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SEISMIC PERFORMANCE OF REINFORCED CONCRETE FRAME WITH PLAN IRREGULARITY

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ABSTRACT

Historically regular buildings perform better in earthquake than irregular buildings which are prone to damage during earthquake. But due to functional and architectural requirements irregularity in structure is unavoidable. While trying to understand the seismic response of irregular structure many researches attempt by using nonlinear static pushover analysis. Performance point in pushover analysis may evaluate the capacity and demand of overall structure. But the response of individual member in the structure with reference to its capacity and the demand that exist in the member needs in depth study. This paper reports results of such study on three different structures. The members so identified are modified so that the structure not only satisfies performance point requirement but also at local level all the members have enough capacity that far exceeds the demand requirement.

Keywords: Plan irregularity; pushover analysis; performance; irregularity level.

1. INTRODUCTION

Irregularities in structures are almost unavoidable due to functional and architectural requirement. In irregular structures, the lateral torsional coupling due to eccentricity between centre of mass and centre of rigidity generates torsional vibration even under purely translational ground shaking. The nonlinear static pushover analysis has been in use for seismic performance assessment of structures and performance based design of structures.

However extension of the use of pushover analysis for irregular structures is not yet consolidated. But it is not wise to limit such a simple and popular method due to its inadequacy to capture torsional motion. If one can understand the limitation of this method for irregular structure, application of pushover to irregular structure will become a reality. The paper aims to attempt this gap and has considered three regular and irregular structures for study. The gaps in pushover analysis are brought out and possible improvements

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required is also suggested. In addition pushover analysis needs the exact nonlinear behaviour of plastic hinges as input to evaluate the global response. A calibration of plastic hinge model (M3 and PMM) is carried out based on the experimental results reported in earlier literature.

2. MODELLING AND ANALYSYS

To verify the validity of pushover analysis with the actual situation and for fixing the pushover parameters for this work, a study was carried out on a three storey reinforced concrete frame and the results were checked with experimental results reported in literature [1]. As given in the paper, a three storied 2x2 bay structure is modelled and analysed in the SAP2000 software. Plan, elevation and reinforcement detailing of the structure is shown in Figs. 1 to 3 respectively.

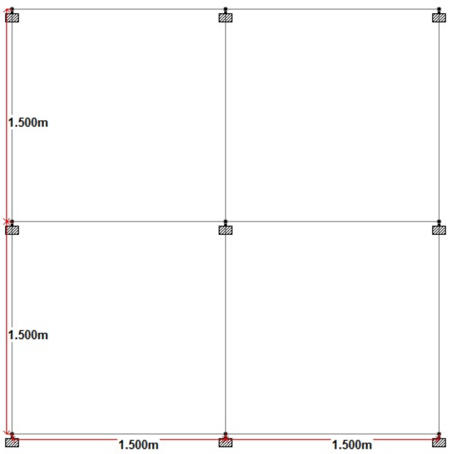

Figure 1. Plan

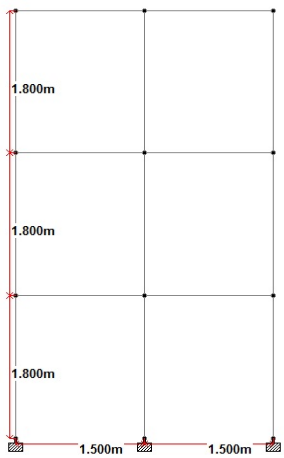

Figure 2. Elevation

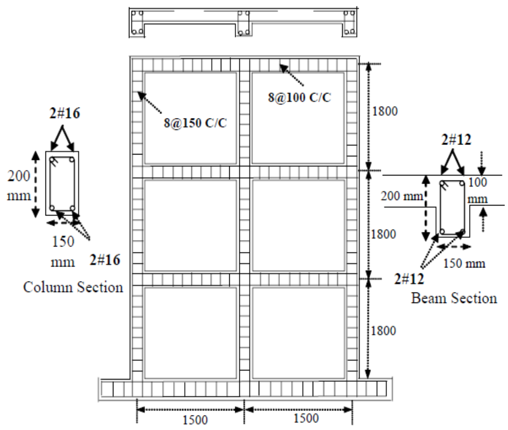

Figure 3. Reinforcement detailing

The results of the pushover analysis and the experimental results reported are shown in Figs. 4 and 5. As can be seen from these figures the load deformation behaviour is identical and predicts well. The nonlinear hinge properties of the reinforced concrete element for M3 and PMM are suitably modified to suit the experimental results. These modified hinge properties are used in the present study.

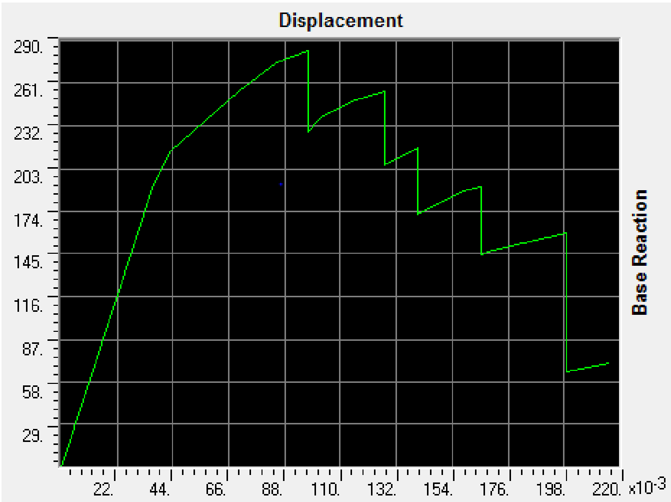

Figure 4. Pushover curve in SAP2000

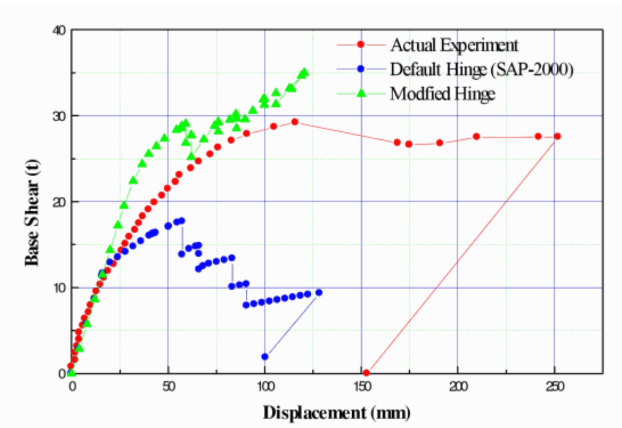

Figure 5. Comparison of experimental results with analysis

The plastic hinge properties were thus fixed for beam and column model using M3 and PMM type of hinges for further pushover analysis of proposed model. Thus the procedure of pushover analysis and hinge properties is finalised.

Residential structures which have irregular plan were chosen and for comparison, regular buildings were also considered. The typical plan of the structure I which has five storeys is shown in Fig. 6. In order to consider variation in plan additionally five storied Structures II and III are also studied. They are taken as residential buildings located in zone V area. The soil is assumed to be hard.

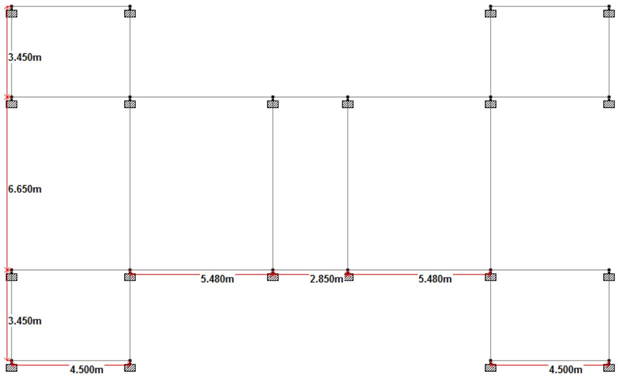

Figure 6. Typical irregular plan for structure I

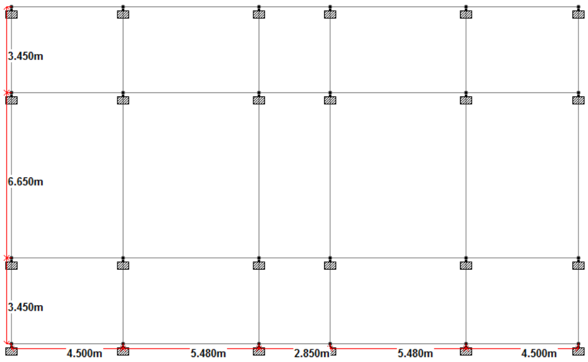

Figure 7. Typical regular plan for structure I

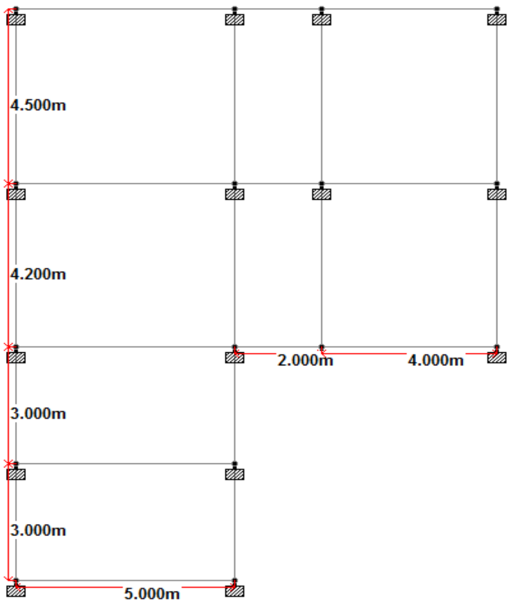

Figure 8. Typical irregular plan for structure II

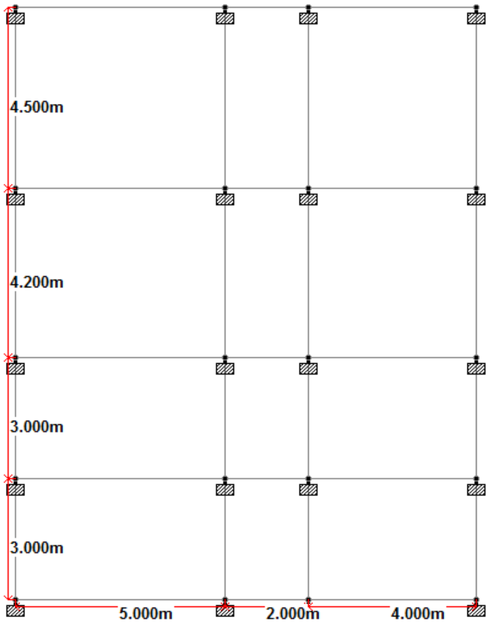

Figure 9. Typical regular plan for structure II

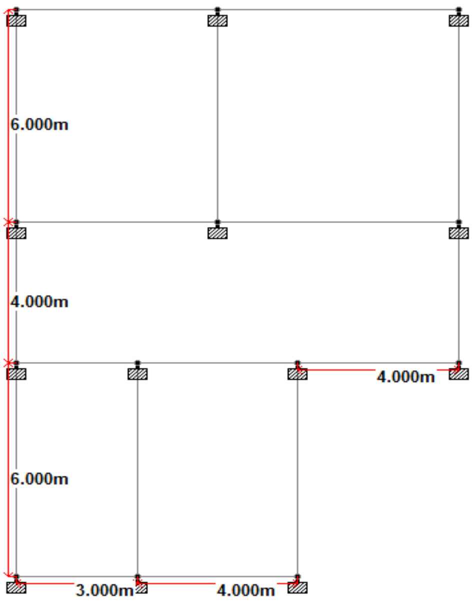

Figure 10. Typical irregular plan for structure III

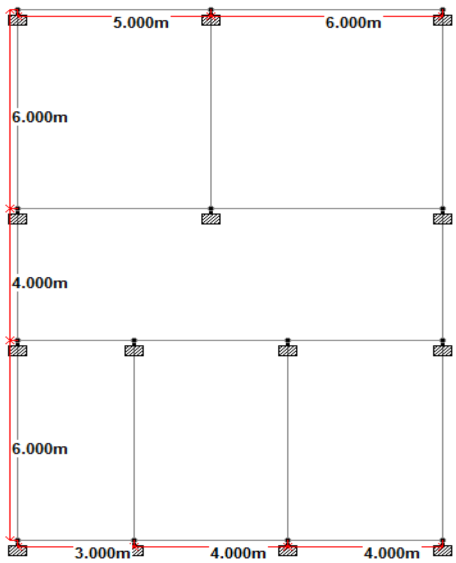

Figure 11. Typical regular plan for structure III

The analysis and design of the structure is done in STAAD Pro. Detailing of beam and columns are obtained and given in Table 1 and Table 2, respectively.

Table 1: Geometrical and reinforcement details of the structural members of structure I with IS456: 2000

Structural Member	Cross-section	Longitudinal Reinforcement	Transverse Reinforcement
Columns	250x400	8#12mm φ	1#6mm φ@200mm
X Beams	250x450	2 #12mm φ & 2#16mm φ	1#6mm φ@150mm
Y Beams	250x600	4#16mm φ & 4#20mm φ	1#6mm φ @150mm

Table 2: Geometrical and reinforcement details of the structural members structure I with IS13920:1993

Structural Member	Cross-section	Longitudinal Reinforcement	Transverse Reinforcement
Columns	600x600	12#20mm φ	1#8mm φ @100mm
X Beams	300x600	6#16mm φ	1#8mm φ @130mm
Y Beams	300x550	8#16mm φ	1#8mm φ @130mm

Table 3: Geometrical and reinforcement details of the structural members of the proposed structures II and III

Structural Member	Cross-section	Longitudinal Reinforcement	Transverse Reinforcement
Columns	300x450	8#16mm φ	1#6mm φ @150mm
Beams	230x600	4#16mm φ	1#6mm φ @150mm

With the help of design and detailing obtained from STAAD Pro., the proposed structure is modelled in SAP2000. All the properties has been assigned and analysed. Pushover analysis is done on all the models in X and Y directions for irregular and regular structures, using SAP2000.

3. RESULT AND DISCUSSION

Results are obtained for different cases given in the previous section by carrying pushover analysis. Comparison of base shear and roof displacement can be seen from Figs. 12 to 15. Base shear and roof displacement for global structure and at the performance point are given in Tables 3 and 4. Comparison of irregular and regular frame is done with respect to same parameters.

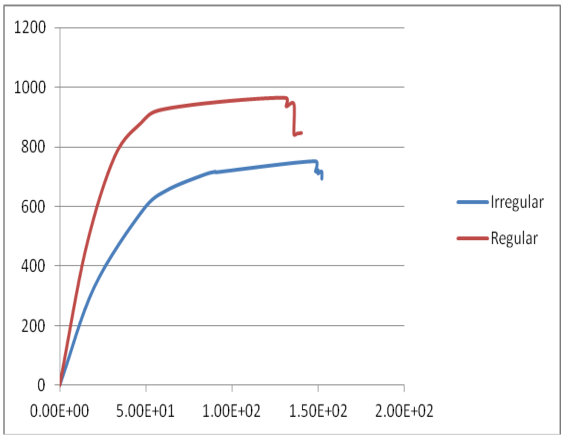

Figure 12. Typical pushover curves for IS456 in X direction

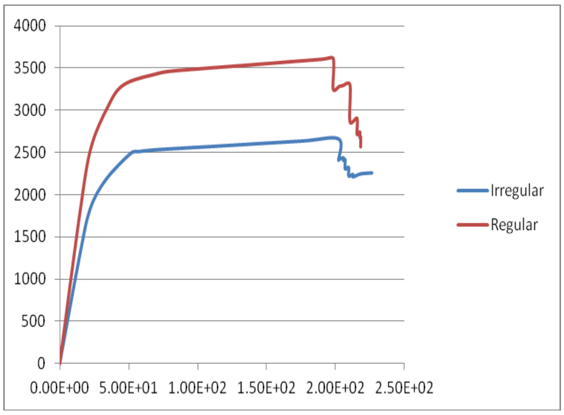

Figure 13. Typical pushover curves for IS13920 in X direction

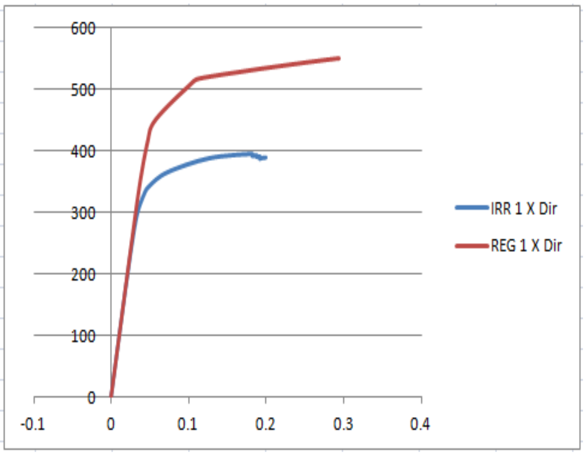

Figure 14. Pushover curves for IS13920 in Y direction

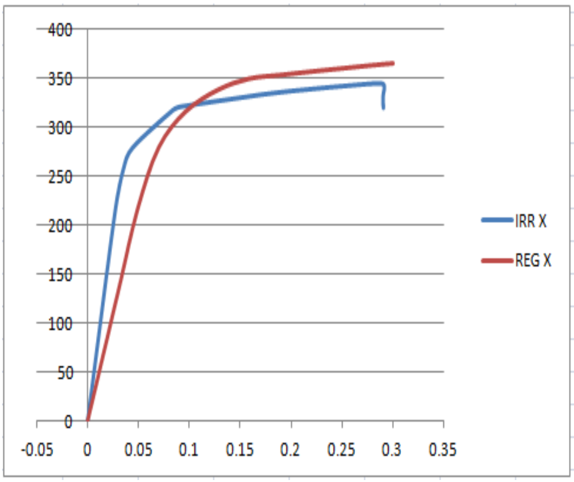

Figure 15. Pushover curves for IS13920 in Y direction

Table 4: Base shear and roof displacement for global structure

			Irregular		Regular	
			Base Shear (kN)	Roof Displacement (mm)	Base Shear (kN)	Roof Displacement (mm)
Structure I	BIS 456	X	756	160	**1040**	160
		Y	980	104	**1000**	104
	BIS 13920	X	2700	200	**3600**	**215**
		Y	2750	200	**3800**	**215**
Structure II		X	400	175	**552**	**285**
		Y	440	255	**630**	**290**
Structure III		X	344	285	**370**	**300**
		Y	392	288	**415**	**350**

Table 5: Comparison of shear force and displacement at performance point

			Irregular		Regular	
			V (kN)	D (mm)	V(kN)	D(mm)
Structure I	BIS 456	X	459	**34**	**715**	29
		Y	769	**27**	**900**	27
	BIS 13920	X	1563	**18**	**2110**	18
		Y	1603	**24**	**2221**	23
Structure II		X	266	**59**	**431**	52
		Y	382	**79**	**473**	51
Structure III		X	279	**65**	**284**	64
		Y	278	**67**	**280**	67

Bending moment of the re-entrant column is checked for all frames at the performance level i.e bending moment demand and, moment capacity of section. Bending moment capacity of the column is calculated manually using sectional properties. Bending moments so obtained are tabulated in Table 6.

Table 6: Comparison of bending moment with respect to demand and capacity at performance point

Structure				Bending Moment Demand	Bending Moment Capacity
Structure I	BIS 456	Irregular	X	**83**	80
			Y	63	70
		Regular	X	64	75
			Y	64	70
	BIS 13920	Irregular	X	**402**	338
			Y	408	486
		Regular	X	405	448
			Y	245	378
Structure II		Irregular	X	**57**	50
			Y	**60**	50
		Regular	X	62	78
			Y	81	96
Structure III		Irregular	X	**86**	79
			Y	**74**	68
		Regular	X	87	87
			Y	90	90

From Table 6, it is observed that the bending moment demand is more than the capacity for both the irregular structures I i.e IS456 and IS13920 when pushover analysis is done in X direction and more for irregular Structures II and III in both direction. Though the demand and capacity is matching for global structure as shown in Fig. 16, we need to take due care while designing re-entrant corner columns, as moment at the re-entrant corner columns is more than the capacity of the column. It can be seen from Table 6.

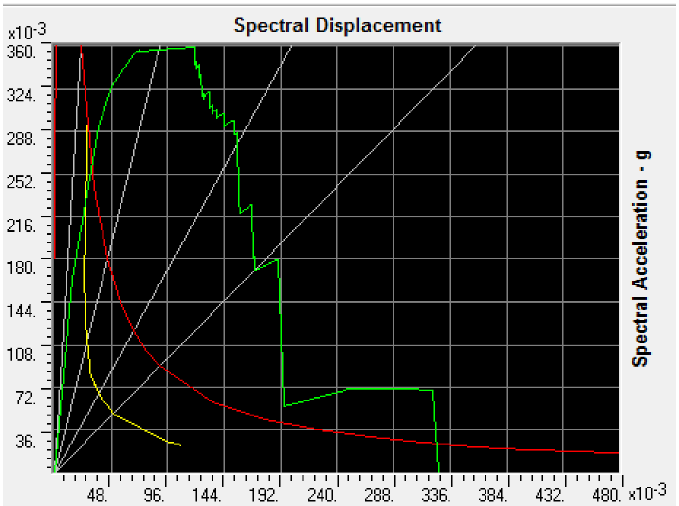

Figure 16. Typical capacity spectrum for pushover analysis of irregular 456 in X direction

Table 7: Geometrical details of the modified structural members of the proposed structures

Structure		**Cross-section**	**Longitudinal Reinforcement**	**Transverse Reinforcement**
Structure I	456	400x400	12#12mm φ	1#6mm φ @150mm
	13920	650x650	12#25mm φ	1#8mm φ @100mm
Structure II		300x550	8#20mm φ	1#8mm φ @150mm
Structure III		300x550	8#20mm φ	1#8mm φ @150mm

To match with required demand of bending moment, the re-entrant corner colums are modified. The modified details of column are given in Table 7.

Again pushover analysis is done on both the modified structures. The bending moment demand and capacity is given in Table 8.

Table 8: Comparison of bending moment with respect to demand and capacity at performance point of original and modified structure

Structure		Bending Moment Demand		Bending Moment Capacity	
		Original	Modified	Original	Modified
Structure I	456 X	83	94	80	112
	13920 X	402	306	335	617
Structure II	X	57	95	50	155
	Y	60	80	50	135
Structure III	X	58	82	79	138
	Y	78	89	68	149

Comparison of base shear and roof displacement of original and modified structure are given from Fig. 10 to 13.

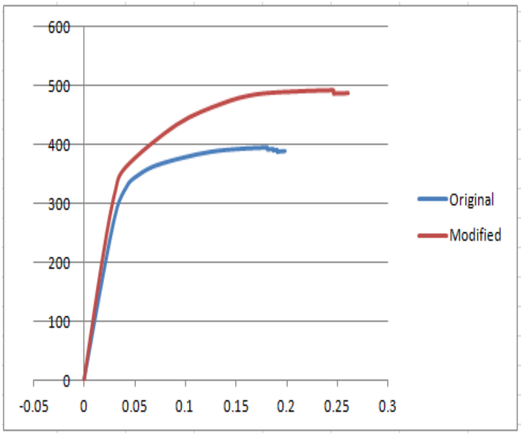

Figure 17. Typical Pushover curves for structure II in X Direction

Table 9: Comparison of shear force and displacement at performance point with original and modified irregular structures

		ORIGINAL		MODIFIED	
		V(kN)	D(mm)	V(kN)	D(mm)
Structure I	BIS456 X	459	**34**	**475**	33
	BIS13920 X	1563	**18**	**1582**	18
Structure II	X	266	**59**	**322**	31
	Y	382	**79**	**429**	78
Structure III	X	279	**65**	**300**	44
	Y	278	**67**	**322**	66

Table 10: Lateral roof displacements of node 1 and node 2 of irregular structures

		ORIGINAL		MODIFIED	
		Node 1	Node 2	Node 1	Node 2
Structure II	X	150	244	148	**163**
	Y	138	209	132	**150**
Structure III	X	142	210	139	**153**
	Y	250	276	250	**256**

Irregularity Level is calculated as response of regular structure to the irregular structure and is given in Table 11

Table 11: Irregularity level at performance point

Structure		Difference (%)
Structure I	BIS 456	27
	BIS 13920	25
Structure II		27
Structure III		5

4. CONCLUSION

Irregularity in plan is unavoidable. It is because of many reasons like requirement of client, functional requirements, etc. Due care is needed while designing such structures.

It is observed from above study that the re-entrant columns need more attention than the other columns. These columns should be designed properly.

The bending moment capacity of those columns was increased to meet the demand. The base shear for regular structure is lower than irregular structure as seen from the table. The reason for such reduced force is due to non-consideration of torsional effect due to irregularity. Base shear for regular structures is likely to be more than that of irregular structures if the force due to torsional moment is considered. Base shear for modified structures is more than the original structures. Irregularity level is almost about 25% for the irregular structures 1 and 2 & 5% for Structure 3. Ductility ratio and response reduction factor is more for regular structures. Irregular structures can behave as regular structures if proper precautions and modifications are made.

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