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Non-Linear Static Response of Reinforced Concrete Building with Irregularities

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Abstract: - Structural systems like plan asymmetry is mostly seen in modern multi-storey constructions in urban areas. In the present study, the behavior of G+5 storied reinforced concrete frame buildings having irregularities confirming to IS 1893 (Part 1), 2016 subjected to an earthquake such as, re-entrant corner and diaphragm discontinuity located in seismic zone V is analyzed under non-static response pushover analysis using SAP2000 v21 software. The main objective of the study is to carry out the performance-based analysis-pushover analysis to obtain performance levels of asymmetric buildings for the future earthquakes and to understand different irregularity. Different types of model such as R1, R2 for re-entrant corner and D1, D2 for diaphragm discontinuity analyzed in the study. The various parameters like capacity spectrum curve, performance point and roof displacement of different models are considered for comparison. It is observed that the model with diaphragm discontinuity has more load carrying capacity than the model with re-entrant corner. Further it is observed that asymmetric model has different displacement value in both direction while in symmetric model, displacement values are same.
Keywords: - Diaphragm discontinuity, Load carrying capacity, Pushover analysis, Re-entrant corner.

I. INTRODUCTION

Many buildings in the present scenario have irregular configurations both in plan and elevation, which in future may subject to devastating earthquakes hence it is necessary to identify the performance of the structures to withstand against disaster primarily due to earthquake. Irregularities are not avoidable in construction of buildings; however, the behavior of structures with these irregularities during earthquake needs to be studied so that adequate precautions can be taken. A detailed study of structural behaviors of the buildings with irregularities is essential for design and behavior in earthquake. Several related studies have focused on evaluating the response of “regular” structures. However, there is a lack of understanding of the seismic response of structure with irregularities. Therefore, a comprehensive evaluation of the effect of vertical and horizontal irregularities on the seismic demand of building structures is greatly needed. (Modakwar, Meshram, & Gawatre, 2014)

In this type of the irregular structure the static pushover analysis is becoming a popular tool for seismic performance evaluation of existing and new structures. The expectation is that the pushover analysis will provide adequate information on seismic demands imposed by the design ground motion on the structural system and its components. The recent advent of structural design for a particular level of earthquake performance, such as immediate post-earthquake occupancy, termed as performance-based earthquake engineering, has resulted in guidelines such as ATC-40, FEMA-356 and standards such as ASCE-41. Among the different types of analysis, pushover analysis comes forward because of its optimal accuracy, efficiency and ease of use. (Govind, Shetty, & Hegde, 2014)

Ahmed and Raza, (2014) investigated seismic vulnerability of RC building by considering plan irregularities using pushover analysis. In this study to find the most vulnerable building various analytical approaches are performed to identify the seismic demand in both linear and nonlinear way and the effect of different load patterns on the performance of various irregular buildings in pushover analysis. It was observed that the point displacement is more in diaphragm discontinuity model as there are openings in the building.

Siva Naveen, Nimmy Mariam Abraham, S.D Anitha Kumari (2018) has investigated 9 storeyed building by incorporating irregularities in both plan and elevation. They have prepared 34 models with single irregularity and 20 with combination of irregularities. It was concluded that in single irregularities, stiffness irregularity found maximum influence on the response and the combination of stiffness and vertical geometric irregularities has shown maximum displacement response whereas the combination of re-entrant corner and vertical geometric irregularities has shown less displacement response.

II. NUMERICAL STUDY

In the present study, the pushover analysis for asymmetric RCC structure is carried out. The building considered is with different plan irregularity R1, R2 for re-entrant corner and D1, D2 for diaphragm discontinuity are prepared.

Table-1 Properties of Structure

Considered Parameters for Model R1, R2, D1, D2	
Plan dimension of structure = 24 m × 24 m	Floor finish load (typical floor) = 1.5 kN/m^2
No of bays in X-direction and Y-direction = 6	Floor finish load (terrace) = 2.5kN/m^2
Spacing of bays in X-direction and Y-direction = 4 m	Live load (typical floor) = 3 kN/m^2
Height of all typical floors = 3 m	Live load (terrace) = 1.5 kN/m^2
Size of columns = 450 × 450 mm	Zone = V
Size of beams = 230 × 600 mm	Response reduction factor = 5
Slab thickness = 150 mm	Type of soil = Medium

The model R1 has 50 % re-entrant corner in X-direction and 66.66 % re-entrant corner in Y-direction. The model R2 has 33.33 % re-entrant corner in both X direction and Y direction. So, both the model R1 and R2 are said to have re-entrant corner as their structural configuration in plan has a projection of size greater than 15 percent of its overall plan dimension in that direction. The model D1 has 22.22 % discontinuity, and model D2 has 11.11 % discontinuity.

The below figure 1 and figure 2 shows the plan view and 3-D model for R1 plan irregularity which is L-shape Building.

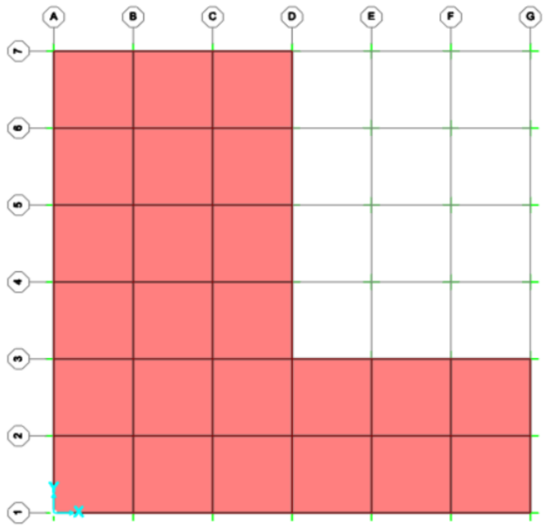

Fig -1: ***Plan View of Model R1***

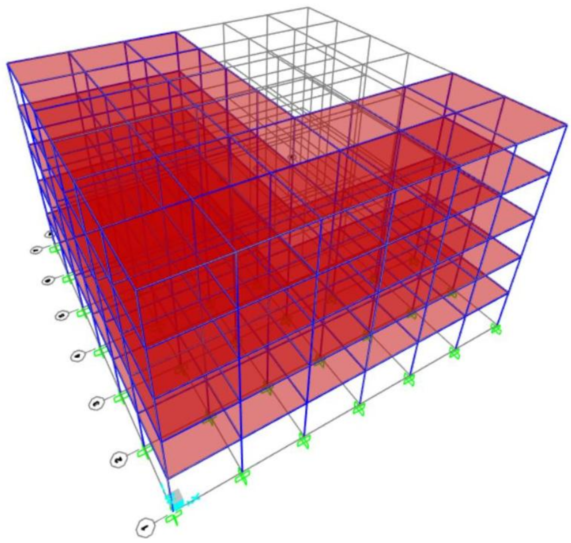

Fig -2: ***3-D View of Model R1***

The capacity spectrum curve obtained from nonlinear static analysis in X and Y direction is shown in figure-3 and figure 4. The ultimate lateral load carrying capacity of building at performance point is around 6140.52 KN and the corresponding roof displacement is 44 mm in X-direction and ultimate lateral load carrying capacity of building at performance point is around 6170.59 KN and the corresponding roof displacement is 47 mm in Y-direction.

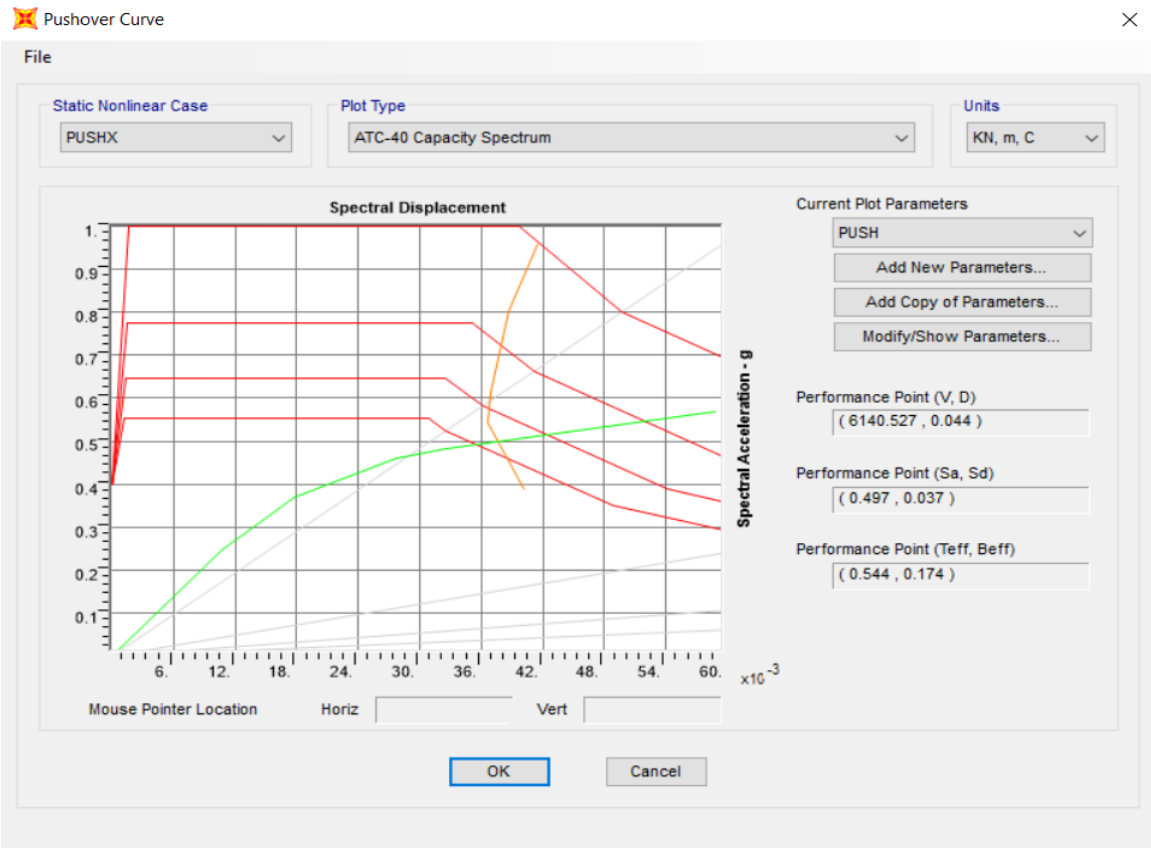

Fig-3: ***Capacity Spectrum Curve of Model R1 in X-direction***

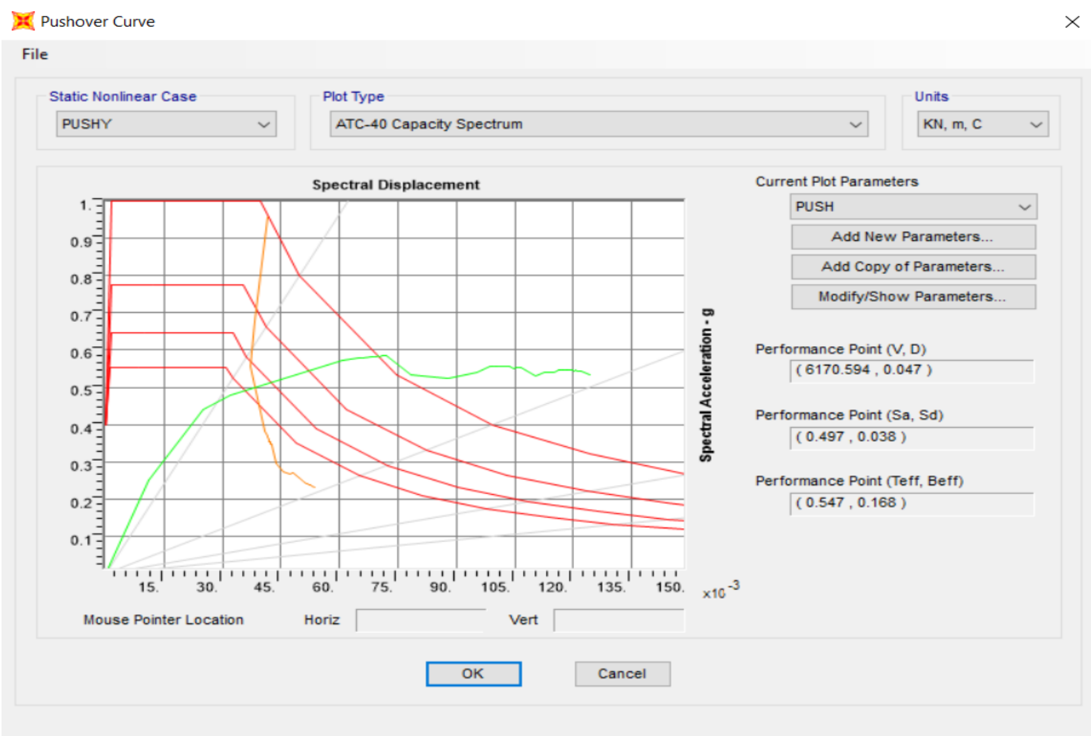

Fig-4: ***Capacity Spectrum Curve of Model R1 in Y-direction***

Below figure -5 shows the deform shape of the L-shape building. At performance point, out of 1940 assigned hinges, 1438 hinges were in linear range, 502 were in B – IO (Immediate Occupancy) range. Thus, the overall building performance is considered to be in IO level.

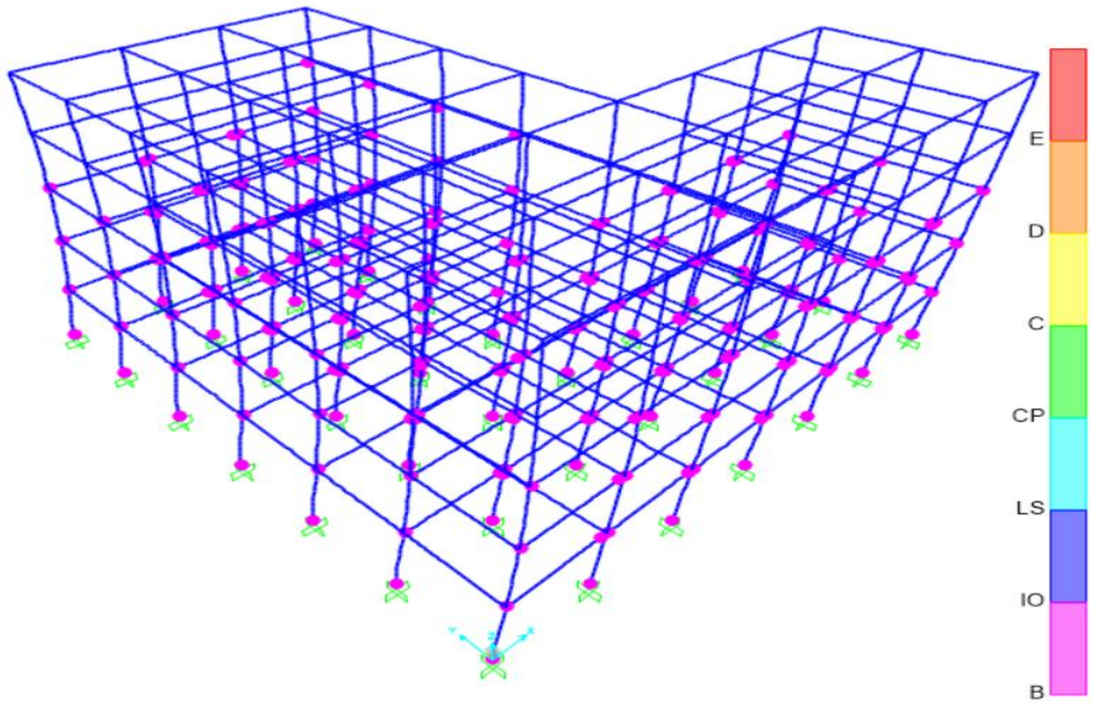

Fig-5: ***Deform Shape of Model R1***

The below figure-6 and figure 7 shows the plan view and 3-D model for R2 plan irregularity which is Plus-shape Building.

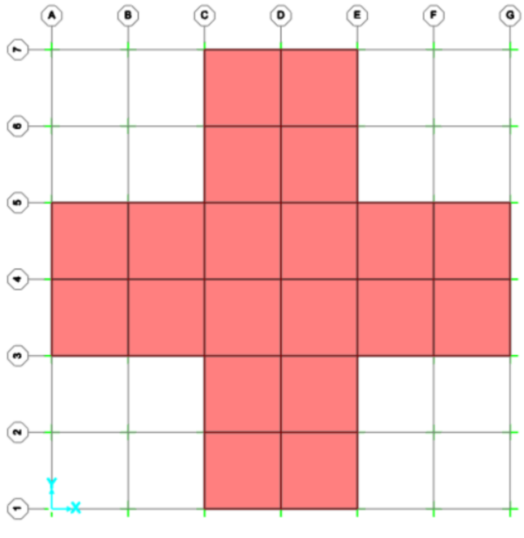

Fig -6: ***Plan View of Model R2***

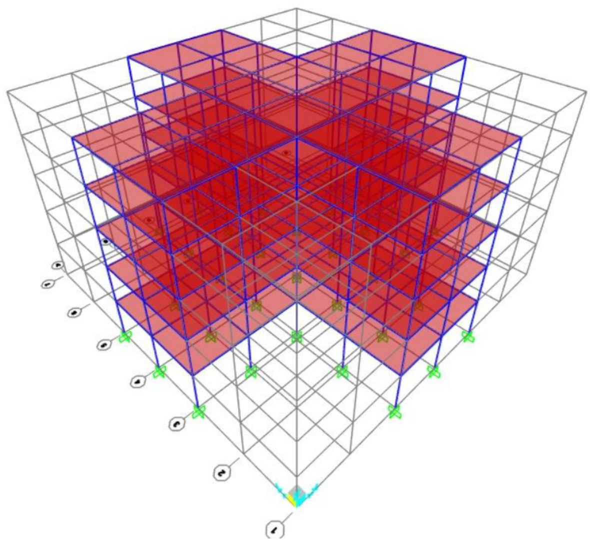

Fig -7: ***3-D View of Model R2***

The capacity spectrum curve obtained from nonlinear static analysis in X and Y direction is shown in figure-8 and figure 9. The ultimate lateral load carrying capacity of building at performance point is around 5311.94 KN and the corresponding roof displacement is 45 mm in X-direction and ultimate lateral load carrying capacity of building at performance point is around 5312.41 KN and the corresponding roof displacement is 45 mm in Y-direction.

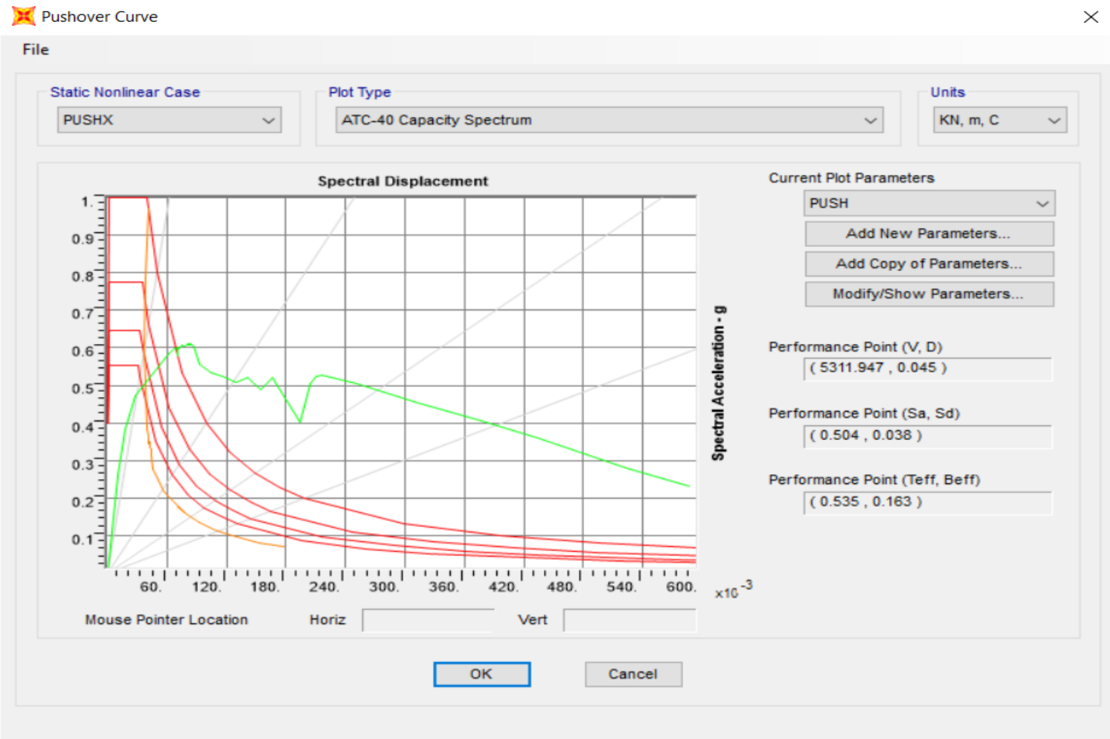

Fig-8: ***Capacity Spectrum Curve of Model R2 in X-direction***

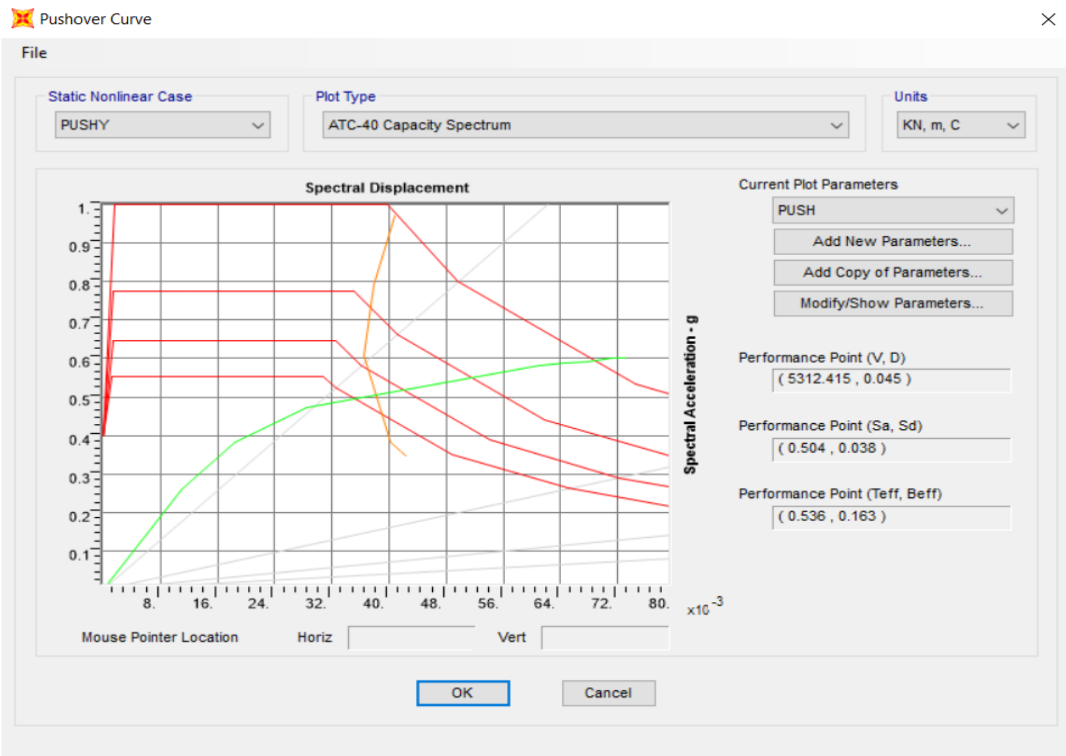

Fig-9: ***Capacity Spectrum Curve of Model R2 in Y-direction***

Below figure-10 shows the deform shape of the Plus-shape building. At performance point, out of 1700 assigned hinges, 1250 hinges were in linear range, 450 were in B – IO (Immediate Occupancy) range. Thus, the overall building performance is considered to be in IO level.

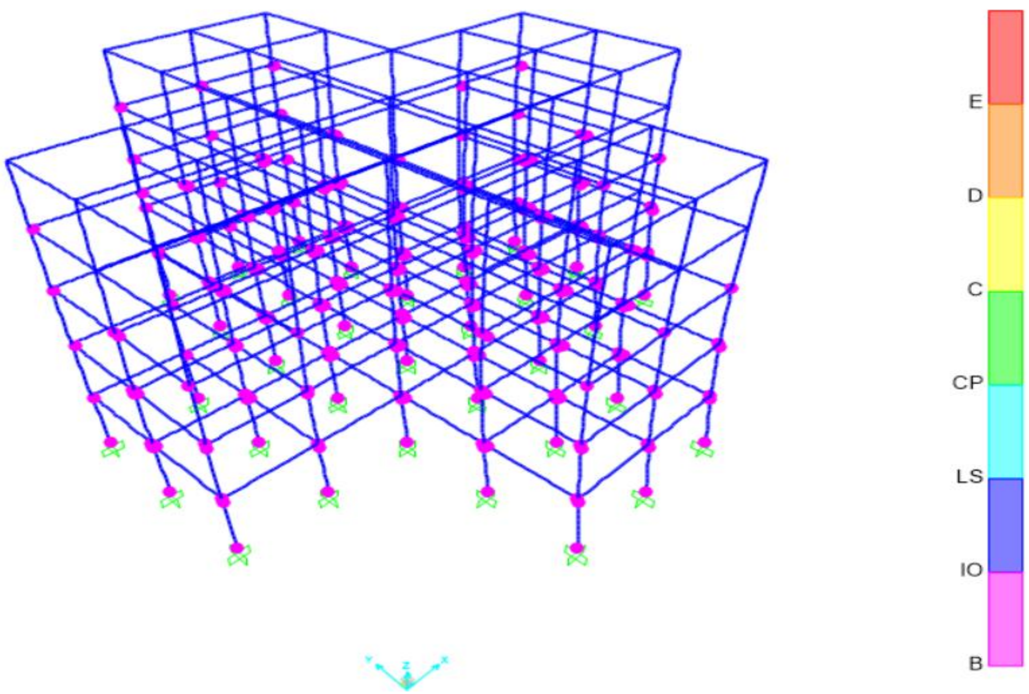

Fig-10: ***Deform Shape of Model R2***

The below figure-11 and figure 12 shows the plan view and 3-D model for D1 plan irregularity which has double cut-out at the center of the building.

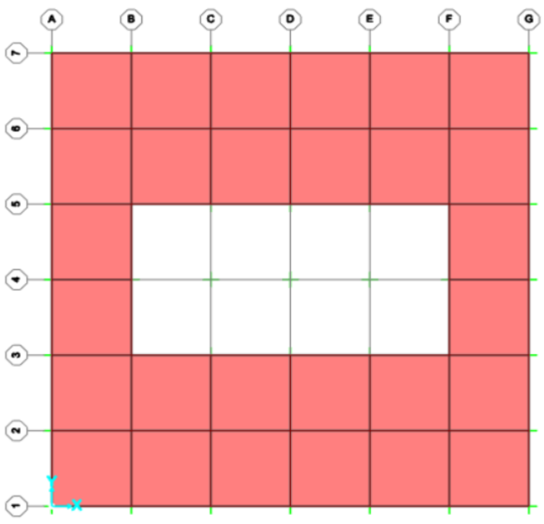

Fig -11: ***Plan View of Model D1***

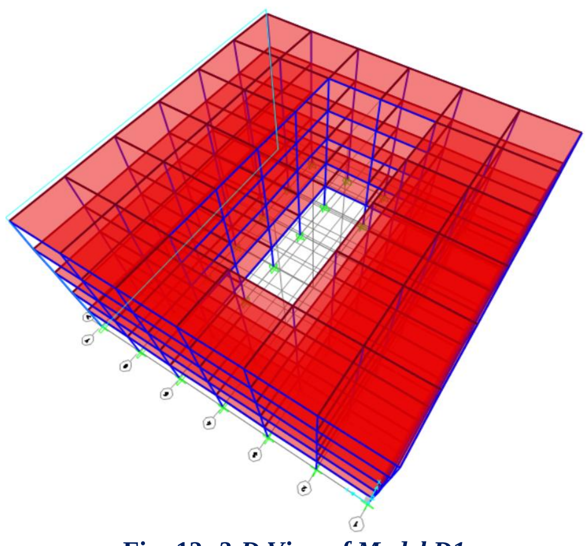

Fig -12: ***3-D View of Model D1***

The capacity spectrum curve obtained from nonlinear static analysis in X and Y direction is shown in figure-13 and figure 14. The ultimate lateral load carrying capacity of building at performance point is around 7520.72 KN and the corresponding roof displacement is 45 mm in X-direction and ultimate lateral load carrying capacity of building at performance point is around 7434.85 KN and the corresponding roof displacement is 46 mm in Y-direction.

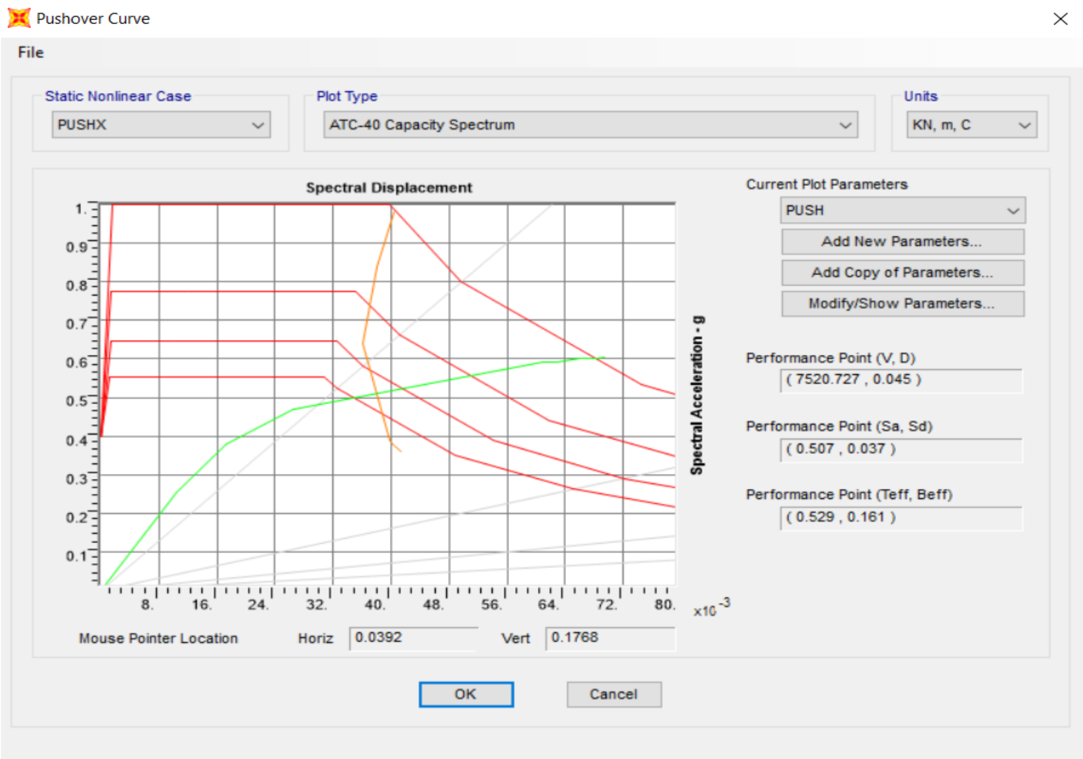

Fig-13: ***Capacity Spectrum Curve of Model D1 in X-direction***

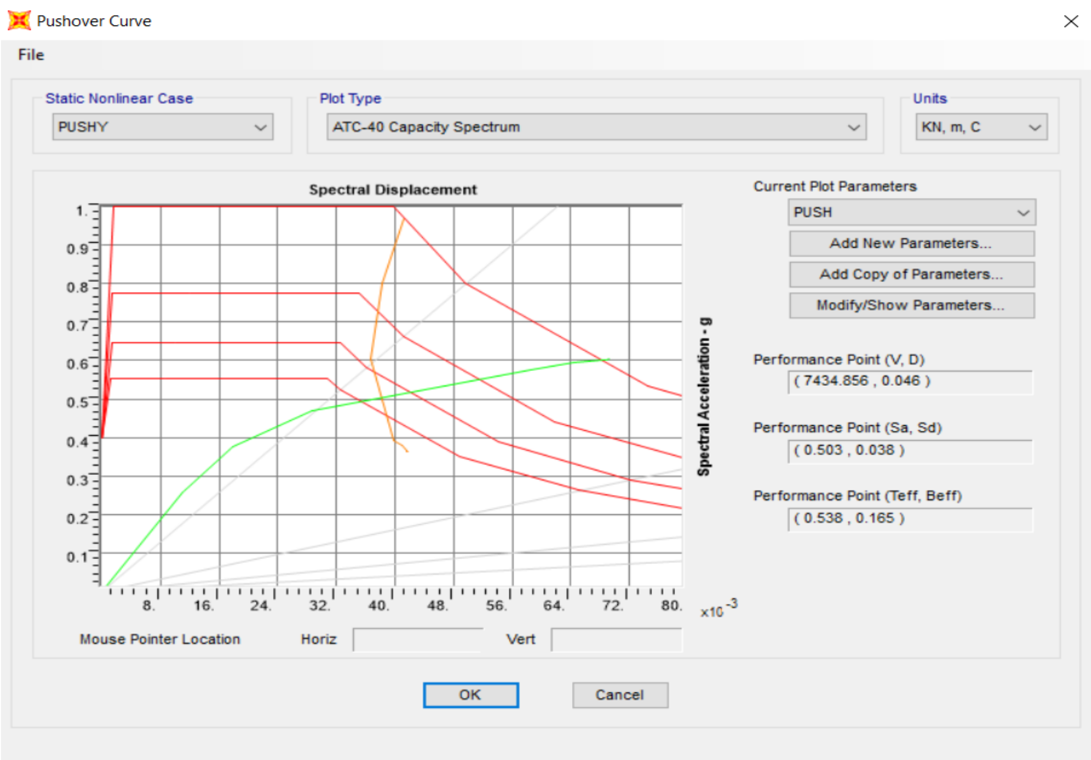

Fig-14: ***Capacity Spectrum Curve of Model D1 in Y-direction***

Below figure-15 shows the deform shape of the D1 building. At performance point, out of 2400 assigned hinges, 1740 hinges were in linear range, 660 were in B – IO (Immediate Occupancy) range. Thus, the overall building performance is considered to be in IO level.

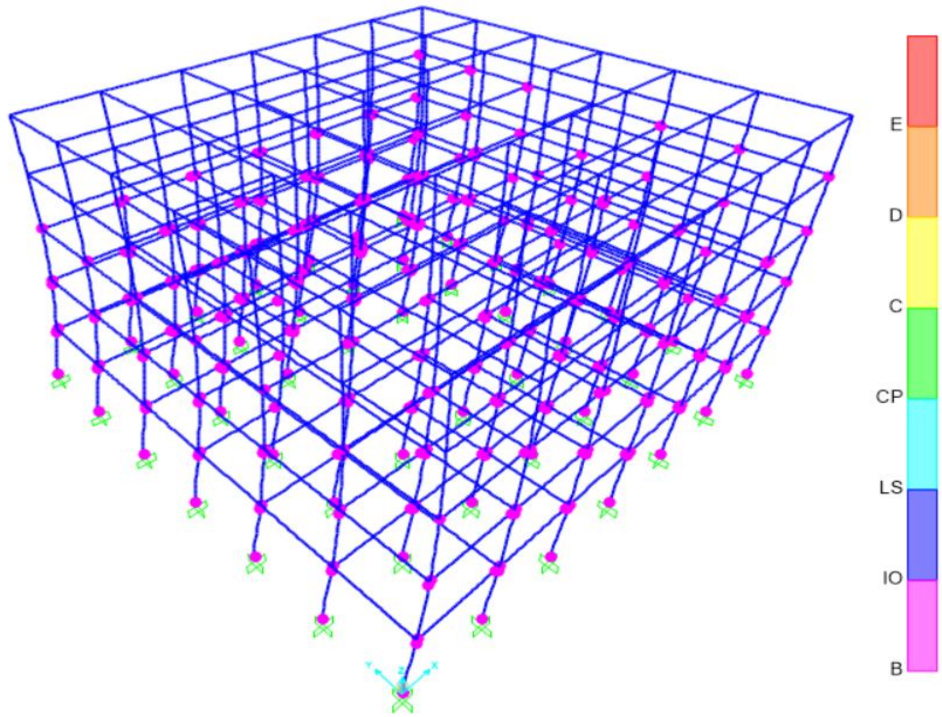

Fig-15: ***Deform Shape of D1 Model***

The below figure-16 and figure 17 shows the plan view and 3-D model for D2 plan irregularity which has single cut-out at the edge of the building.

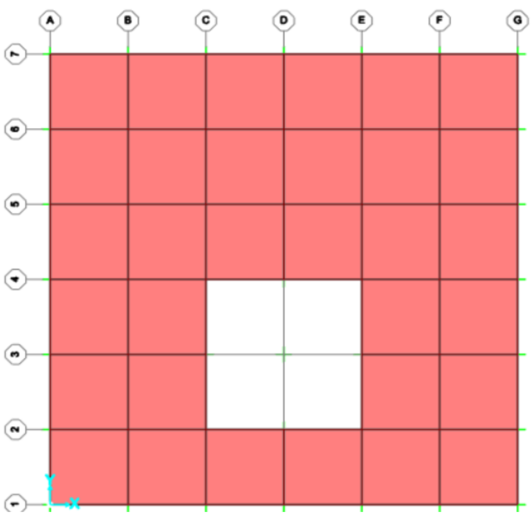

Fig -16: ***Plan View of Model D2***

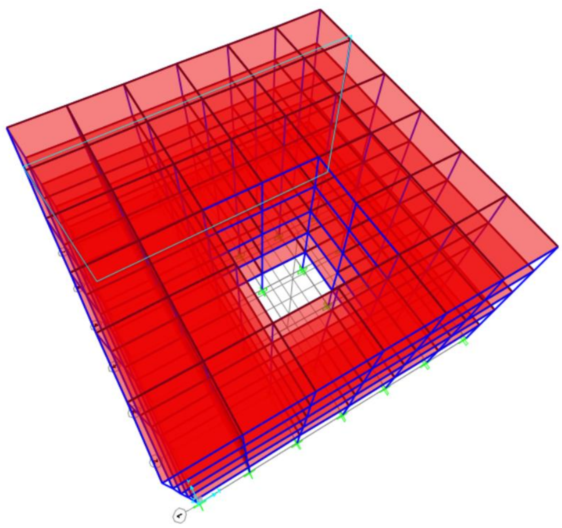

Fig -17: ***3-D View of Model D2***

The capacity spectrum curve obtained from nonlinear static analysis in X and Y direction is shown in figure-18 and figure 19. The ultimate lateral load carrying capacity of building at performance point is around 8102.60 KN and the corresponding roof displacement is 46 mm in X-direction and ultimate lateral load carrying capacity of building at performance point is around 8108.15 KN and the corresponding roof displacement is 46 mm in Y-direction.

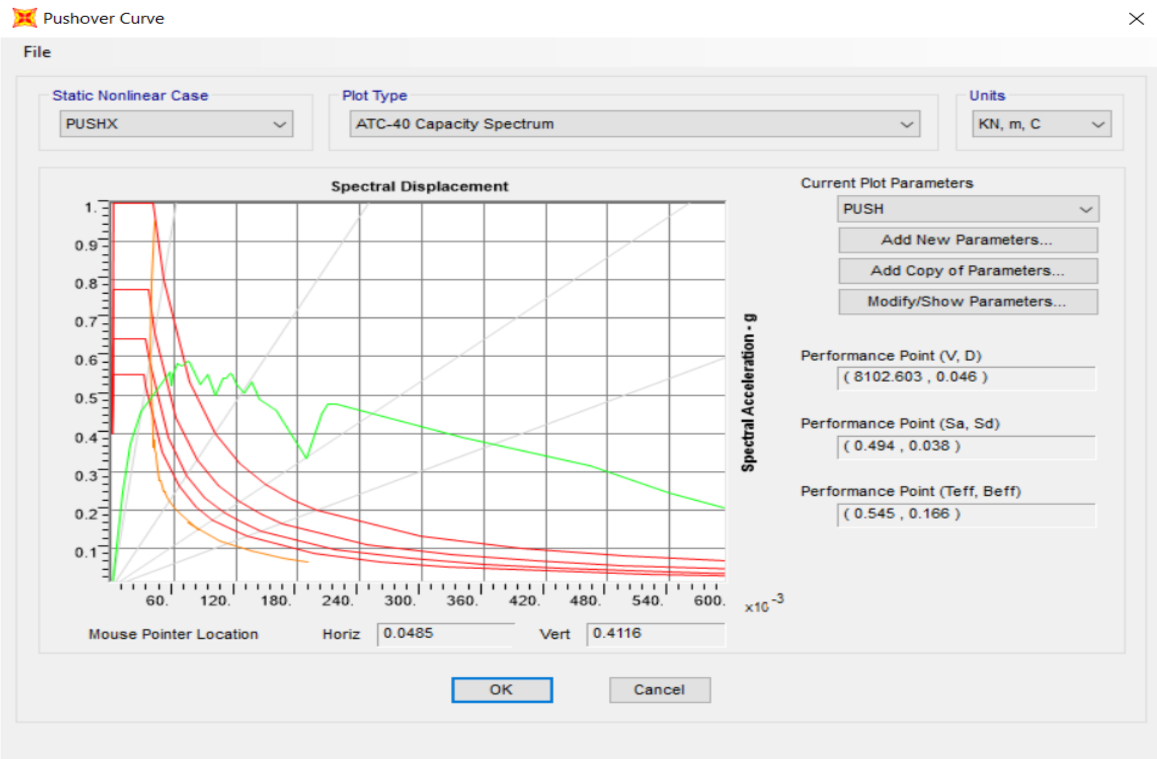

Fig -18: ***Capacity Spectrum Curve of Model D2 in X-direction***

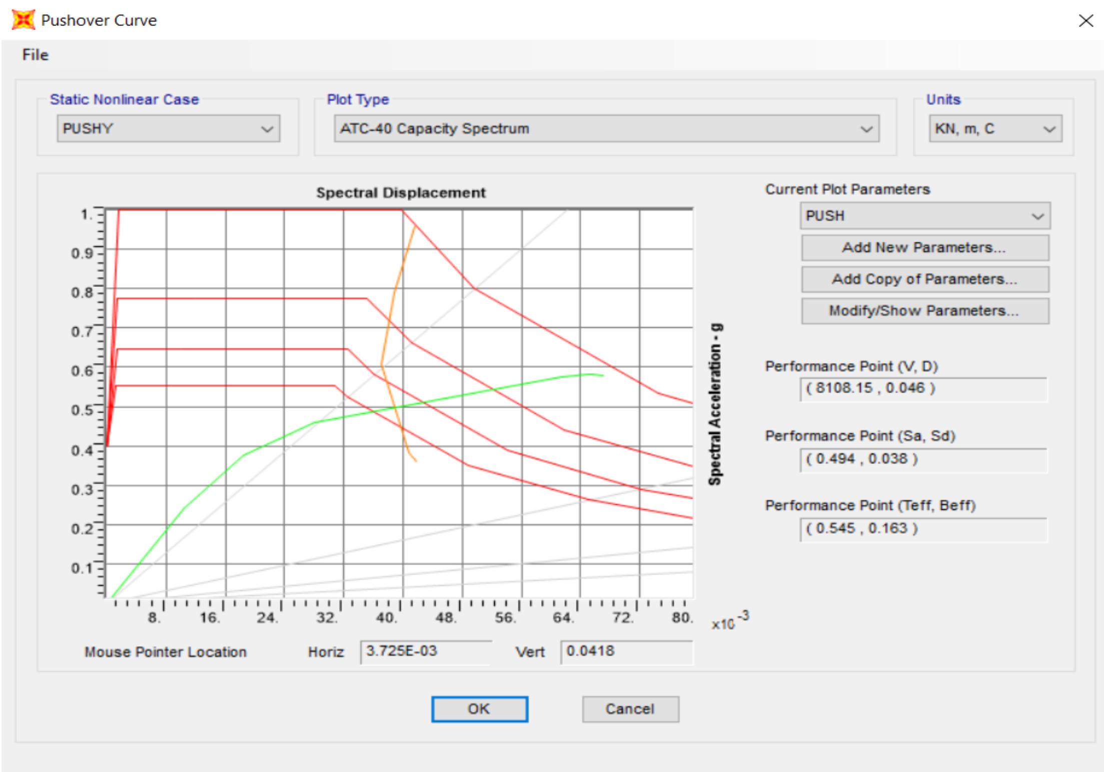

Fig -19: ***Capacity Spectrum Curve of Model D2 in Y-direction***

Below figure-20 shows the deform shape of the D2 building. At performance point, out of 2560 assigned hinges, 1852 hinges were in linear range, 708 were in B – IO (Immediate Occupancy) range. Thus, the overall building performance is considered to be in IO level.

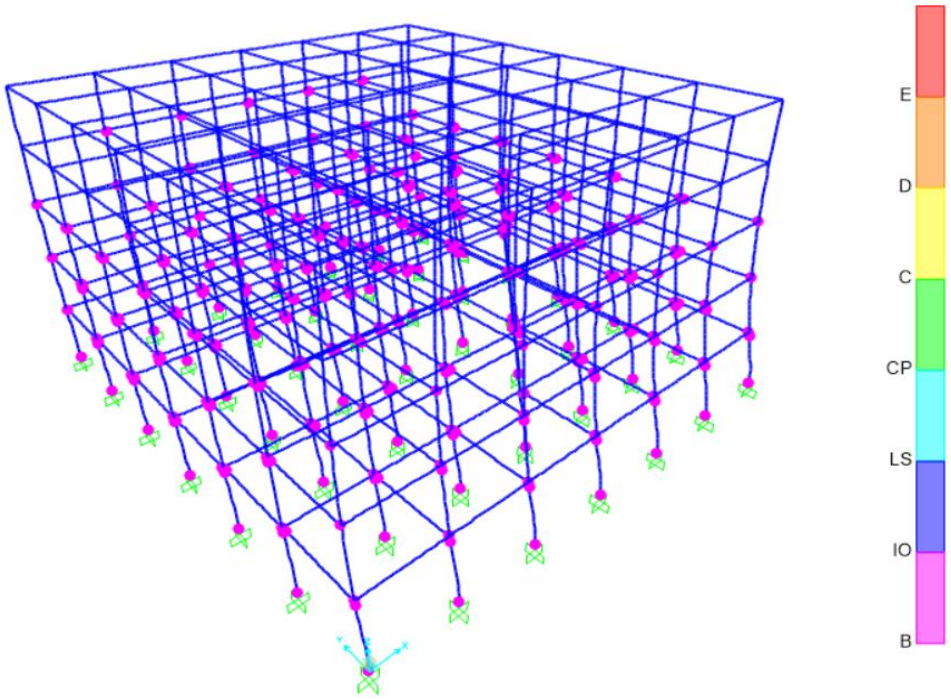

Fig -20: ***Deform Shape of D2 Model***

III. RESULTS AND DISCUSSIONS

The comparison of load carrying capacity of building and displacement at the performance point are shown in figures-21 and figure 22 respectively. The results obtained from this study show that building with re-entrant corner is inherently vulnerable to collapse due to earthquake load.

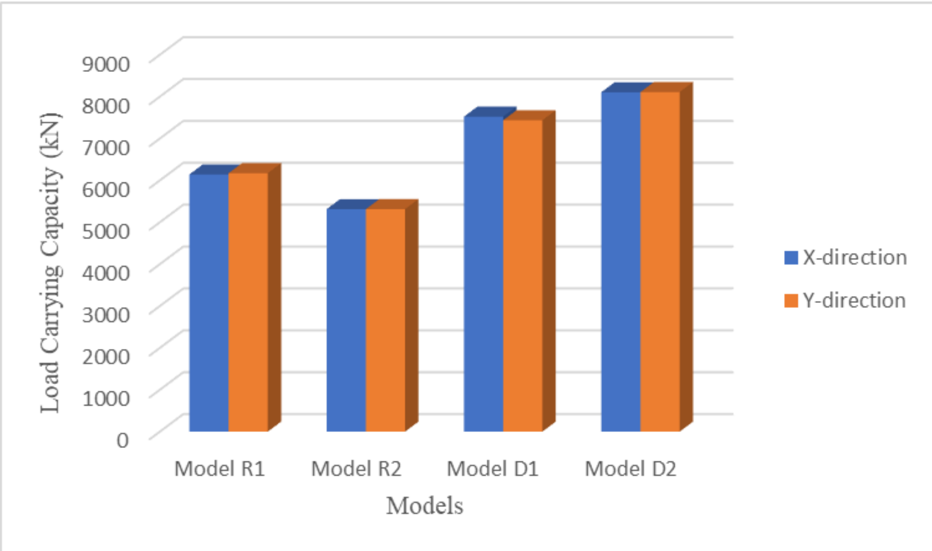

Fig -21: ***Comparison of Load Carrying Capacity of Different Model***

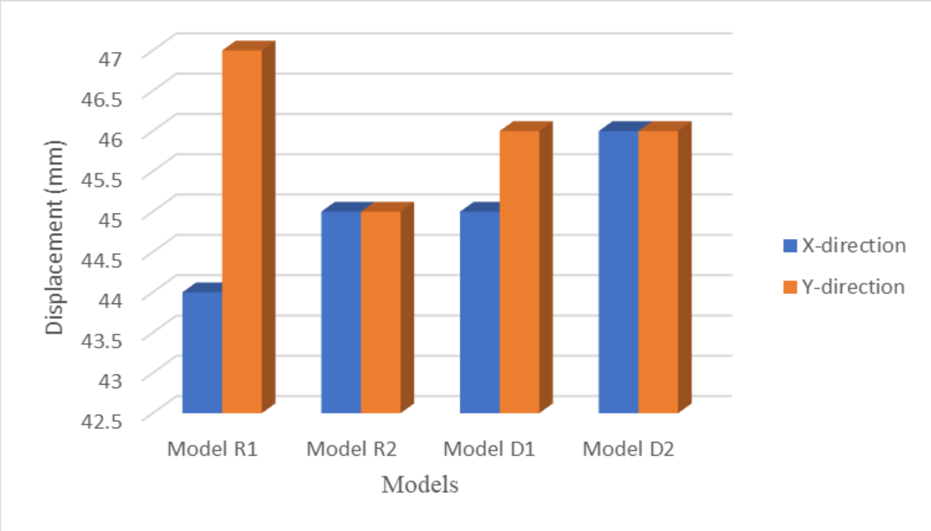

Fig -22: ***Comparison of Displacement at Performance Point of Different Models***

IV. CONCLUSION

Based on the analysis carried out in the present study, the following conclusions can be drawn:

1) RC frame building with diaphragm discontinuity has more lateral load carrying capacity as compared to the building with re-entrant corner.
2) Model D2 has 24% more load carrying capacity than model R1, 34.5% than R2 and 8% than D1.
3) At performance point, the building having re-entrant corner may collapse during earthquake because of greater displacement in Y-direction as it has 66.66 % of re-entrant corner.
4) The building with plan asymmetry needs higher column section to obtain the performance point.
5) The buildings having irregular plan configuration has experienced more damage during the earthquake as compared to the building having simplified plan configuration.

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