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Design Simulation of Irregular Shape RC Structure for Progressive Collapse using Non-Linear Analysis

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Abstract: In the past few years, the requisite to plan high-rise buildings in reinforced concrete structures due to aggrandize in population, so the structure is designed based on structural reliability theory to assure their safety. Over time, structures undergo unintended acts, both natural and man-made, leading to damage or failure. The "Progressive Collapse Analysis of Building" studies this type of failure. When a vertical load-bearing part is removed due to a man-made or natural hazard, the building's weight is transferred to adjacent columns, causing the failure of adjacent members and ultimately a partial or total breakdown of the structure.

This study analyses five 15-story RC Framed Structure models, one regular framed structure, and four regular framed structures with vertical member removal. Non-liner static analysis is performed using SAP2000.V23, applying load according to GSA guidelines 2003. The building plan has trapezoidal geometry with 7x10 bays in zone V. The study considers demand capacity value, maximum base-shears v/s displacement, and hinge formation. The building has a high potential for progressive collapse, and the structure behavior for this collapse is compared in parametric studies. comparison of demand capacity value, Base shear vs Maximum Storey Displacements. This study aims to minimize failure due to external forces on a structure through analysis and design simulation, preventing minimal loss of life and structure.

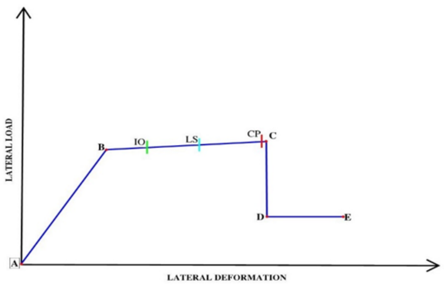
Index term: Progressive collapse, Column Removal, Static linear analysis, Pushover analysis, GSA.

I. INRODUCTION

Progressive collapse is the phrase used to describe the eventual breakdown of a structure or the proportionately huge failure of a piece of a structure because of local failure spreading from element to element across the structure. Progressive collapse in the building or any other structure is mainly occurring due to the less capacity of frames / structure as compared to the external forces coming to that, while studying the aspect of a structure building there are very safety concerns which we considered in our life to ensure the lives reside in that building should be safe when sudden collapse happen. the structure of our building is strong and durable enough so it can bear the unplanned unintended acts, resulting in localized damage or failure, as a result if the remaining structure system is unable to absorb the internal forces variation induces by the initial failure, the structure as a whole or a portion is collapse which cause the life damage.

Nonlinear Pushover Analysis is a structural engineering method used to evaluate the behavior of buildings and structures under lateral loads, such as those from earthquakes or strong winds. Here is a simplified explanation:

Firstly, Understanding Structural Response of the building by pushing it for some lateral forces with its Nonlinear Behavior with assessing safety of the structure and lastly make some design improvement if needed.



IO-IMIDIATE OCCUPANCY
LS-LIFE SAFTY
CP-COLLAPSE PREVENTION

Figure 1 performance based hinges formation graph

II. LITERATURE REVIEW

Akash Rajoria, Ravindra Nagar (2023) [1] A study using a finite element approach simulates building collapse behaviour in hilly areas. Results show that a flat slab building in mountainous terrain may be susceptible to progressive collapse if a key structural element is removed. Strategies like steel bracing systems can reduce this risk. The findings can be applied to design and construct more resilient structures, reducing the likelihood of progressive collapse, and ensuring occupant safety.

Pujari, A.B., Sangle, K.K. (2023) [2] The study evaluated the vulnerability of three-dimensional special moment resistant frames with six bays at low, mid, and high rises using Indian Standard codes. Different analysis methods were used, including linear static analysis (LSA), non-linear static analysis (NLSA), linear dynamic analysis (LDA), and non-linear dynamic analysis (NLDA), using the Alternate Path Method (APM). Results showed minimal displacement and less vibration when the internal column was removed suddenly. The structure's height also significantly impacted the structure's behaviour.

Musavi-Z, M. & Sheidaii, M.R. (2023) [3] The study evaluated the progressive collapse performance of reinforced steel moment frames using local strengthening techniques. Results indicated that using suggested beam strengthening methods increased steel moment frame progressive collapse resistance and created a more appropriate seismic response. The approach can be applied to moment-resisting frames of various geometries and heights.

Pawan Kumar et al (2022) [4] This study uses non-linear dynamic analysis and linear static analysis to analyze vertical displacement responses in RC buildings. ETABS software is used for removing internal, penultimate, corner, and edge columns. Results show that all damage scenarios have a safe progressive collapse demand value at the bottom end of adjacent columns, but the top end is dangerous. The penultimate column removal case with the highest PCD values is the most critical.

Abhishek Maheshwaram et al (2022) [5] The study examined a ten-story RC building with square and circular plan geometry, designed for loads from gravity, wind, and earthquakes, and considering progressive collapse scenarios. The results showed that the circular plan building performed 10%-20% better than the square plan building under various loading circumstances, indicating that the structural elements achieve alternate equilibrium of the load path.

C. K. Mohamed Saqlain & Y. K. Guruprasad et al (2022) [6] The paper uses nonlinear pushover analysis to evaluate the stability of a nine-story RC hospital building with irregular plans. It assesses the plastic hinges on the structural members, evaluating lateral storey displacements and critical zones. The analysis considers global and local retrofits to find a safe solution to reduce collapse likelihood, reduce plastic hinge formation, and restore structure stability under earthquake conditions.

Vigneshwaran Rajendran et al (2022) [7] This work examines the performance of a 10-story structure with 5 bays and a 4m span. Pushover analysis is performed using E-tabs software, and buildings are designed in accordance with Indian Standard code. Columns are eliminated in accordance with GSA regulations. Frames are examined for seismic zones using non-linear static analysis, and the critical column is determined using the axial load carrying capability of the frame.

M. Vinay et al (2022) [8] This research examines the potential of a ten-story reinforced concrete frame building to endure progressive collapse using SAP2000 version 20 modelling. It examines column removal scenarios, demand capacity ratios, and steel requirements for failed structural parts. The findings can be used to enhance the robustness of reinforced concrete core-wall buildings and design a nonlinear numerical model for studying progressive collapse behaviour in high-rise buildings.

Rohini Nagargoje et al (2022) [9] In response to damage caused by seismic actions, the purpose of this study is to examine the progressive collapse potential of steel moment-resisting and braced frames designed in accordance with Egyptian local standards—TABS CONNECTEDITION in accordance with Indian Standard codes—for four distinct cases following corner section evacuation conditions. Normal portions are removed one at a time, with planning and evaluation coming before collapse. The ultimate objective of this research on progressive collapse in buildings is to create better guidelines for building appraisal and design that structural engineers may utilize to stop collapse in both new and old buildings.

N. Parthasarathi et al (2022) [10] This study investigates the behaviour of a four-bay, three-story, two-dimensional RC frame under high temperatures and 50% working load. The experimental study uses a one-fifth scale model and a 1/5th scale version of the prototype model. The infilled frame expands by 1.02 mm, while the bare frame expands by 2.32 mm vertically at the middle column. At the third-floor level, failure occurs due to expansion caused by high temperature and 50% working load. The infilled frame has a 90.98% lower vertical displacement in the centre column compared to the naked frame.

III. METHODOLOGY

3.1 Overview

In this push over analysis, a G+15 RC framed structure with the seismic and gravity loads has been examined. In order to observe the non-linear behaviour of the structural member, the identified critical elements (columns) are first removed from their respective locations and non-linear static analysis is performed for each of the critical cases under consideration. In this research work, the applied load is gradually increased until an extreme load or displacement is reached.

3.2 Methodology Steps

There is two-step process i.e. firstly the analysis is carried out to be linear, after define the pushover load cases and non-linear analysis is carried out.

- **Model Creation:** Define structure's geometry, materials, and supports in SAP2000.
- **Nonlinear Material Properties:** Specify nonlinear behaviour like yield strength and strain-hardening.
- **Nonlinear Geometric Properties:** Account for large deformations and initial imperfections.
- **Static Pushover Analysis Setup:** Set up incremental lateral loading with defined load patterns.
- **Pushover Load Pattern:** Create load pattern increments for gradual loading.
- **Pushover Analysis Parameters:** Define convergence criteria and control methods.
- **Running the Analysis:** Execute pushover analysis, monitoring convergence at each step.
- **Post-Processing and Results:** Analyse displacement profiles and capacity curves to assess performance.

Table 3.1-Building Specification

Type of Building	Residential building
Typical Storey Height	3m
Base Storey Height	3.5m
Concrete grade	M30
Density of RCC	25 KN/m^3
Density of Masonry	20 KN/m^3
Column size	600X600mm
Beam size	300x600mm
Slabs thickness	150mm, One way slab-150

Bottom support condition	Fixed
Dead load	Self-weight of section
Live load	IS875:2015(Part-2)
Seismic zone	V
Seismic zone factor (Z)	0.36
Importance factor (I)	1.2
Site type	Medium,ii
Response reduction (R)	5

3.2.1 SAP Modelling

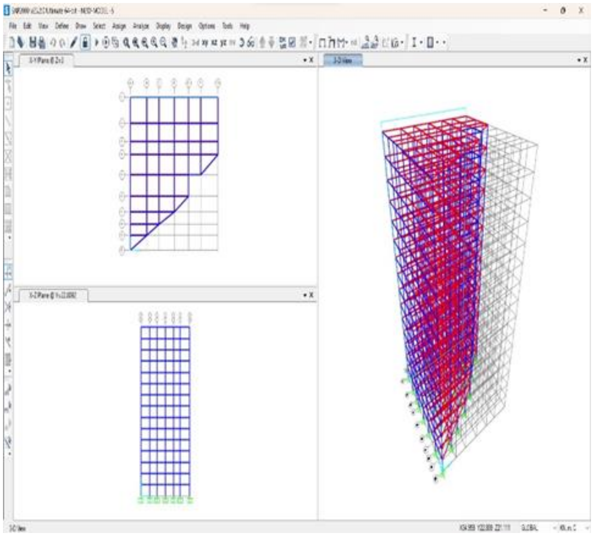


Figure 2. MODEL-1 No column removal

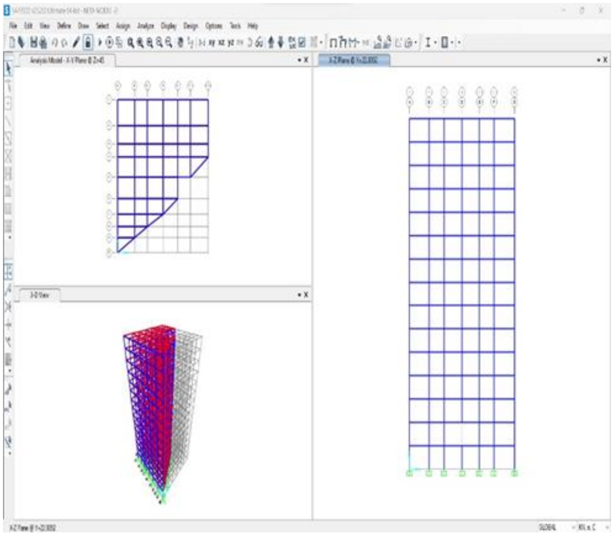


Figure 3. MODEL-2 Column removed from shorter side

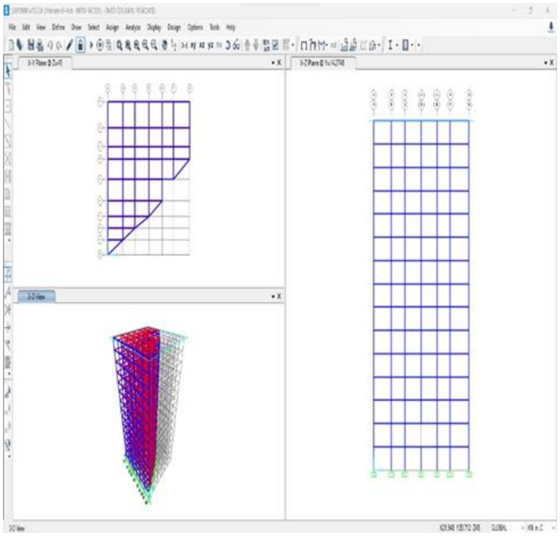


Figure 4. MODEL-3 Column removed from middle

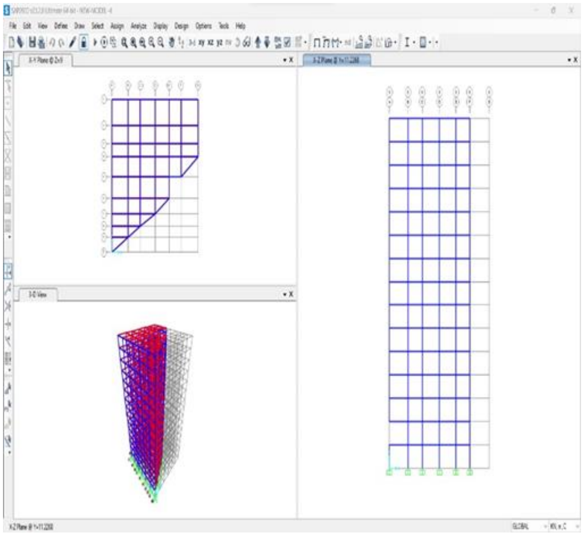


Figure 5. MODEL-4 Column removed from longer side

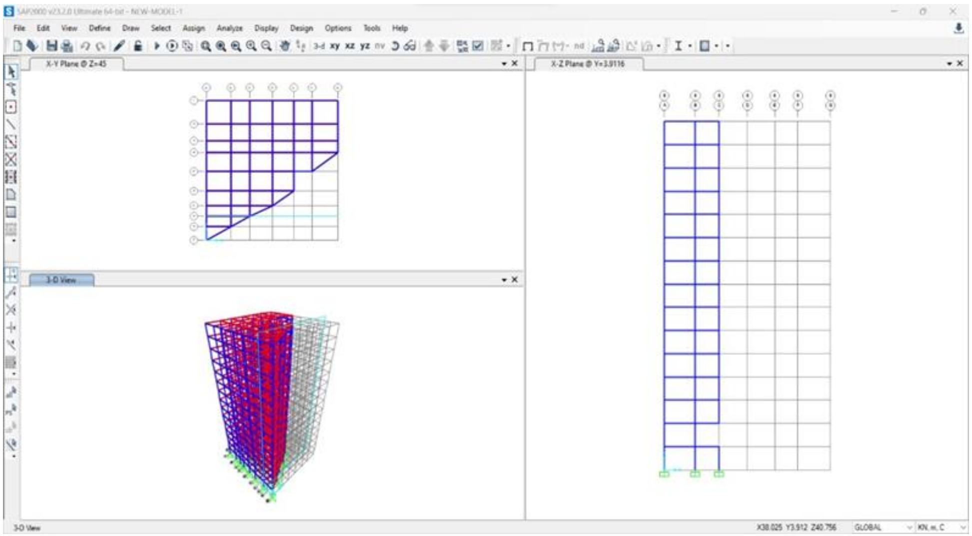


Figure 6. MODEL-5 Column removed from inclined side

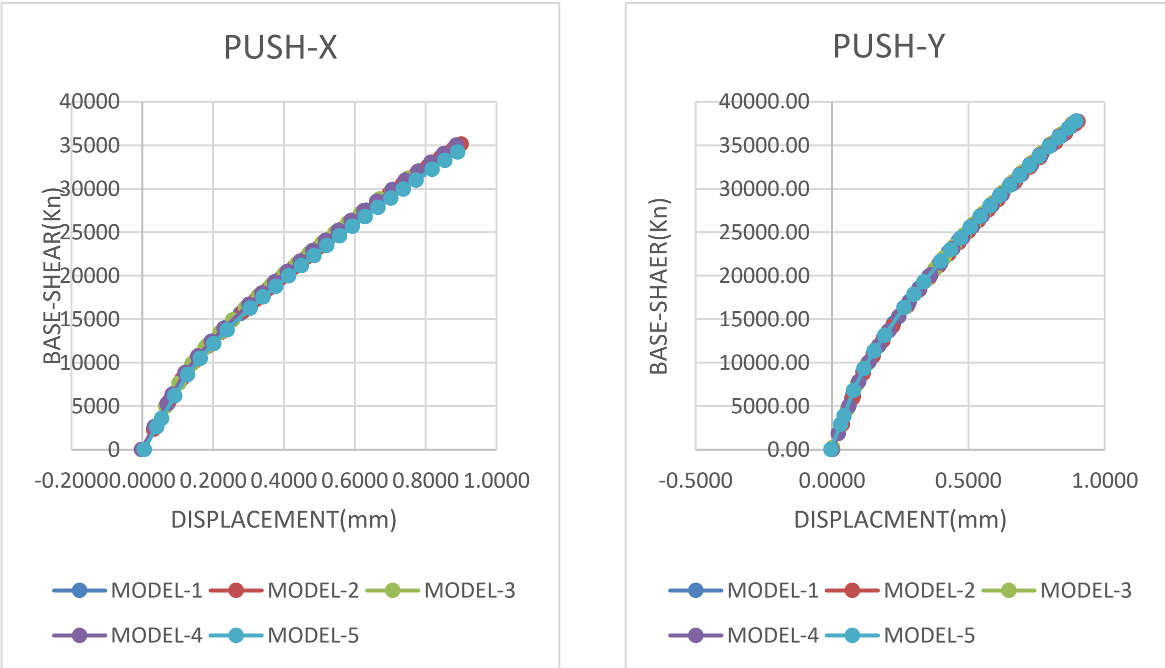
IV. RESULT AND DISCUSSION

In this section analysis of a Models and their respective parameter are compared for different findings. All parameter is collected from all Values, graph and table are shown to compare to their results and by studies these graphs and tables result are obtained.

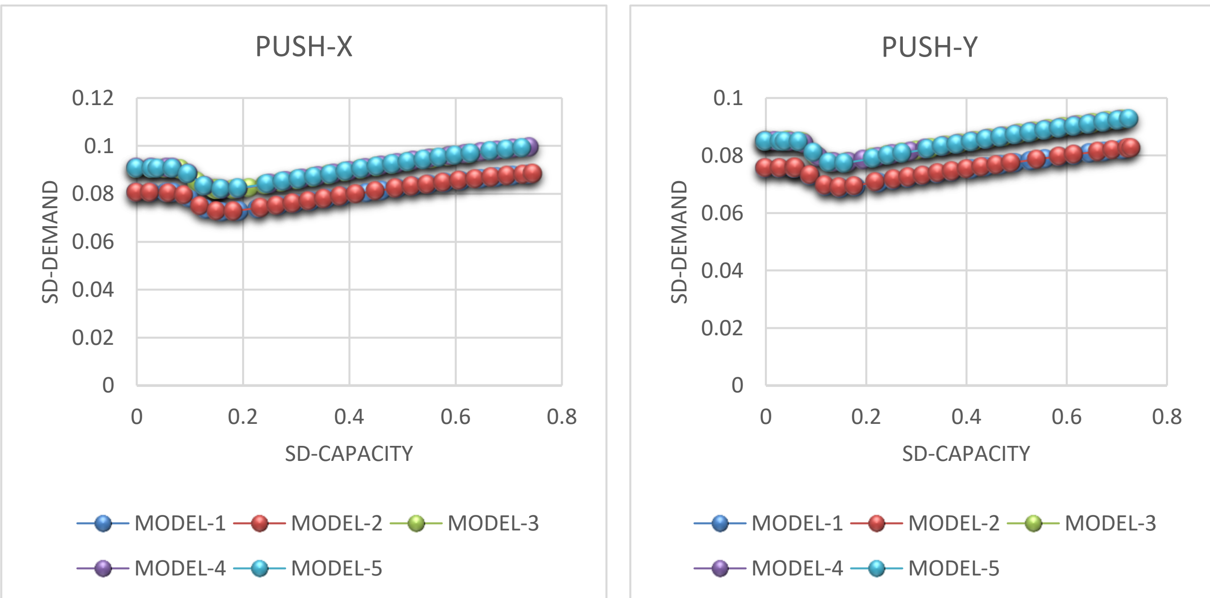
In this analysis and result chapter we conclude the result in the form of tables and graphs

The graph for each model for

- Base Shear v/s Displacements
- ATC-40 Capacity Demand Curve
- Hinges formation in Models



Graph 1. BASE-SHEAR V/S DISPLACEMENT IN PUSH-X & PUSH-Y



Graph 3. DEMAND CAPACITY CURVE PUSH-X & PUSH-Y

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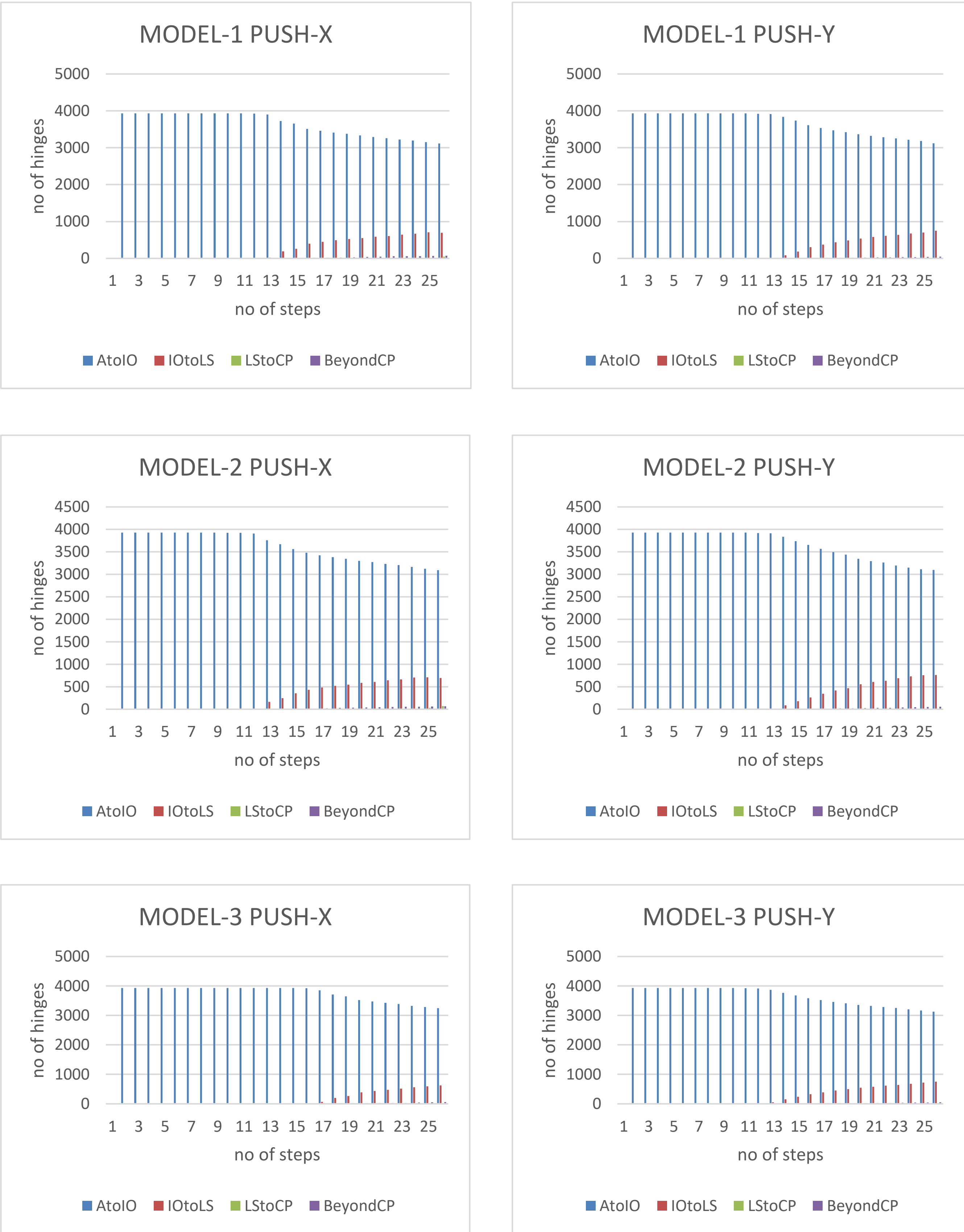

Graphs 3,4,5. HINGES RESULT FOR MODELS IN BOTH DIRECTION

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Graphs 6,7. HINGES RESULT FOR MODELS IN BOTH DIRECTION

V. CONCLUSION AND FUTURE SCOPE

5.1 Conclusion

In the conclusion of our dissertation, we found of many aspects which we are considered in our analysis of the G+15 storey pushover analysis with the help of SAP2000, our finding concludes that the structure having plan irregularity or unsymmetric plan of a building show the following result while analysis for G+15 storey building for different findings.
For base-shear v/s displacement graph, we found that the model-3 of our study gives the less displacement with regards of maximum base shear value or steps to be followed from all models and findings.
Here, hinges which are formed due to lateral forces shows the deformations occurs and the model 3 created less hinges by means it is more susceptible to progressive collapse when removal of column.
For finding demand capacity value we conclude that the maximum demanded displacement is 0.900m by that the capacity value should be more, in that context we find model 3 shows that it has the maximum capacity to resist the demand.

5.2 Future scope

- The geometry should be changes or may be more complex than in this study.
- The Storey height is more than fifteen storey structure.
- Storey Drift vs Base shear is finding in high rise structure.
- Dynamic analysis will be used to findings progressive collapse of structure.
- Target displacement and performance point shall be considered
- The Include of Vertical as well as lateral load combination will be changed.

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