COMPARATIVE STUDY OF RC FRAMED STRUCTURES USING SPECTRA BASED PUSHOVER ANALYSIS

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Abstract

Spectra based multimodal adaptive pushover analysis considers higher modes of vibration and combines them using SRSS rule and scale factors. Damage index for the structures are calculated to evaluate the degree of damage occurred after a seismic event. For the present study the Spectra based multimodal adaptive pushover analysis is adopted for G+ 4 storeys Symmetric and G+ 4 storeys Asymmetric Reinforced concrete framed structures. The Expended Energy based damage index methods are used to calculate Damage Index for symmetric and asymmetric structures. ETABS 2015 software is utilized for modeling and analysis of Reinforced concrete framed structures. The comparative studies are carried out between the structure considering only 1st mode and considering all modes and compared between 3 methods of damage index. It is observed that the capacity obtained by considering all modes is less than the capacity obtained by considering only 1st mode. The target displacement obtained considering only 1st mode is less than the target displacement obtained considering all modes. And the damage index obtained by considering all modes is more than the damage index obtained by considering only 1st mode. Therefore it is necessary to consider all modes to get accurate results. In asymmetric building the ductility is less, the capacity is less, demand is high, and degree of damage is more when compared with symmetric building.

Keywords: *pushover analysis, damage index, RC frame, multimodal, symmetric and asymmetric*

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1. INTRODUCTION

The Spectra based multimodal adaptive pushover analysis which is proposed by K. Shakeri, M. Mohebbi Asbmarz and M.A. Shayanfar 2008[3] is adopted for G+4 storey Symmetric and G+4 storey Asymmetric building in the analysis of Reinforced concrete framed structures. The Expended Energy based damage index methods which is proposed by Anthugari Vimala, Pradeep Kumar, Ramancharla (2014) [10] are used to calculate Damage Index for symmetric and asymmetric structures. ETABS 2015 software is utilized for modelling and analysis of Reinforced concrete framed structures.

Spectra based multimodal adaptive pushover analysis considers higher modes of vibration and combines them using SRSS rule and scale factors. All these factors are very essential to increase the accuracy of the results. Damage index for the structures are calculated to evaluate the degree of damage occurred after a seismic event. The Expended energy based damage index is represented as ratio of inelastic energy dissipated at any displacement to the total inelastic energy capacity of the structure. The energy method is used to calculate Global damage index of the structure.

This project work focuses on Evaluation and Comparative study of damage index of symmetric and asymmetric RC framed structures using Spectra based multimodal adaptive pushover analysis.

In our present study we have adopted two example reinforced concrete framed structures (i) 5 storey symmetric structure and (ii) 5 storey asymmetric structure. Spectra based multimodal adaptive pushover analysis used as RC framed analysis. ETABS 2015 is utilized for modelling and analysis. Damage indices are calculated and compared with symmetrical and asymmetrical structures.

2. MODELS CONSIDERED FOR STUDY

2.1 Symmetric Model

A G+4 storey, 7-bay by 2-bay symmetrical reinforced concrete framed residential building is considered.

Dimension of Column	0.23 X 0.4 m
Dimension of Beam	0.23 X 0.35 m
Thickness of slab	0.125 m
Thickness of wall	0.23 m
Soil type	II
Live load	2 KN/m
Location of building	Mysore, Karnataka, India.

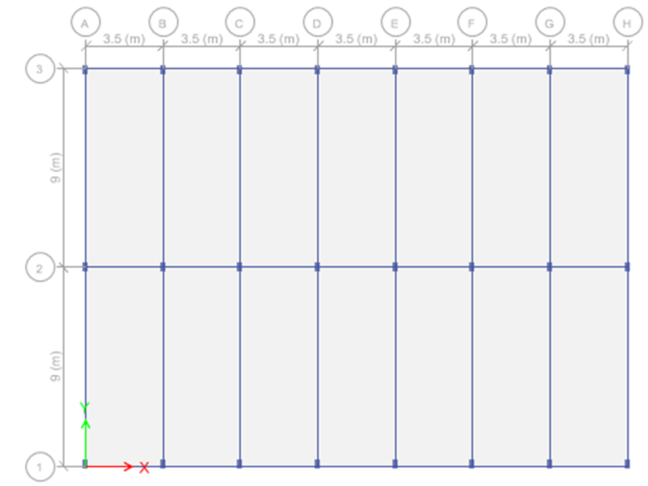

Fig 1 Plan of Symmetric Building

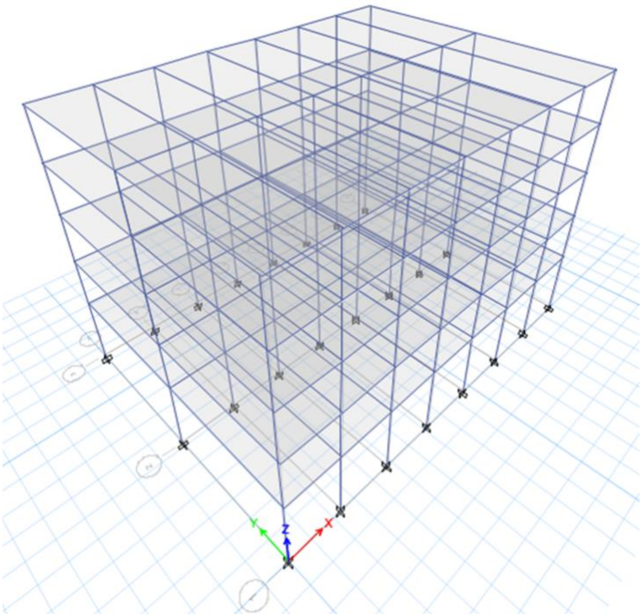

Fig 2 3D View of Symmetric Building

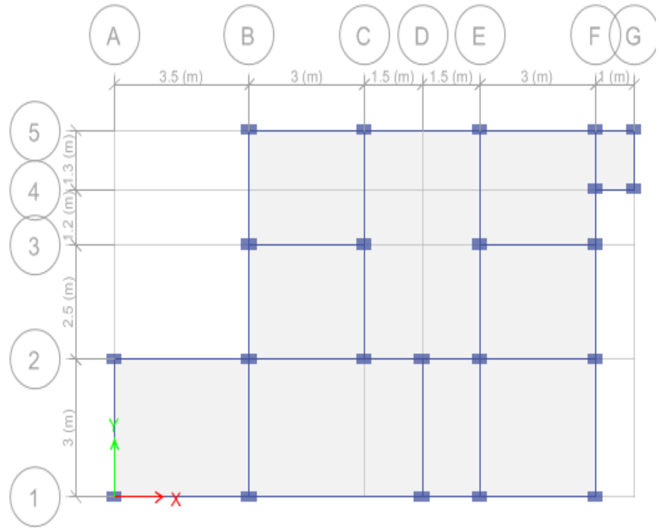

Fig 3 Plan of Asymmetric Building

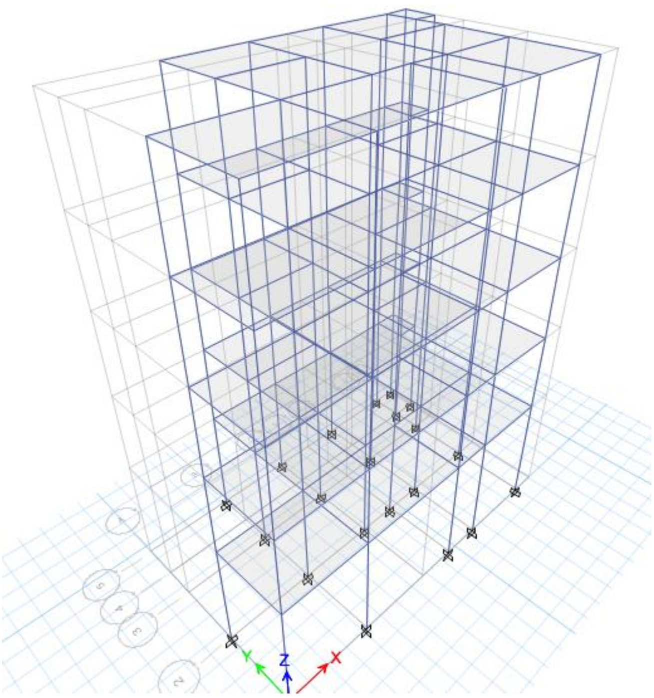

Fig 4 3D View of Asymmetric Building

2.2 Asymmetric Model

An Asymmetrical residential building is as shown in figure below.

Dimension of column	0.23 X 0.4 m,
Beam	0.23 X 0.35m
Thickness of slab	0.125 m
Thickness of wall	0.23 m
Soil type	II
Live load	2 KN/m
Location of Building	Mysore, Karnataka, India.

3. SUMMARY OF ANALLYSIS IN ETABS 2015

1. Create the model with nonlinear properties.
2. Set the maximum number of modes as the number of stories multiplied by 3 for 3D Analysis.
3. Perform gravity analysis and modal analysis. From modal analysis result the direction of modes (weather X-direction or Y-direction) are obtained.
4. In case of asymmetric structures it is needed to calculate the eccentricity ratio in each storey and apply it to lateral load pattern.
5. Define the nonlinear load case for each mode separately in X or Y direction according to the direction of mode.

6. Perform pushover analysis and note down the maximum base shear in each mode and combine them by SRSS rule.
7. Calculate scale factor for each mode and apply them to nonlinear load cases in each mode.
8. Again perform pushover analysis, resulting base shears are combined by SRSS rule and scale factors are calculated.
9. Apply these scale factors to a separate nonlinear load case which contain all the mode in X and Y direction with above computed scale factor and perform pushover analysis.
10. From bilinear pushover curve we can obtain target displacement. Compare target and monitored displacement with applied displacement in the nonlinear load case, if target displacement is more than applied load case then apply target displacement as applied load and perform the final pushover analysis.
11. Calculate damage index for the structure from the pushover curve results using,

$$D_1 = \frac{E - E_{ie}}{E_T - E_{ie}} \times 100$$

$$D_2 = \frac{E - E_e}{E_T - E_{ie}} \times 100$$

$$D_3 = \frac{E_L - E_{NL}}{E_{LT} - E_{NLT}} \times 100$$

Where,
D_1, D_2 $and D_3$ Are Damage index for method 1, method 2 and method 3 respectively.
E = Energy dissipated at which damage is being estimated,
E_{ie} = Initial yield energy of structure;
E_T = Total energy absorbed by structure;
E_e = Instantaneous elastic energy at which damage is being estimated
E_L= Linear energy at displacement level at which damage is being estimated;
E_{NL} = Nonlinear energy at which damage is being estimated;
E_{LT}= Linear energy at maximum displacement of structure;
E_{NLT}= Nonlinear energy at maximum displacement of structure

4. RESULTS AND DISCUSSIONS

4.1 Pushover Curve Results

The 1st mode reaches ultimate yielding point at 181.7 mm, 1216.5638 KN whereas final combined load case reach ultimate yielding point at 105.3 mm, 98.4257 KN. Here it can be observed that by considering all the modes, the capacity of the structure is decreased by 43% when compared with only one mode. Hence adopting spectra based adaptive multimode analysis is very useful in getting accuracy of the results which include all the modes.

Ductility of symmetric building is more when compared to asymmetric structure.

Symmetric structure shows post yielding behavior and also strength degradation behavior.

Asymmetric structure is showing post yielding behavior but there is no strength degradation behavior this shows that asymmetric structure is undergoing brittle failure of structural members.

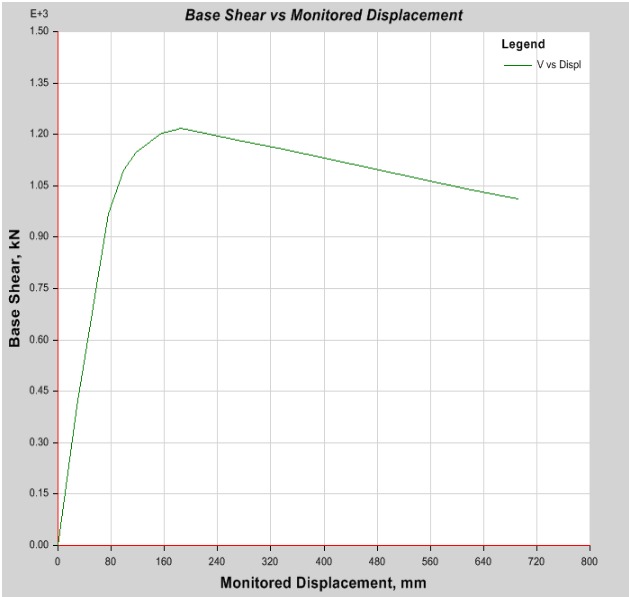

Fig 5 Pushover Curve For Symmetrical Structure At Mode-1 In X-Direction

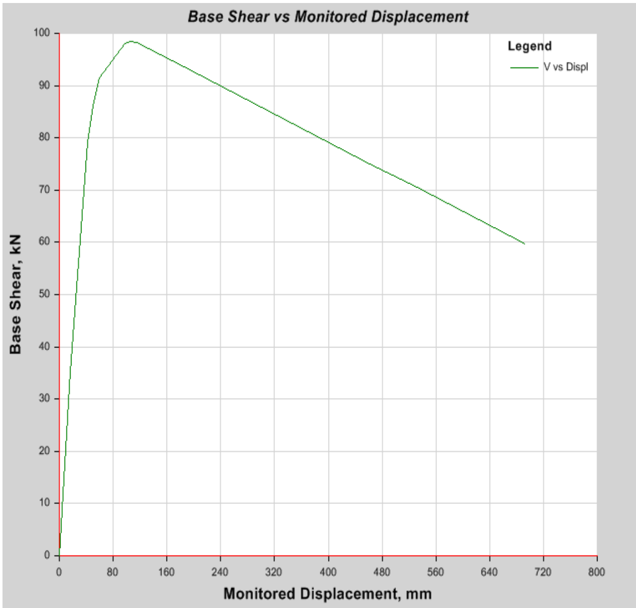

Fig 6 Pushover Curve For Symmetrical Structure By Combining All Modes In X-Direction

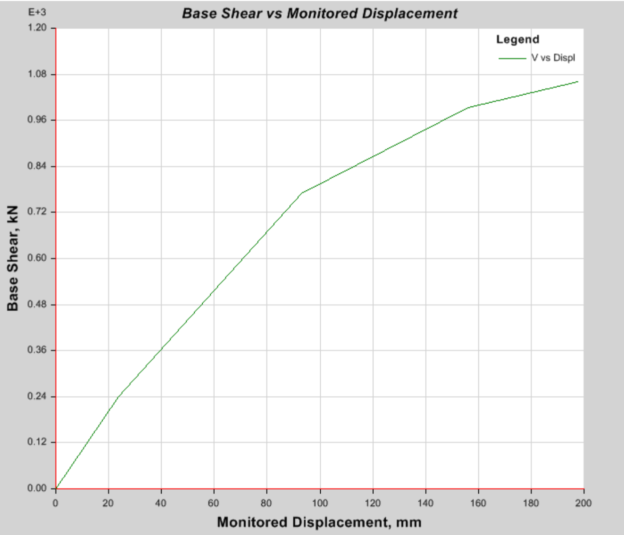

Fig 7 Pushover Curve For Asymmetrical Structure At Mode-1 In Y-Direction

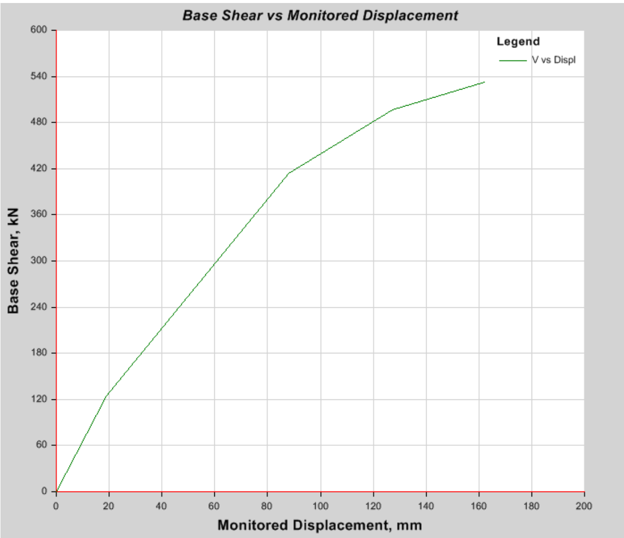

Fig 8 Pushover Curve For Asymmetrical Structure With Combined Loading In Y-Direction

4.2 S_a vs S_d Curve Results

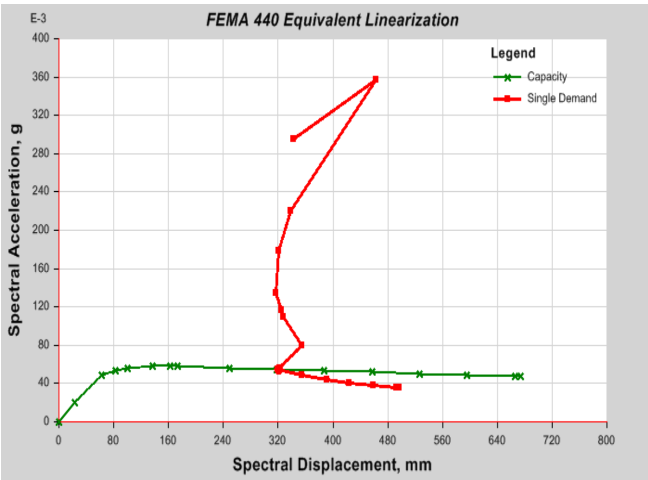

Fig 9 S_a vs S_d Curve For Symmetric Structure At Mode-1 In X-Direction

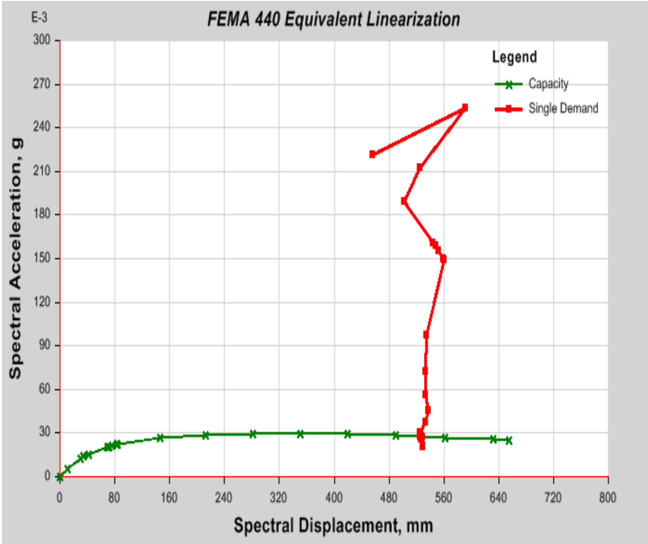

Fig 10 S_a vs S_d Curve For Symmetric Structure For Combined Load Case In X-Direction

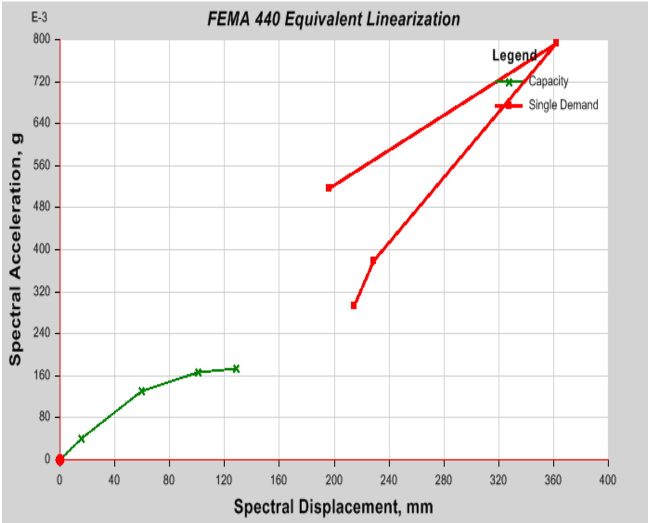

Fig 11 S_a vs S_d Curve For Asymmetric Structre At Mode-1 In Y-Direction

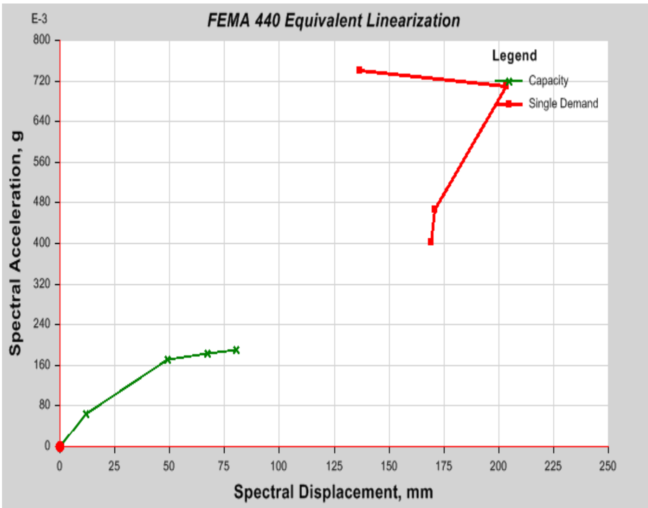

Fig 12 S_a vs S_d Curve For Asymmetric Structure For Combined Load Case In Y-Direction

In symmetric structure the performance point is found only in mode-1. The displacement at performance point in mode-1 is 340.8 mm. and in all modes the displacement at performance point 565.9 mm which means participation of mode-1 in the analysis is more than any other modes. But other 40% cannot be neglected, thus we need to consider all the modes for combined effect.

In asymmetric structure the performance point is found only in mode-4. The maximum displacement occurred in mode-4 is 34.3 mm. In final result also there is no meet of point observed. Therefore it is very much necessary to adopt spectra based adaptive multimodal pushover procedure to know the changes in behavior of structure at different modes. Hence this method help to choose peak performance results for the design of structure.

From the above results the capacity of the symmetric structure is greater when compared with asymmetric structure.

4.3 Bilinear Curve Results

Target displacements obtained are used in the design of structure.

In symmetric model first mode represents the target displacement of 378.3mm whereas all modes combined final target displacement is 523.4mm. Here it can be observed that 27% less target displacement is obtained when considering only 1st mode. Therefore considering all the mode is important to get accurate results and good design.

In symmetric model the target displacement is within the capacity of the structure whereas in asymmetric model the target displacement is beyond the capacity of the structure.

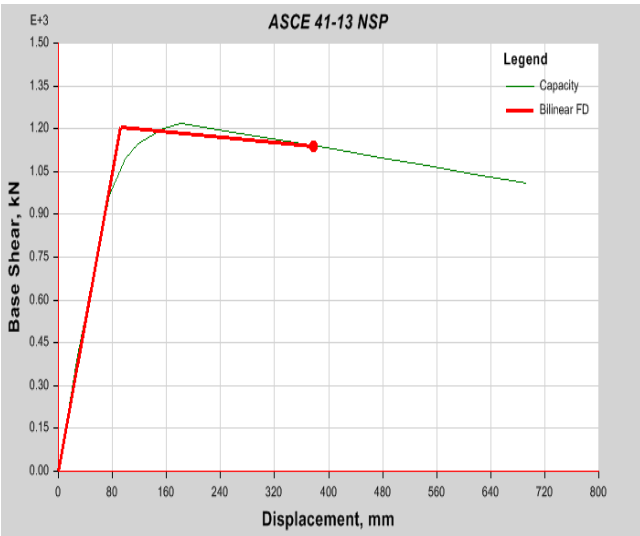

Fig 13 Bilinear Pushover Curve For Symmetric Structure At Mode-1 In X-Direction

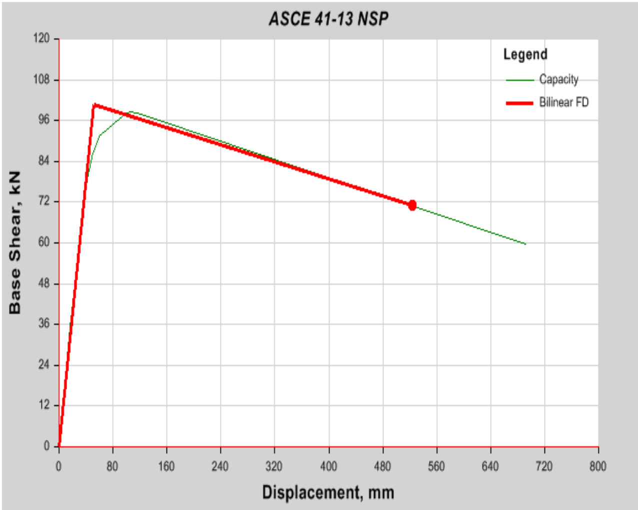

Fig 14 Bilinear Pushover Curve For Symmetric Structure For Combined Load Case In X-Direction

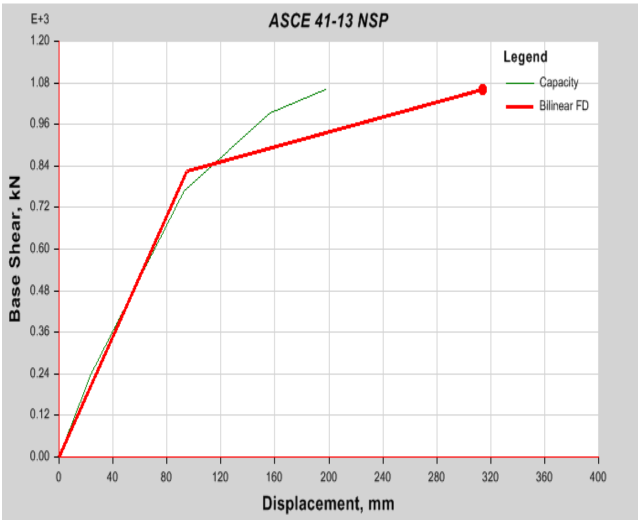

Fig 15 Bilinear Pushover Curve For Asymmetric Structure At Mode-1 In Y-Direction

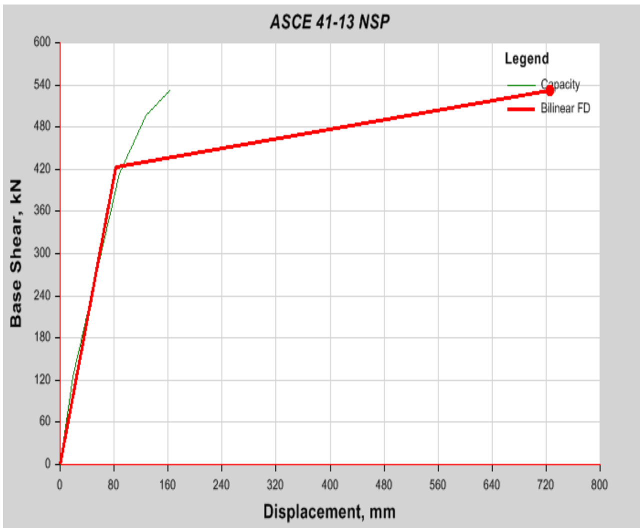

Fig 16 Bilinear Pushover Curve For Asymmetric Structure For Combined Load Case In Y-Direction

4.4 Hinge State Results

Table 1 Performance Level

PERFORMANCE LEVEL	DESCRIPTION
Operational Level (OL)	Building will be under construction. Minor repairs may be required.
Immediate occupancy level (IO)	Building will be available to accommodate.
Life safety level (LS)	Very low chances of collapse of structural members. No harm to life occurs.
Collapse prevention level (CP)	This requires stability under vertical loads.

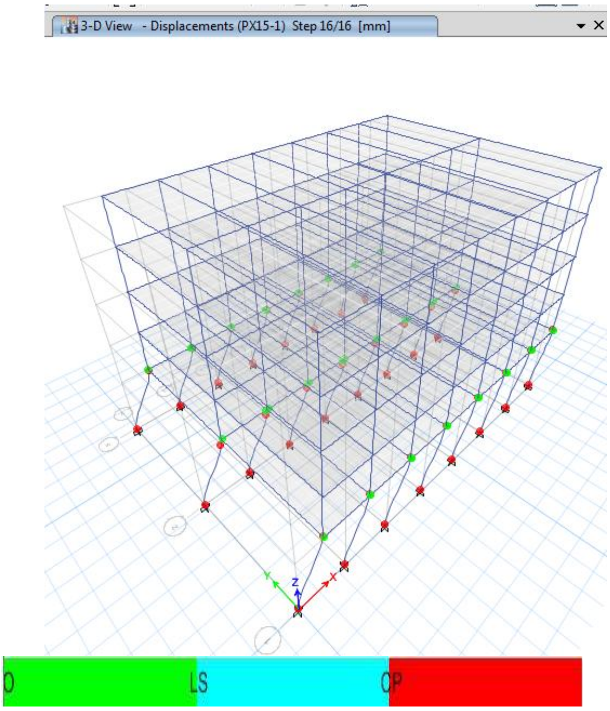

Fig 17 Hinge State For Symmetrical Structure At Mode-1 in *X*-Direction

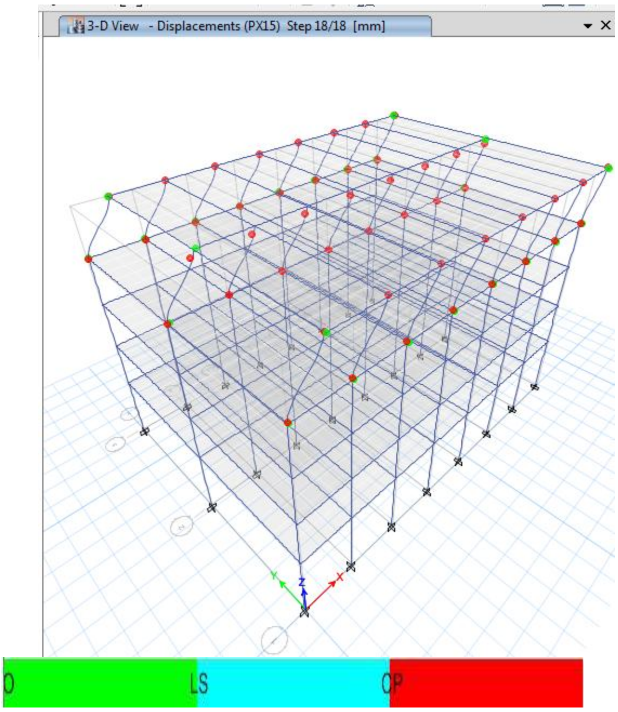

Fig 18 Hinge State For Symmetrical Structure For Combined Load Case In *X*-Direction

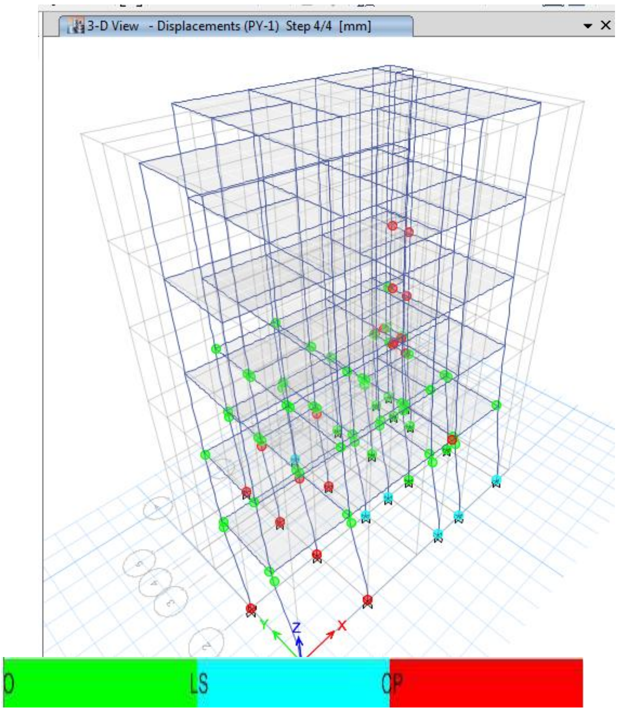

Fig 19 Hinge State For Asymmetrical Structure At Mode-1 In *Y*-Direction

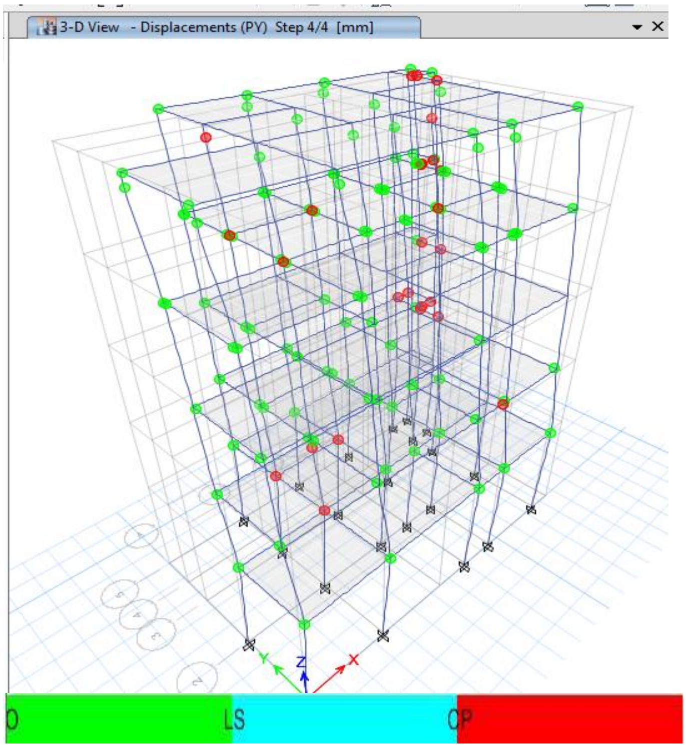

Fig 20 Hinge State For Asymmetrical Structure For Combined Load Case In Y-Direction

In symmetrical structure, the first mode contain total of 1165 hinges of which 1075 hinges are in immediate occupancy level, 42 hinges are in life safety level, 0 in collapse prevention level and 48 are beyond collapse prevention level. When all modes combined case results contain total of 1165 hinges of which 1081 hinges are in immediate occupancy level, 36 hinges are in life safety level, 0 in collapse prevention level and 48 are beyond collapse prevention level.

Thus in spectra based adaptive multimodal analysis, the behavior of the structure in every single step of analysis can be observed.

The failure of hinges occurs first where the columns are placed closely. Therefore columns should be placed at equal distances as far as possible.

The failure of hinges starts at bottom storey and gradually transfers to upper stories with each mode.

4.5 Damage Index Results

Table 2 Ranges Of Damage Index (Dorde Ladinovic, Aleksandra Radujkovic, Andrija Raseta (2011) [16])

Degree of damage	Damage index	State of structure
Minor	0.0-0.2	Serviceable
Moderate	0.2-0.5	Repairable
Severe	0.5-1.0	Irreparable
Collapse	>1.0	Loss of building

Table 3 Damage Index For Symmetric Structure

DAMAGE INDEX FOR SYMMETRICAL STRUCTURE			
Mode no.	METHOD 1	METHOD 2	METHOD 3
PX1	0.230776	0.166491	0.023737
PX4	0.162262	0.131261	0.016884
PX7	1	0.004032	1
PX10	0.14566	0.135823	0.013773
PX11	0.947425	0.23723	2.468422
PY2	0.966751	0.732177	1.072819
PY5	1	0.269953	1
PY8	1	0.185354	0.28759
PY13	1	0.819354	1
PY14	0.809682	0.33357	2.834754
OVERALL DAMAGE INDEX IN X-DIRECTION	0.1362	0.09985	0.01345
OVERALL DAMAGE INDEX IN Y-DIRECTION	0.6663	0.1907	0.5262

Table 4 Damage Index For Asymmetric Structure

DAMAGE INDEX FOR ASYMMETRICAL STRUCTURE			
Mode no.	METHOD 1	METHOD 2	METHOD 3
PX3	0.349008	0.347986	2.274995
PX6	1	0.680699	1
PX10	1	0.124079	1
PX13	1	0.516721	1
PX15	0.932206	0.580708	0.76984
PY1	1	0.601102	1
PY4	1	0.677741	1
PY7	1	N/A	1
PY9	0.571256	0.432167	1.42617
PY11	0.84921	0.745895	1.086192
OVERALL DAMAGE INDEX IN X-DIRECTION	1	0.52	1
OVERALL DAMAGE INDEX IN Y-DIRECTION	1	0.628	1

The higher value of damage index is observed in all modes combined case when compared with the damage index by considering only 1st mode. Therefore to get accurate results, all the modes need to be considered.

The severe and collapsed state is observed more in asymmetric model than symmetric model. Therefore as the asymmetry increases the damage also increase.

Out of three methods, the Method 1 and Method 3 is indicating little higher degree of damage when compared with Method 2.

5. CONCLUSION

From the pushover curve results it is observed that the capacity of the structure obtained by considering all modes is less than the capacity obtained by considering only 1st mode. Hence adopting spectra based adaptive multimode analysis is very useful in getting more accurate results.

By adopting asymmetric structure over symmetric structure the ductility of structure may be compromised. Hence suitable precautionary measures should be taken while adopting asymmetric structures.

In symmetric model the capacity is meeting the demand of the building where as in asymmetric model the demand is very high. Thus we can conclude that, as the asymmetry of structure increases the capacity of the structure decreases.

From bilinear curve results it is observe that target displacement obtained considering only 1st mode is less than the target displacement obtained considering all modes. Therefore considering all the modes is important to get accurate results and good design.

More number of hinges reach failure in asymmetric model when compared with symmetric model. Failure occurs early where columns are placed closely. Therefore columns should be placed at equal interval as far as possible.

The higher value of damage index is obtained by considering all modes when compared with considering only 1st mode. Therefore to get accurate results we need to consider all the modes.

The severe and collapsed state of damage is observed more in asymmetric model than in symmetric model. Therefore as the asymmetry increases the damage also increase.

Out of three methods of damage index, the Method 1 and Method 3 is indicating little higher degree of damage when compared with Method 2.

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