To Locate the Critical Portion in Plan Symmetric and Plan Asymmetric Buildings Subjected to Seismic Force

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Abstract : **Nowadays, seismic analysis of structures has a great scope in civil engineering field. In this work seismic analysis of structures with plan irregularities and with varying diaphragm is considered. In this work two structures are considered, those are L-shape and C-shape, all are with six stories, and up to eight models are taken two for membrane rigid and membrane semirigid and other two for shell rigid and shell semirigid for each structure. The paper mainly concentrates on parameters like bending moment and lateral displacement of the models. For analysis ETABS 2015 software is used and non-linear static method known as pushover analysis is used as method of seismic analysis.**

***IndexTerms* - Push over analysis, Plan irregularity, ETABS, Seismic behavior, Diaphragm rigidity**

I. INTRODUCTION

Seismic analysis comes under structural analysis which deals with the study of structures which is subjected to earthquake load. An earthquake is shaking the surface of the earth, resulting from the sudden release of energy in the earth's lithosphere that creates seismic waves.

During an earthquake, failure of structure starts at points of weakness. This weakness arises due to discontinuity in mass, stiffness and geometry of structure. The structures having this discontinuity are termed as Irregular structures. The irregularity in the building structures may be due to irregular distributions in their mass, strength and stiffness along the height of building. When such buildings are constructed in high seismic zones, the analysis and design becomes more complicated. There are two types of irregularities- Plan Irregularities and Vertical Irregularities. A plan which do not have symmetry either along X- axis nor along Y-axis are termed as plan irregularity. Structures having significant physical discontinuities in vertical configuration or in their lateral force resisting systems are termed as vertical irregularity. There are five Types of vertical irregularities, they are Stiffness Irregularity, Mass Irregularity, Vertical Geometric Irregularity, In-Plane Discontinuity Vertical Elements Resisting Lateral Force, Discontinuity in Capacity.

Seismic analysis is always been an important branch in civil engineering particularly in structural engineering. Seismic analysis also includes study of structures with plan irregularity, mass irregularity, vertical irregularity, etc. Thus seismic analysis is having a great scope. In this document authors started their research on seismic analysis with plan irregularity and varying diaphragm. For analysis ETABS 2015 is used, method of seismic analysis used is non-linear static analysis known as pushover analysis.

ETABS is an engineering software product that may be used in the design and analysis of multistoried buildings. It is a product of Computers and Structures, Inc. (CSI), a structural and earthquake engineering software company founded in 1975 by Mr. Ashraf Habibullah and based in Walnut Creek, California with an additional office located in New York. ETABS 2015 is an improved version of the earlier software package series named ETABS which also include earlier versions from the years 2009 and 2013, the latest version of the software being that from the year 2016.

The seismic analysis methods are classified into two major categories based on the linear and non-linear nature of analysis. Further it is subdivided into two categories based on the static and dynamic nature of the analysis. Static linear analysis is known as equivalent static load method, static non-linear analysis is known as pushover analysis, dynamic linear analysis is known response spectrum method and dynamic non-linear analysis is known as time history analysis.

Another important point to be considered is, even though earthquake is a dynamic force and dynamic analysis gives effective results compared to static analysis, dynamic analysis is quite complex in nature and hence it is not used. Thus for better quality of results non- linear static method that is pushover analysis is used

II. OBJECTIVE OF THE STUDY

[1] To understand the behavior of plan symmetric and plan asymmetric buildings under seismic loading.
[2] To understand the behavior of roof modeling for plan symmetric and plan asymmetric buildings under seismic loading.

[3] To describe the importance of non-linear (pushover analysis method) analysis in seismic analysis of regular and irregular structures and to make the comparison between the structural responses.

[4] To study the influence of structural configuration on the building having L, and C- shape in plan, on the seismic response of the structure.

III. METHODOLOGY

For analysis authors have incorporated ETABS 2015 and non-linear static method known as pushover analysis. In Pushover analysis, a static horizontal force profile, usually proportional to the design force profiles specified in the codes, is applied to the structure. The force profile is then incremented in small steps and the structure is analysed at each step. As the loads are increased, the building undergoes yielding at a few locations. Every time such yielding takes place, the structural properties are modified approximately to reflect the yielding. The analysis is continued till the structure collapses, or the building reaches certain level of lateral displacement. It provides a load versus deflection curve of the structure starting from the state of rest to the ultimate failure of the structure.

The models used for analysis include buildings with asymmetric plans. The asymmetric models are 'L' shaped model (fig-1) and 'C' shaped model(fig-2). Both asymmetric models consist of 6 floors each (G+5), with the floor heights being 3.2m each. The dimensions of the columns being fixed at 450mm x 450mm and that of the beams at 230mm x 450mm for both cases. The column positions have so been fixed, that the spans of all the beams in both X and Y directions are kept same and equal to 5m. The loading conditions for both models are similar. Also both the models have been analysed for rigid and semi rigid diaphragm conditions.

This research focuses only on the effect of variations in plan configuration along with different diaphragm conditions. Typical column position layouts for 'Box' shaped buildings and 'L' shaped buildings used in the analysis are as shown in figures 3 and 4 respectively.

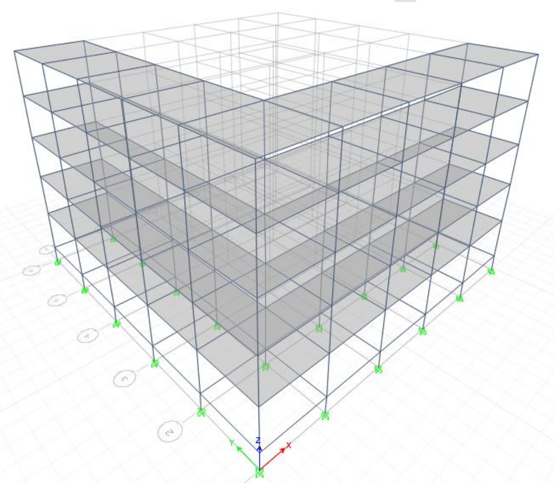

Fig-1: 3D View of L- Shaped Building

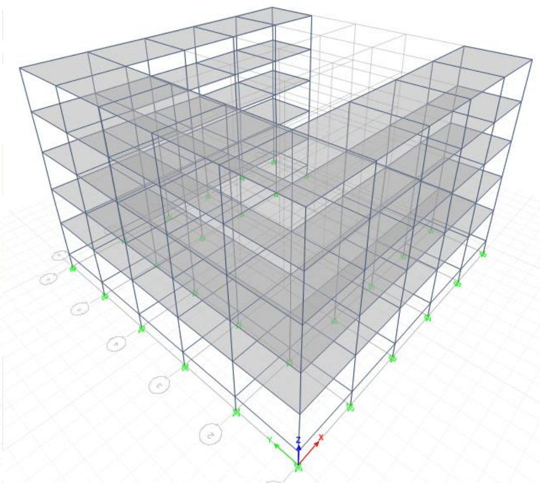

Fig-2: 3D View of C- Shaped Building

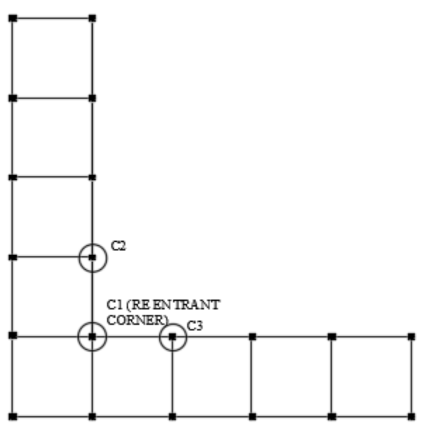

Fig-3: 'L' Shaped Model

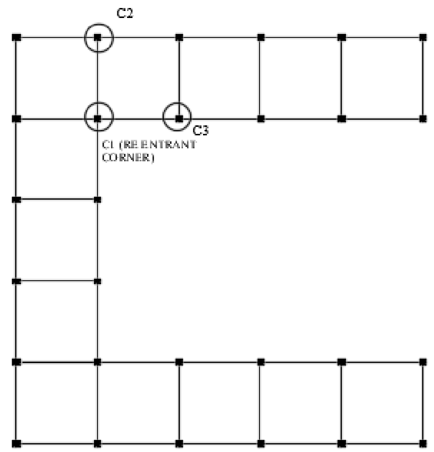

Fig-4: 'C' Shaped Model

IV. Analysis

The recent advent of performance based design has brought the nonlinear static pushover analysis procedure to the forefront. Pushover analysis is a static, nonlinear procedure in which the magnitude of the structural loading is incrementally increased in accordance with a certain predefined pattern. With the increase in the magnitude of the loading, weak links and failure modes of the structure are found. The loading is monotonic with the effects of the cyclic behavior and load reversals being estimated by using a modified monotonic force-deformation criteria and with damping approximations. Static pushover analysis is an attempt by the structural engineering profession to evaluate the real strength of the structure and it promises to be a useful and effective tool for performance based design. The ATC-40 and FEMA-273documents have developed modelling procedures, acceptance criteria and analysis procedures for pushover analysis. These documents define force-deformation criteria for hinges used in pushover analysis.

It is expected that most buildings rehabilitated in accordance with a standard, would perform within the desired levels when subjected to the design earthquakes. Structures designed according to the existing seismic codes provide minimum safety to preserve life and in a major earthquake, they assure at least gravity-load-bearing elements facilities will still function and provide some margin of safety. However, compliance with the standard does not guarantee such performance. They typically do not address performance of non-structural components neither provide differences in performance between different structural systems. This is because it cannot accurately estimate the inelastic strength and deformation of each member due to linear elastic analysis. Although an elastic analysis gives a good indication of elastic capacity of structures and indicates where first yielding will occur, it cannot predict failure mechanisms and account for redistribution of forces during progressive yielding.

To overcome this disadvantages different nonlinear static analysis method is used to estimate the inelastic seismic performance of structures, and as the result, the structural safety can be secured against an earthquake. Inelastic analysis procedures help demonstrate how buildings really work by identifying modes of failure and the potential for progressive collapse. The use of inelastic procedure for design and evaluation helps engineers to understand how structures will behave when subjected to major earthquakes. This resolves some of the uncertainties associated with code and elastic procedures. The overall capacity of a structure depends on the strength and deformation capacities of the individual components of the structure. In order to determine capacities beyond the elastic limit some form of nonlinear analysis, like Pushover Analysis is required.

Table-1: Parameters considered for the study

Structure Type	Ordinary moment resisting frame
Number of storey	G+5 storey
Typical storey height	3.2(m)
Bottom storey height	1.25(m)
Material property	
Grade of concrete	M_{20}
Grade of steel	Fe500
Density of concrete	25KN/m^2
Member properties	
Beam size	0.23(m)*0.45(m)
Column size	0.45(m)*0.45(m)
Slab thickness	0.15(m)
Wall size	0.23(m)
Load intensities	
Live load	4 KN/m^2
Reducible live load	2 KN/m^2
Wall load	12.65 KN/m^2
Partition wall load	3 KN/m^2
Floor finish	1 KN/m^2

V. RESULTS AND DISCUSSION

This section discusses the results obtained from the analysis with regards to the bending moment. The Fig.5 to Fig.16 and Table 2 to table 7 shows the variation of bending moment at the different storey levels. In all the cases the bending moment is more at the bottomstorey and it goes on reducing as it reaches the topstoreys. Here three critical columns namely C1, C2 and C3 as shown in Fig.3 and Fig.4 are considered and the bending moment results are plotted.It is also observed that the bending moment values for rigid and semi rigid diaphragm roof modelling conditions are almost same for the Push-X and Push Y load case for both L-shaped and C-shaped buildings.

Table-2: Distribution of Bending moment of L-shape structure at C1 column

COLUMN	STOREY NO	BENDING MOMENT															
		MEMBRANE								SHELL							
		RIGID				SEMIRIGID				RIGID				SEMIRIGID			
		PUSHX		PUSHY		PUSHX		PUSHY		PUSHX		PUSHY		PUSHX		PUSHY	
		M2	M3	M2	M3	M2	M3	M2	M3	M2	M3	M2	M3	M2	M3	M2	M3
C1	6	4	124	54	0	2	128	53	0	4	88	86	4	5	84	57	3
	5	2	153	113	2	4	162	114	1	4	160	157	4	4	157	110	3
	4	2	150	120	2	3	158	121	2	7	230	223	6	6	223	155	4
	3	2	140	112	2	3	146	113	2	6	316	309	8	10	316	209	4
	2	2	303	239	2	5	305	243	3	8	292	300	5	4	284	277	2
	1	9	305	226	3	5	307	225	3	3	314	322	17	6	305	313	3

Table-3: Distribution of Bending moment of L-shape structure at C2 column

COLUMN	STOREY NO	BENDING MOMENT															
		MEMBRANE								SHELL							
		RIGID				SEMIRIGID				RIGID				SEMIRIGID			
		PUSHX		PUSHY		PUSHX		PUSHY		PUSHX		PUSHY		PUSHX		PUSHY	
		M2	M3	M2	M3	M2	M3	M2	M3	M2	M3	M2	M3	M2	M3	M2	M3
C2	6	4	72	54	2	4	75	53	2	0	57	85	1	3	56	56	1
	5	2	134	113	2	4	138	114	2	0	126	147	2	0	123	105	1
	4	2	123	120	2	3	132	121	2	0	176	203	2	2	173	141	2
	3	2	104	113	2	3	115	112	2	5	214	255	4	5	229	173	2
	2	2	284	240	2	5	281	244	2	2	246	318	3	4	239	269	2
	1	9	286	226	2	5	290	223	2	6	262	348	5	12	261	331	2

Table-4: Distribution of Bending moment of L-shape structure at C3 column

COLUMN	STOREY NO	BENDING MOMENT															
		MEMBRANE								SHELL							
		RIGID				SEMIRIGID				RIGID				SEMIRIGID			
		PUSHX		PUSHY		PUSHX		PUSHY		PUSHX		PUSHY		PUSHX		PUSHY	
		M2	M3	M2	M3	M2	M3	M2	M3	M2	M3	M2	M3	M2	M3	M2	M3
C3	6	3	126	36	0	6	129	37	0	1	87	56	0	1	83	37	2
	5	3	153	88	2	3	163	88	0	2	150	123	0	2	148	84	0
	4	2	151	95	1	4	158	96	1	2	207	172	0	3	201	117	0
	3	2	141	78	2	2	145	79	2	7	271	224	3	7	258	137	0
	2	2	303	211	2	7	305	210	3	2	304	245	1	4	295	231	3
	1	9	306	216	3	7	311	225	3	17	328	271	16	5	321	277	3

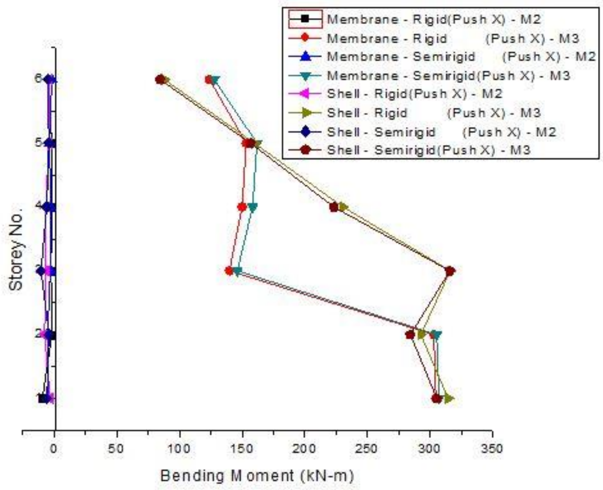

Fig - 5: Variation of Bending moment of L-shape Structure in C1 column due to PUSHX

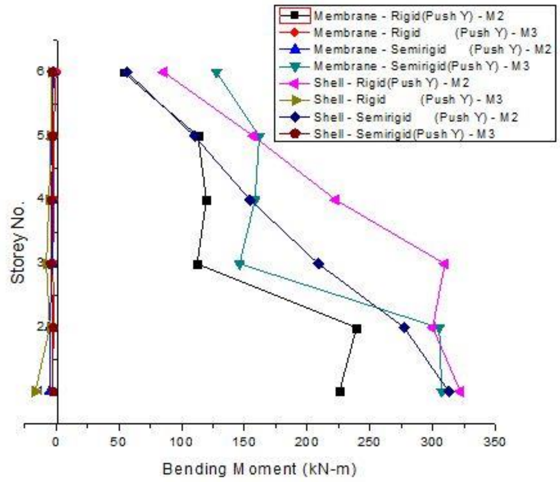

Fig -8: Variation of Bending moment of L-Shape structurein C1 column due to PUSHY

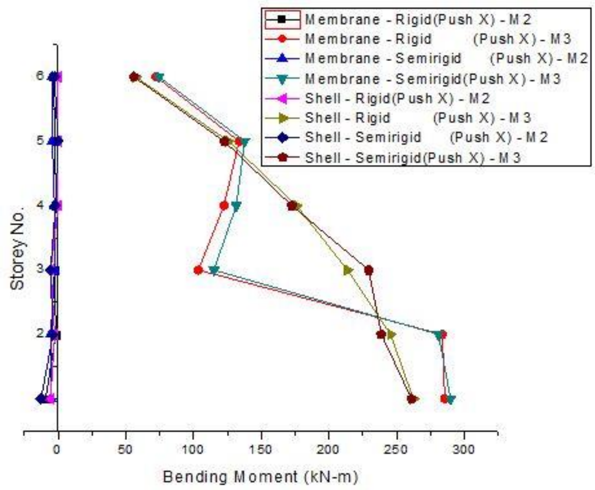

Fig -6: Variation of Bending moment of L-shape structure in C2 column due to PUSHX

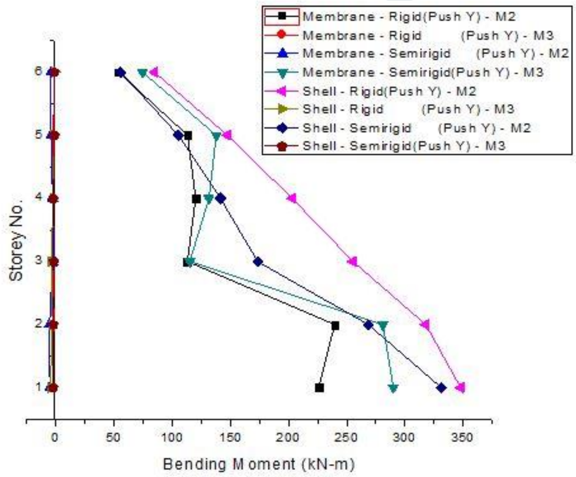

Fig -9: Variation of Bending moment of L-Shape structure in C2 column due to PUSHY

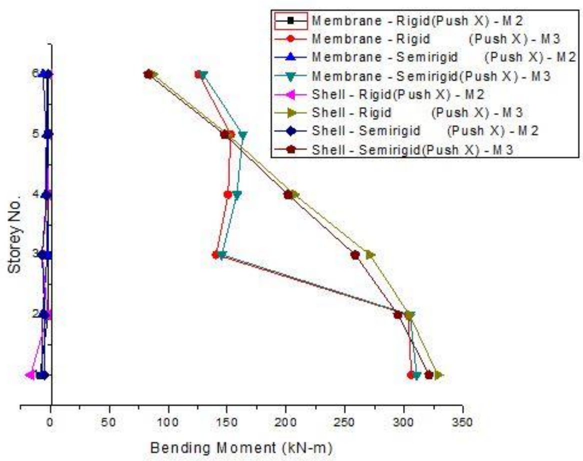

Fig-7: Variation of Bending moment of L-shape Structure in C3 column due to PUSHX

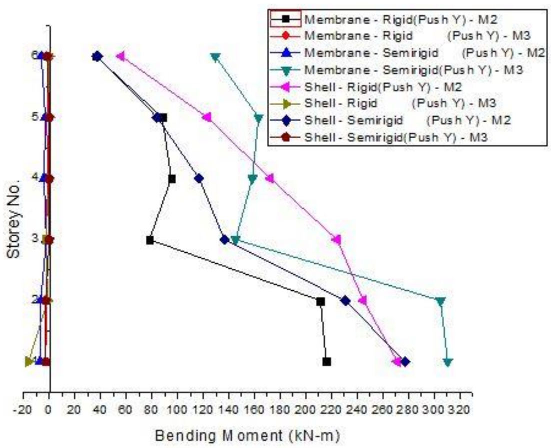

Fig -10: Variation of Bending moment of L-Shape structure in C3 column due to PUSHY

Table -5: Distribution of Bending moment of C-Shape structure at C1 Column

COLUMN	STOREY NO	BENDING MOMENT															
		MEMBRANE								SHELL							
		RIGID				SEMIRIGID				RIGID				SEMIRIGID			
		PUSHX		PUSHY		PUSHX		PUSHY		PUSHX		PUSHY		PUSHX		PUSHY	
		M2	M3	M2	M3	M2	M3	M2	M3	M2	M3	M2	M3	M2	M3	M2	M3
C1	6	1	123	55	3	2	132	31	1	4	59	58..7856	0	6	79	58	2
	5	0	160	107	4	0	171	56	2	5	117	110	0	6	151	110	0
	4	0	153	112	4	2	167	86	3	6	168	154	0	9	217	152	2
	3	0	133	111	4	0	138	83	3	8	215	211	2	10	316	208	3
	2	1	322	224	2	1	311	156	3	4	263	270	4	8	284	269	2
	1	11	321	207	4	0	321	128	3	1	293	344	3	7	305	345	3

Table -6: Distribution of Bending moment of C-Shape structure at C2 Column

COLUMN	STOREY NO	BENDING MOMENT															
		MEMBRANE								SHELL							
		RIGID				SEMIRIGID				RIGID				SEMIRIGID			
		PUSHX		PUSHY		PUSHX		PUSHY		PUSHX		PUSHY		PUSHX		PUSHY	
		M2	M3	M2	M3	M2	M3	M2	M3	M2	M3	M2	M3	M2	M3	M2	M3
C2	6	0	125	34	7	0	133	18	4	0	57	37	6	0	76	36	5
	5	0	159	82	9	0	171	40	5	0	111	81	6	0	143	81	6
	4	0	154	87	8	0	167	59	7	0	154	113	7	0	197	112	7
	3	0	146	75	8	0	137	48	7	0	186	128	8	1	261	127	5
	2	0	322	194	4	0	312	128	5	0	255	234	2	3	294	228	4
	1	11	322	193	7	0	320	119	4	0	302	275	4	6	318	277	4

Table -7: Distribution of Bending moment of C-Shape structure at C3 Column

COLUMN	STOREY NO	BENDING MOMENT															
		MEMBRANE								SHELL							
		RIGID				SEMIRIGID				RIGID				SEMIRIGID			
		PUSHX		PUSHY		PUSHX		PUSHY		PUSHX		PUSHY		PUSHX		PUSHY	
		M2	M3	M2	M3	M2	M3	M2	M3	M2	M3	M2	M3	M2	M3	M2	M3
C3	6	0	125	37	3	1	133	20	1	0	58	38	1	0	78	38	0
	5	0	159	81	4	0	171	42	2	0	112	83	2	0	143	83	1
	4	0	154	87	4	1	167	59	3	0	154	112	2	1	197	111	2
	3	0	146	76	4	2	137	49	3	0	185	125	3	0	257	124	1
	2	0	322	194	2	1	311	128	3	0	254	227	1	3	294	222	3
	1	11	322	195	4	1	320	124	3	1	302	335	2	3	321	348	3

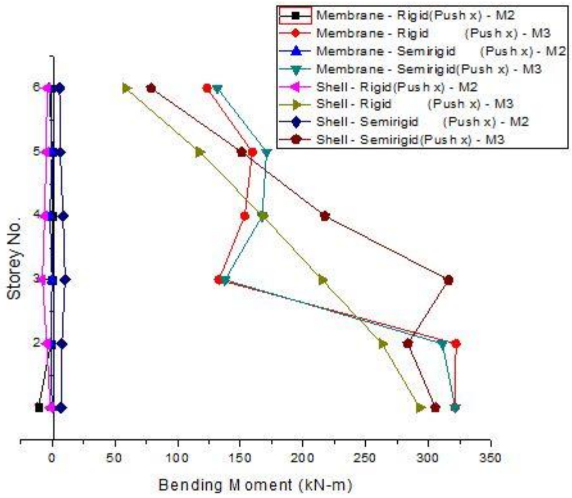

Fig -11: Variation of Bending moment of C-shape Structure in C1 column due to PUSHX

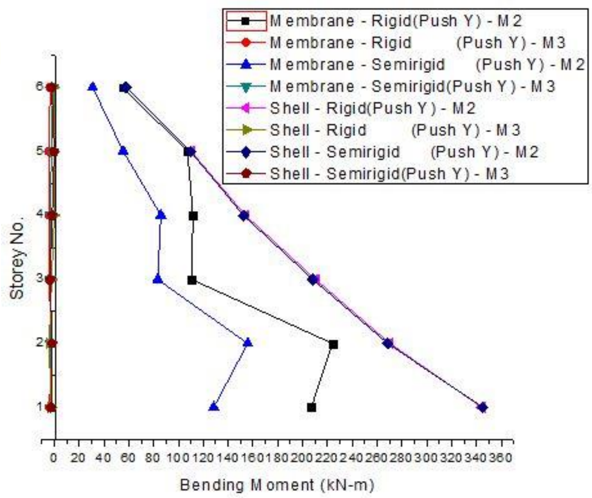

Fig-14: Variation of Bending moment of C-Shape structure in C1 column due to PUSHY

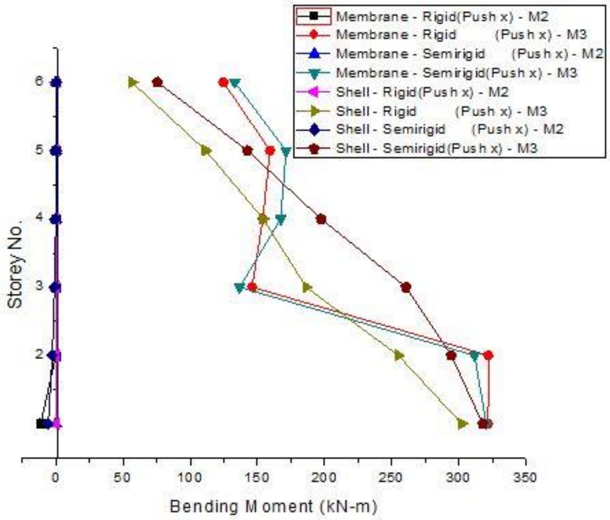

Fig-12: Variation of Bending moment of C-shape structure in C2 column due to PUSHX

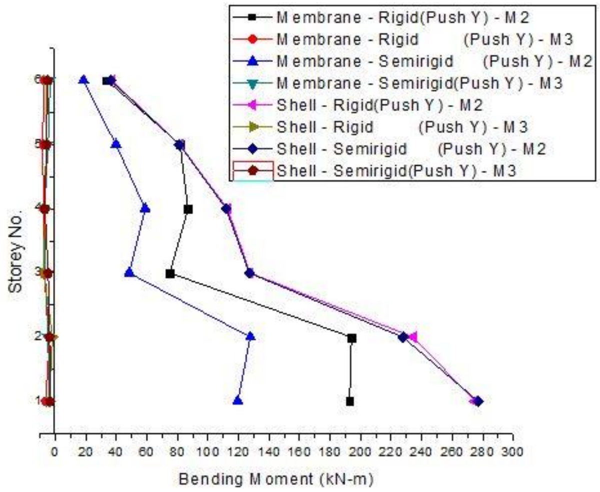

Fig-15: Variation of Bending moment of C-Shape structure in C2 column due to PUSHY

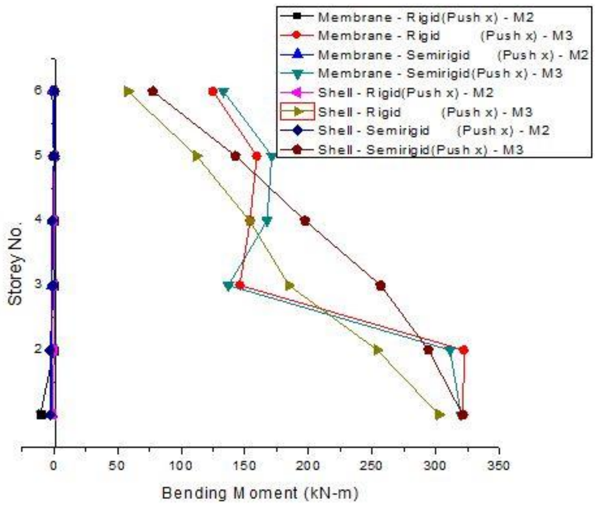

Fig-13: Variation of Bending moment of C-shape Structure in C3 column due to PUSHX

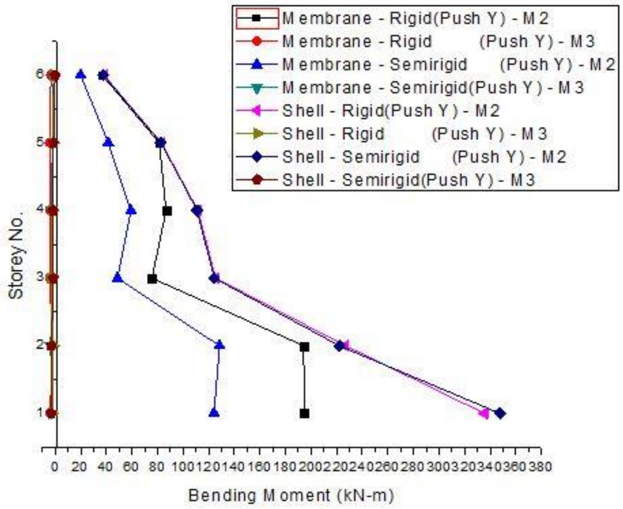

Fig-16: Variation of Bending moment of C-Shape structure in C3 column due to PUSHY

VI. CONCLUSION

From the past earthquakes it has been noticed that the plan asymmetric buildings have performed very poorly. Hence to understand the behavior of the structure performance based analysis like pushover analysis is very useful. Also it is observed that the bending moment values for rigid and semi rigid diaphragm roof modelling conditions are almost same for the Push-X and Push Y Load Case for both L-shaped and C-shaped buildings. Thus from this, it may concluded that the buildings with semi rigid roof modelling/diaphragm condition are more stable than those with rigid roof modelling/ diaphragm condition.

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