m^3
Density of masonry: 20 KN/m^3
Live load on each floor: 3 KN/m^3
Floor finish: 1.0 KN/m^3
Wall load: 12.42 KN/m^3
Seismic zone: III
Type of soil: Medium
Importance factor: 1
Response reduction factor: 5
Damping of structure: 5 percent

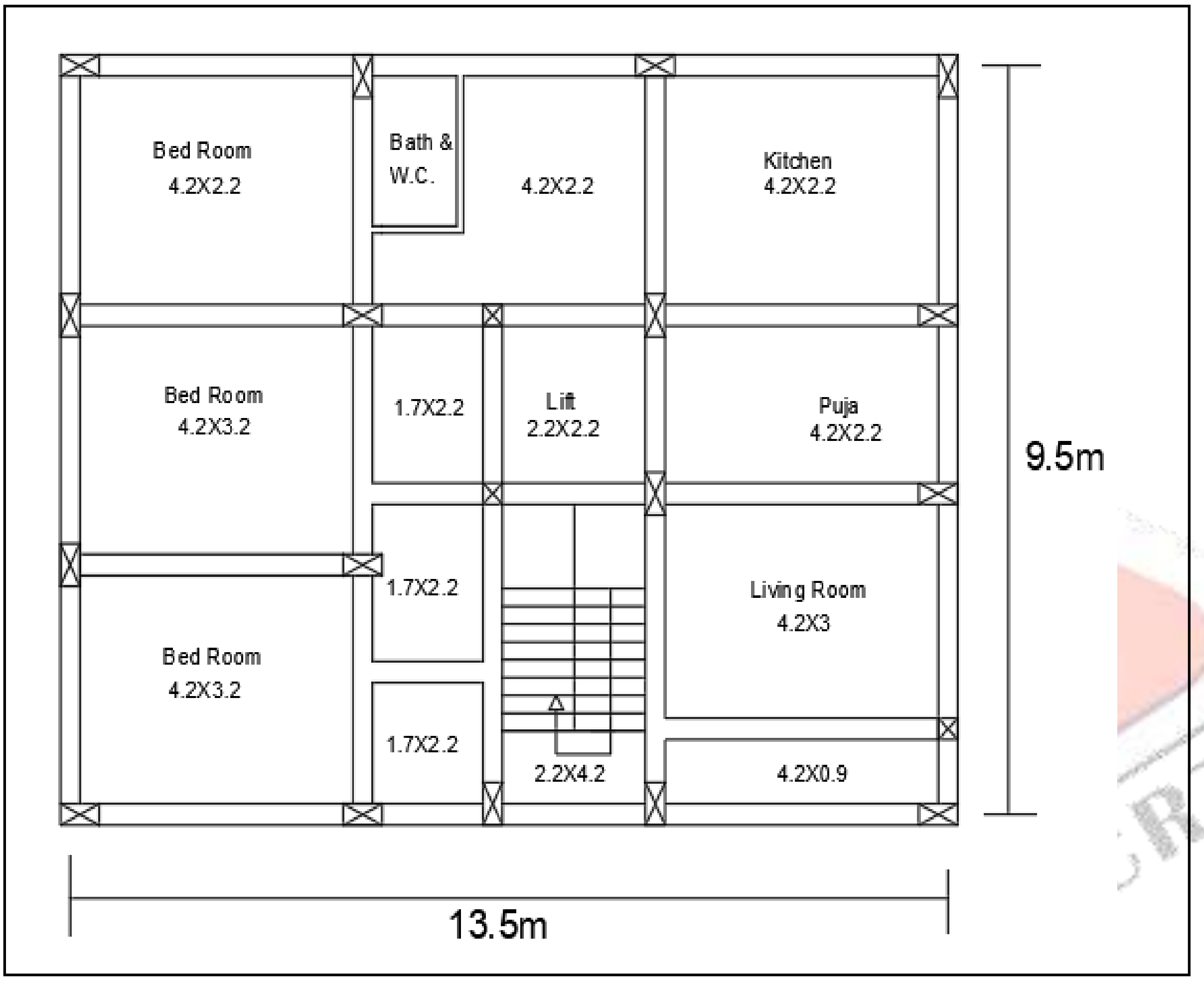


Figure 6: Floor Plan of Building

5.2 Gravity load calculation

Dead load of members

C1 = 0.6 x 0.3 x 25 = 4.5 KN/m

C2 = 0.3 x 0.3 x 25 = 2.25 KN/m

B = 0.3 x 0.3 x 25 = 2.25 KN/m

Slab(125mm thick) = 25 x 0.125 = 3.125 KN/m^2

Brick wall (230mm thick) = 0.23 x 2.7(wall height) x 20 = 12.43 KN/m

Parapet wall (230 mm thick) = 0.23 x 1 x 20 = 4.6 KN/m

Dead floor finish = 1 KN/m^2

Live Load = 3 KN/m^2

Case 1: Building Without Shear Wall

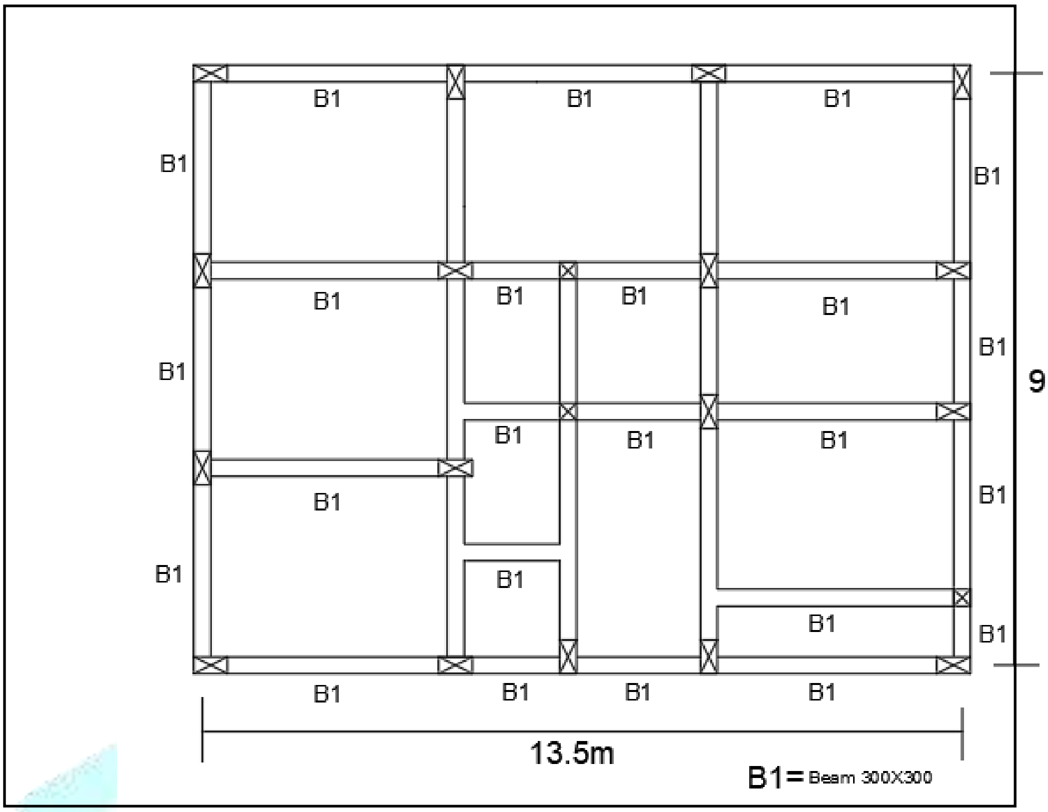


Figure 7: Building without Shear Wall in AutoCad Plan

Case 2: Shear Wall at 3 periphery sides of lift

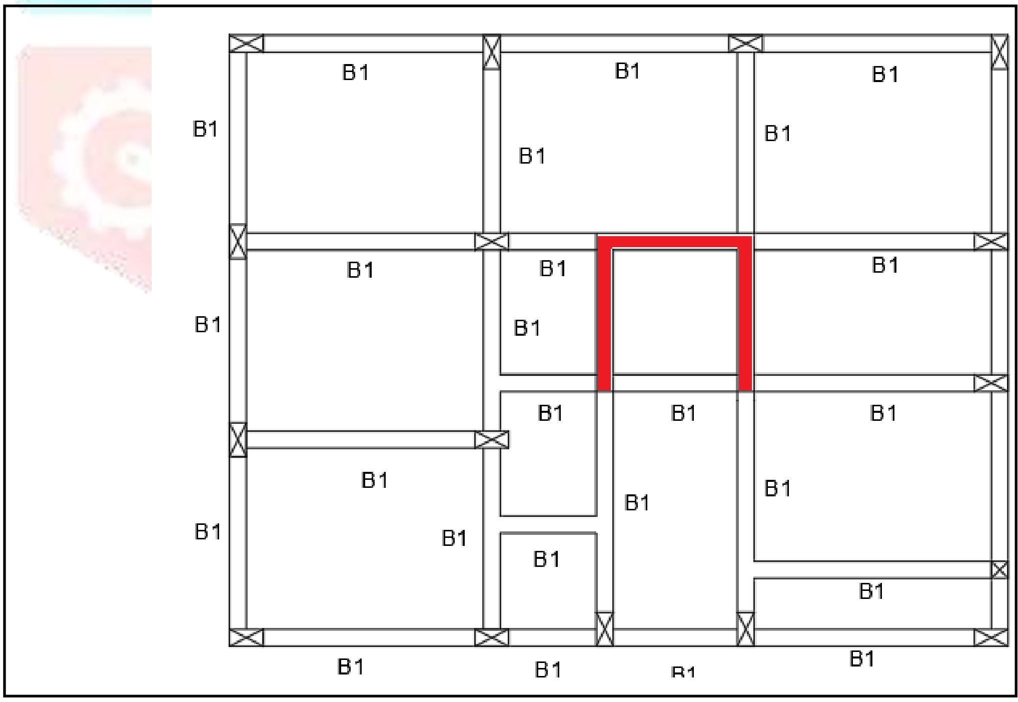


Figure 8: Shear Wall at Three periphery sides of lift Auto-Cadd Plan

Case 3: Shear Wall at middle along periphery of structure

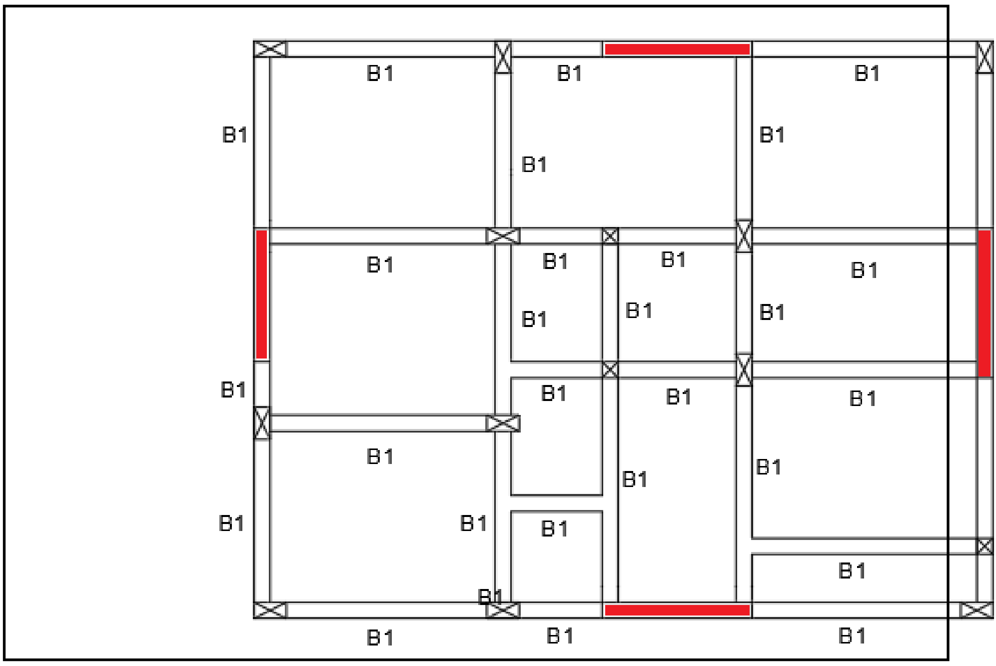


Figure 9: Shear Wall at middle along periphery of structure Auto-Cadd Plan

Case 4: Shear Wall at Corner along Periphery of Structure in L Shape

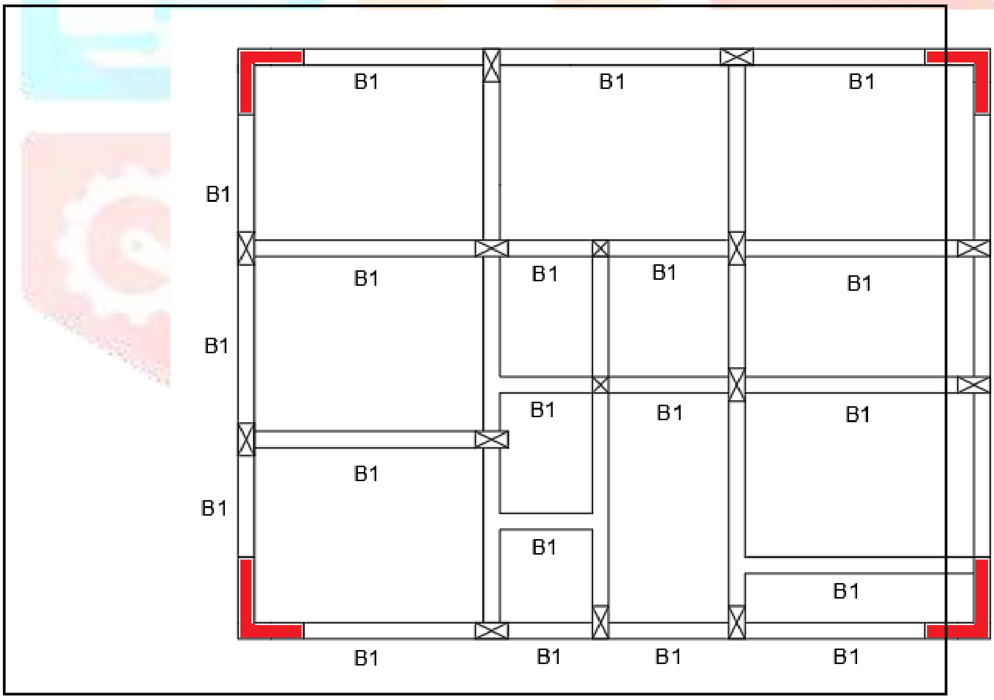


Figure 10: Shear Wall at Corner along Periphery of Structure in L Shape plan in AutoCadd

7. RESULTS AND DISCUSSION

7.1 Equivalent Static Method:

Table 1: Lateral Displacement along X-Direction

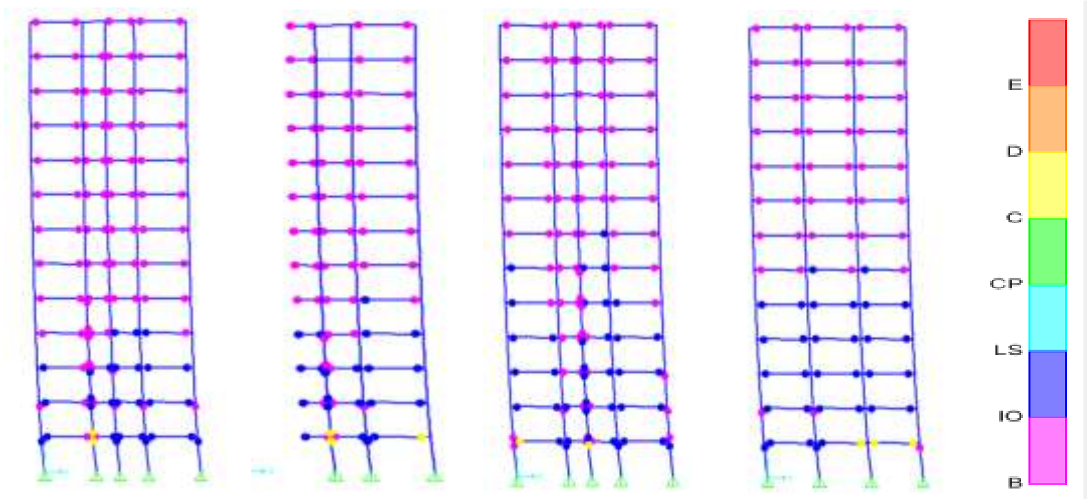
Storey No.	Elevation (m)	Lateral Displacement (mm)			
		CASE 1	CASE 2	CASE 3	CASE 4
13	39	17.1	21.3	14	14.7
12	36	16.6	20.3	13.2	14
11	33	16	19.1	12.3	13.2
10	30	15.2	17.7	11.2	12.2
9	27	14.1	16.1	10	11
8	24	13	14.4	8.8	9.8
7	21	11.7	12.5	7.5	8.4
6	18	10.3	10.6	6.1	6.9
5	15	8.9	8.7	4.7	5.5
4	12	7.4	6.7	3.4	4
3	9	5.9	4.8	2.2	2.6
2	6	4.3	3	1.1	1.4
1	3	2.5	1.5	0.3	0.4
Base	0	0	0	0	0

Table 2: Lateral Displacement along Y-Direction

Storey No.	Elevation (m)	Lateral Displacement (mm)			
		CASE 1	CASE 2	CASE 3	CASE 4
13	39	17	15.4	14.3	14.7
12	36	16.5	14.4	13.5	13.8
11	33	15.8	13.3	12.5	12.9
10	30	14.9	12.1	11.5	11.8
9	27	13.8	10.8	10.2	10.7
8	24	12.6	9.4	8.9	9.4
7	21	11.3	8	7.6	8
6	18	10	6.5	6.2	6.6
5	15	8.5	5.1	4.8	5.2
4	12	7.1	3.7	3.4	3.7
3	9	5.6	2.5	2.2	2.4
2	6	4.1	1.4	1.1	1.3
1	3	2.4	0.6	0.3	0.4
Base	0	0	0	0	0

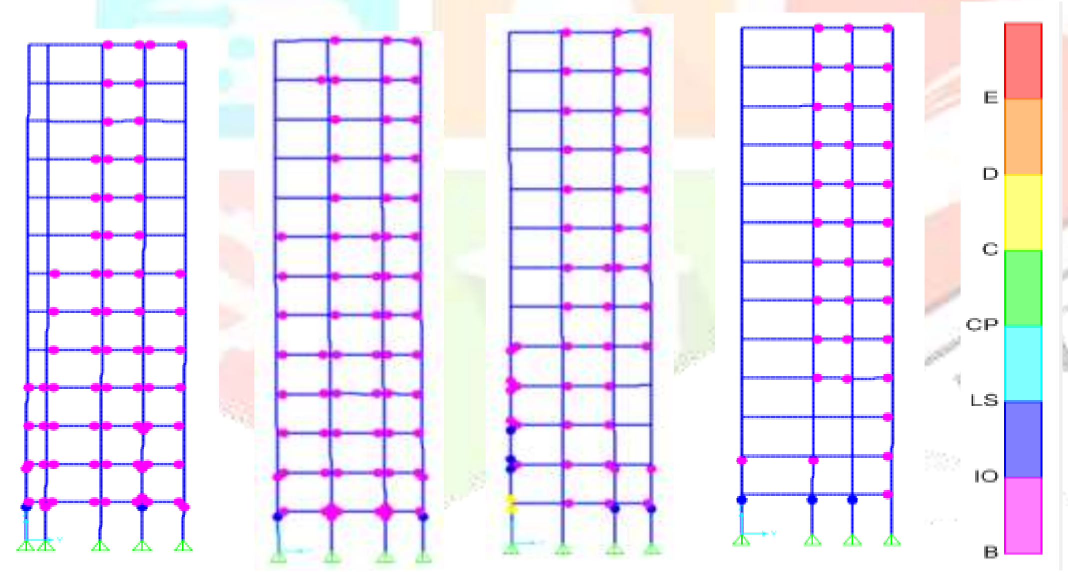
7.2 Push Over Analysis Method:

7.2.1 Hinging Mechanism



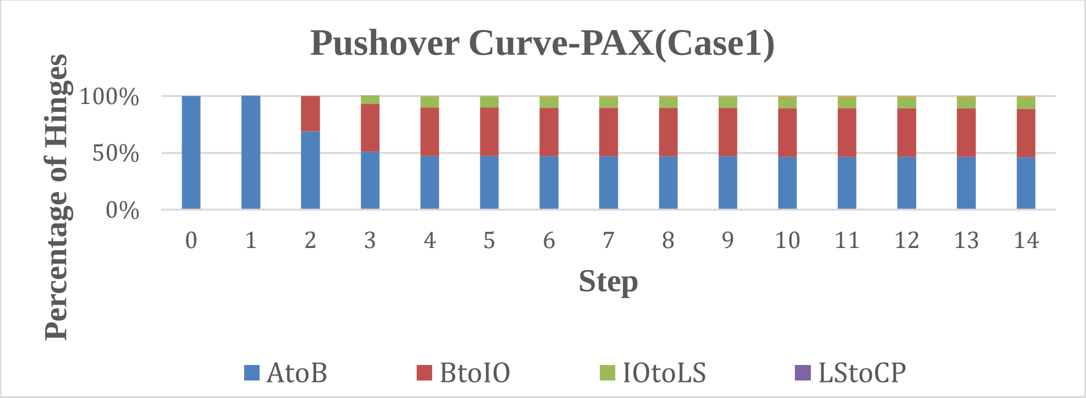
@ 0m @ 4.5m @ 7m @ 9.5m

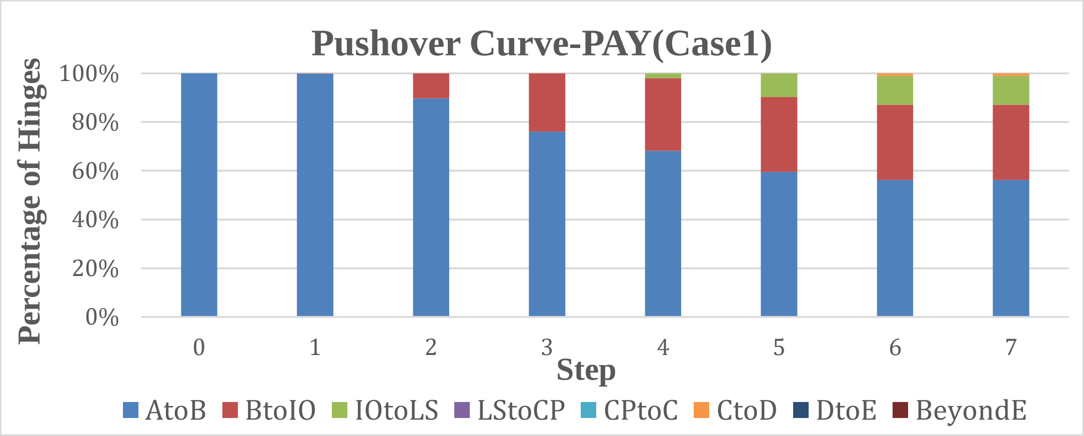
Figure 11: Hinging mechanism in X-Z direction at Step 10 (For Case-1)

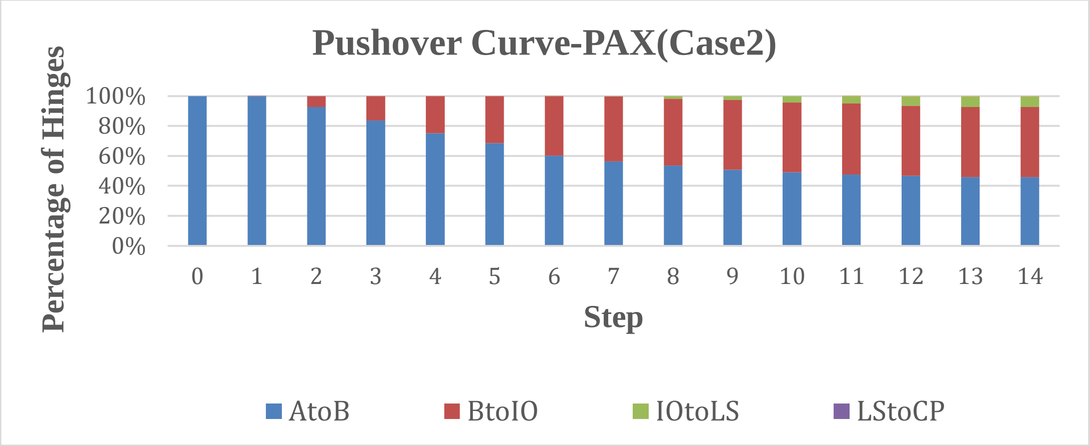


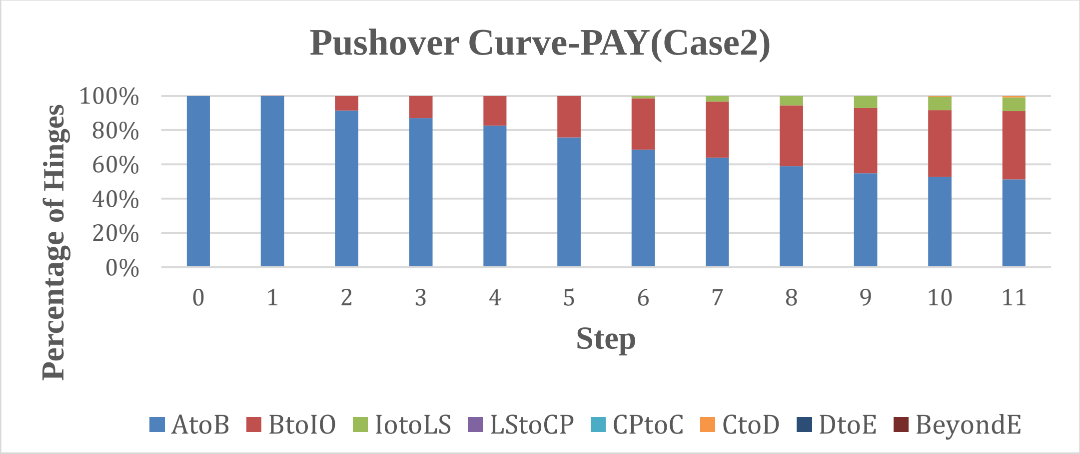
@ 0m @ 4.5m @ 6.5m @ 13.5m

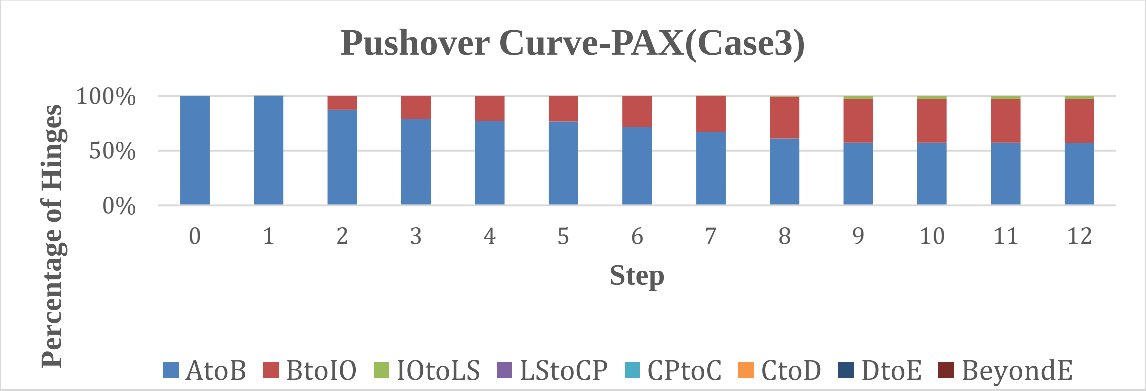
Figure 12: Hinging mechanism in Y-Z direction at Step 10 (For Case-1)

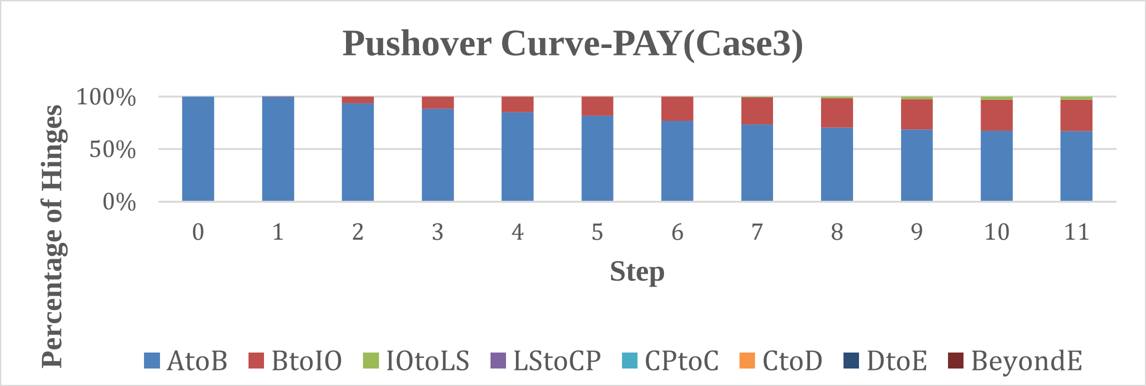


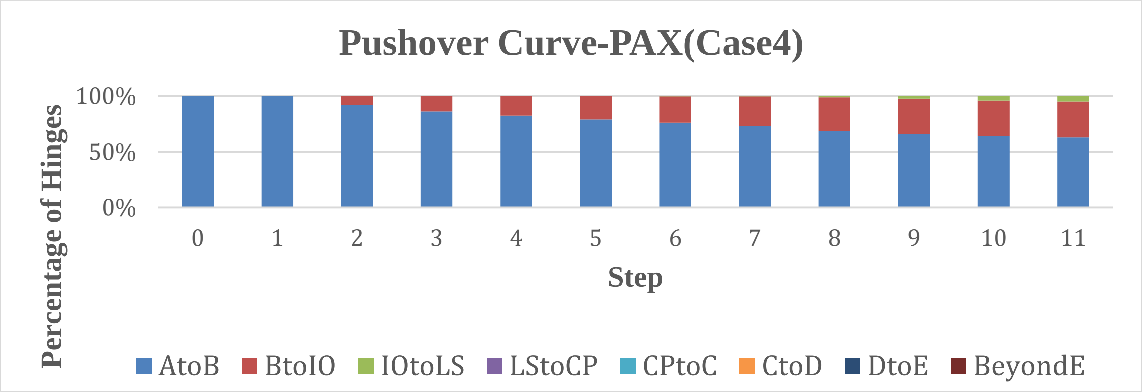

Pushover Curve-PAY(Case1)
Percentage of Hinges
100%
80%
60%
40%
20%
0%
0
1
2
3
4
5
6
7
Step
AtoB
BtoIO
IOtoLS
LStoCP
CPtoC
CtoD
DtoE
BeyondE

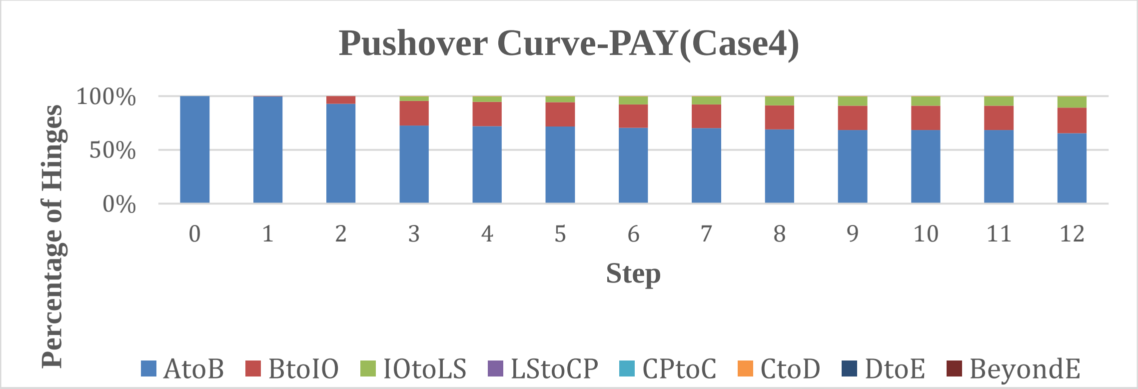

Pushover Curve-PAX(Case2)
Percentage of Hinges
100%
80%
60%
40%
20%
0%
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Step
AtoB
BtoIO
IOtoLS
LStoCP


Pushover Curve-PAY(Case2)
Percentage of Hinges
100%
80%
60%
40%
20%
0%
0
1
2
3
4
5
6
7
8
9
10
11
Step
AtoB
BtoIO
IotoLS
LStoCP
CPtoC
CtoD
DtoE
BeyondE


Pushover Curve-PAX(Case3)
Percentage of Hinges
100%
50%
0%
0
1
2
3
4
5
6
7
8
9
10
11
12
Step
AtoB
BtoIO
IOtoLS
LStoCP
CPtoC
CtoD
DtoE
BeyondE







8. CONCLUSIONS

The performance of reinforced concrete frames was investigated using the pushover Analysis. Based on the above results and observations the following conclusions are drawn.

1) The frame is modeled with default and user-defined hinges properties to study the possible differences in the results of pushover analysis.

2) From table 1 and 2, the lateral displacement in X- and Y-Direction for different cases we get, a significant variation is observed. Case 3 gives minimum lateral displacements in both X and Y direction.

3) Hinging mechanism in case 3, no hinge after LS.

4) The behavior of properly detailed reinforced concrete frame building is adequate as Indicated by the intersection of the demand and capacity curves and the distribution of Hinges in the beams and the columns. Most of the hinges developed in the beams and few in the columns but with limited damage

5) The results obtained in terms of demand, capacity and plastic hinges gives an insight into the real behavior of structures.

6) If the capacity and demand curve are intersected in between immediate occupancy and life safety. Such that building experiences moderate damage when subjected to pushover load.

7) It would be desirable to study more cases before reaching definite conclusions about the behavior of reinforced concrete frame buildings.

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