Seismic Response Modification Of Stiffness Irregular Buildings Using Steel Strips

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Abstract- Due to scarcity of land in big cities, architects propose irregular buildings in order to utilize maximum land area available and to provide adequate light and ventilation in various building components. Most buildings have some degree of irregularity in the distribution of mass, stiffness and strength or in geometric configuration. Due to one or more of these irregularities, the structure develops torsional instability under seismic loads resulting in high force concentrations and displacement amplifications within the resisting elements which can cause severe damages and even collapse of the structure. This paper deals with the study of seismic performance of stiffness irregular buildings using modal analysis and response spectrum analysis and mitigation of the torsional instability using steel strips. It was observed from the study that steel strips effectively reduced the effects of torsion in stiffness irregular buildings.
Keywords – stiffness irregularity, torsion, steel strips

I. INTRODUCTION

Earthquakes are the most devastating and unpredictable of all the natural disasters, which makes it a challenging task to design structures that can withstand minor earthquakes and produce enough caution whenever subjected to major earthquakes. Hence it becomes important to identify the seismic performance of the built environment. The behaviour of a building during an earthquake depends on several factors such as ductility, lateral strength and stiffness, configuration, etc. The demand and lack of space has made planning of irregular configurations inevitable. The seismic response of irregular structures is relatively unpredictable compared to regular buildings due to mass irregularity, stiffness irregularity, strength irregularity, etc.

Buildings with non-uniform distribution of mass, strength and stiffness in plan show torsional behaviour. Larger the eccentricity between the centre of mass and centre of stiffness, larger will be effects of torsion. The torsional response of structures is an area requiring extensive research and hence it will be safer if such effects can be eliminated. A rational methodology can be adopted during the design process for the reduction of torsional effects in new buildings whereas retrofitting techniques can be adopted for torsion in already existing structures. Hence, this study is an attempt to estimate the seismic behaviour of stiffness irregular buildings and the applicability of steel cables to overcome the torsional effects induced in such buildings.

II. BUILDING DETAILS

A 5 storey RC structure consisting of four bays in the X-direction and three bays in the Y-direction is used for the study. The columns are spaced 4m apart in both X and Y directions and the storey height is 3m. The building is assumed to be located in seismic zone V. Stiffness irregularity is introduced by increasing the column section at the left side of the building. Plan of the building is shown in Figure 1.

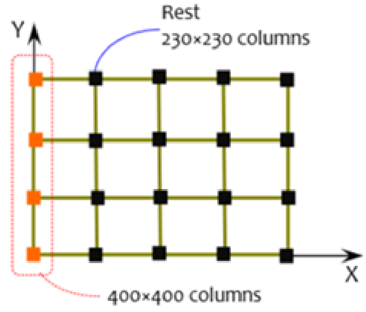


Fig 1: Plan view

Table 1: Description of the building frame

Item	Description
No. of bays in X-direction	4

No. of bays in Y-direction	3
Spacing along X axis	4m
Spacing along Y axis	4m
Story height	3m
No. of floors	G+4
Size of column	300mm x 400mm, 400mm x 400mm
Size of beam	300mm x 400mm
Thickness of Slab	150mm
Grade of Concrete	M30
Grade of Steel	Fe 415
Live load on floor	3 kN/m2
Dead Load from infill wall	10 kN/m
Earthquake load	As per IS-1893 (Part 1) 2002

III. SESMIC ANALYSIS OF STIFFNESS IRREGULAR BUILDING

The building frames were modelled in SAP 2000 and their seismic performance analysed using modal analysis and response spectrum analysis. Figure 2 shows the plan and 3D model of the building frame.

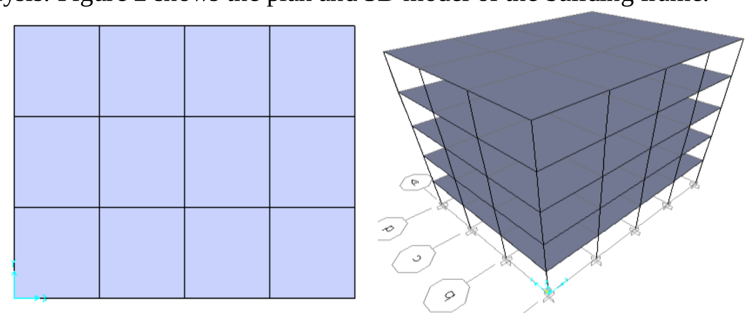


Fig. 2: Plan and 3D view of building frame

Table 2: Results of modal analysis

Mode	Time Period(s)	Mode shape
1	0.91	Torsion
2	0.84	Diagonal
3	0.75	Torsion

Table 3: Results of response spectrum analysis

Base shear (kN)	Column Torsion (kNm)	Column moment (kNm)	Column shear (kN)
417	2.43	43.4	26

As can be seen from Table 2, the stiffness irregular building shows torsional movement under seismic forces. Table 3 shows the base shear in the stiffness irregular building and the maximum values of torsion, bending moment and shear in the columns as obtained from response spectrum analysis.

IV. SEISMIC ANALYSIS OF STIFFNESS IRREGULAR BUILDING

4.1 Retrofitted Using Steel Strips

Case 1: Steel strips provided in one bay

The torsionally unstable irregular building is provided with steel strips of 20mm thickness as vertical and horizontal strips in the exterior bays numbered as shown in Figure 3. 14 such models are analysed to study the influence of cables on the torsional behavior of the stiffness irregular building.

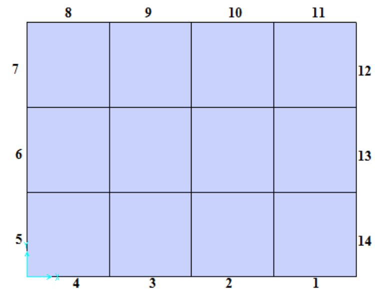


Fig.3: Numbering of exterior bays

The models were analysed in SAP2000 using modal analysis and the results obtained are as given in Table 4.

Table 4: Results of modal analysis

Model	Mode shape with time period (s)			Rotation (degrees)
	1	2	3	
S	T (1.59)	X (1.45)	T (1.07)	2
Ss1	T (1.46)	D (1.19)	T (0.89)	2.5
Ss2	T (1.48)	D (1.17)	T (0.87)	3.4
Ss3	T (1.50)	D (1.17)	T (0.87)	2.3
Ss4	T (1.51)	D (1.17)	T (0.87)	3
Ss5	T (1.53)	X (1.38)	T (0.71)	2
Ss6	T (1.53)	X (1.38)	T (0.70)	2
Ss7	T (1.53)	X (1.38)	T (0.71)	2
Ss8	T (1.51)	T (1.14)	T (0.82)	2.3
Ss9	T (1.50)	T (1.14)	T (0.84)	2
Ss10	T (1.48)	D (1.18)	T (0.88)	2.4
Ss11	T (1.46)	D (1.20)	T (0.90)	2.3
Ss12	Xt (1.19)	Yt (1.17)	T (0.88)	1.8
Ss13	X (1.35)	Yt (1.16)	T (0.94)	0
Ss14	X (1.35)	Yt (1.18)	T (0.94)	0

T-Torsion D- Diagonal mode,
Xt- X translation with torsion Yt- Y translation with torsion

The time period and mode shapes of vibration of the retrofitted building are as shown in Table 4. The maximum reduction of torsion was observed when the steel strips was placed at the 13th position (opposite to stiffness irregularity provided, as in Figure 4) with X translation in the first mode of vibration and torsion in the third modes.

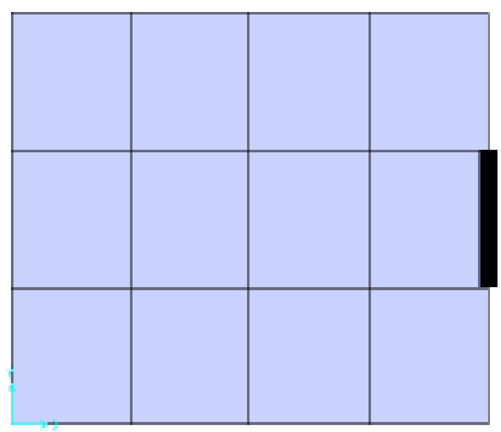


Fig 4: Location of steel strips for maximum reduction of torsion

Response spectrum analysis was also carried out for the 14 models and the results obtained are listed in Table 5.

Table 5: Results of response spectrum analysis

Model	Base shear (kN)	Column Torsion (kNm)	Column Moment (kNm)	Column Shear (kN)	Mode shape
S	417	1.75	43.4	26	Diagonal with torsion
Ss1	408	3.76	12	3.3	Diagonal with torsion
Ss2	402	3.9	9.9	3.4	Diagonal with torsion
Ss3	404	3.86	18.5	5.3	Diagonal with torsion
Ss4	405	4.1	12.6	44.9	Diagonal with torsion
Ss5	419	0.4	42.8	26.4	X translation
Ss6	419	0.1	49.2	30.4	X translation
Ss7	419	0.14	49.9	30.88	X translation
Ss8	398	4.68	38.6	33.5	Diagonal with torsion
Ss9	400	4.63	39.4	24	Diagonal with torsion
Ss10	405	3.81	41.4	25.2	Diagonal with torsion
Ss11	410	3.49	41.2	25.05	Diagonal with torsion
Ss12	464	2.83	18.5	7.26	Diagonal with torsion
Ss13	429	0.14	46	28	X translation
Ss14	428	0.21	45.3	27.5	X translation

As can be seen from Table 5, the results of response spectrum analysis also proves that steel strips placed opposite to the stiffness irregularity provided (bay 13) produced maximum reduction in torsion effects with maximum reduction of column torsion, column moment and column shear by 92%, 33% and 73% respectively and the mode shape changed to pure translation in the X-direction.

Case 2: Steel strips provided in two bays

The torsionally unstable building was analysed with cables provided in two bays, bay 6 and sequentially in bays 15 to 27 (see Figure 5).

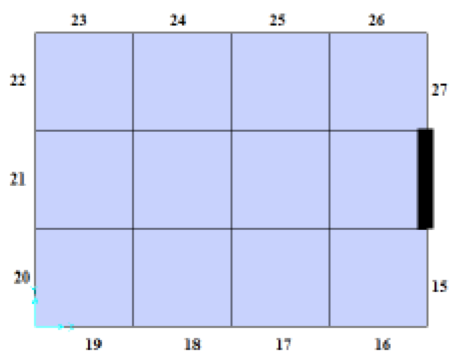


Fig 5: Plan of the building model with fixed steel strips position

The structures were analysed for seismic performance using modal and response spectrum analysis in SAP2000. Table 6 shows results of modal analysis.

Table 6: Results of modal analysis

Model	Mode shape with time period (s)		
	1	2	3
S	T (1.59)	X (1.45)	T (1.07)
Ss15	X (1.35)	Y (1.09)	T (0.90)
Ss16	Xt (1.19)	Y (1.15)	T (0.88)
Ss17	Xt (1.17)	Y (1.15)	T (0.87)
Ss18	Xt (1.17)	Y (1.15)	T (0.86)

Ss19	T (1.16)	D (1.15)	T (0.85)
Ss20	X (1.35)	T (1.12)	T (0.71)
Ss21	X (1.35)	Xt (1.12)	Y(0.69)
Ss22	X (1.51)	Xt (1.35)	Y (1.12)
Ss23	X (1.53)	Xt (1.17)	Y (1.15)
Ss24	Xt (1.17)	Y (1.15)	T (0.86)
Ss25	Xt (1.17)	Y (1.15)	T (0.86)
Ss26	Xt (1.19)	Y (1.15)	T (0.86)
Ss27	X (1.35)	Y (1.09)	T (0.90)

From Table 6, it can be inferred that maximum reduction in torsion was obtained when steel strips were placed as shown in Figure 6. Seismic forces on this model induced translation in the X and Y direction with zero torsion in the first and third mode and X translation with torsion in the second mode.

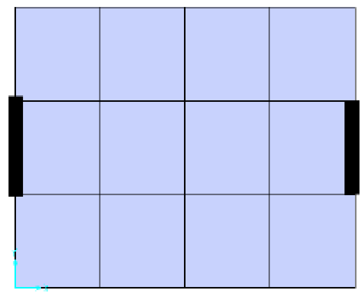


Figure 6: Plan view of model Ss21

Table 7 shows the results of response spectrum analysis of the models with cables provided in two bays. Ascertaining the results of modal analysis, model Ss21 produced the maximum reduction in torsional effects. Column torsion was reduced by 94%, column moment by 16% and column shear by 30% with increase in base shear by 4%. Therefore it can be seen that steel strips provided in two bays are more effective in reducing torsion in the building, compared to steel strips provided in a single bay.

Table 7: Results of response spectrum analysis

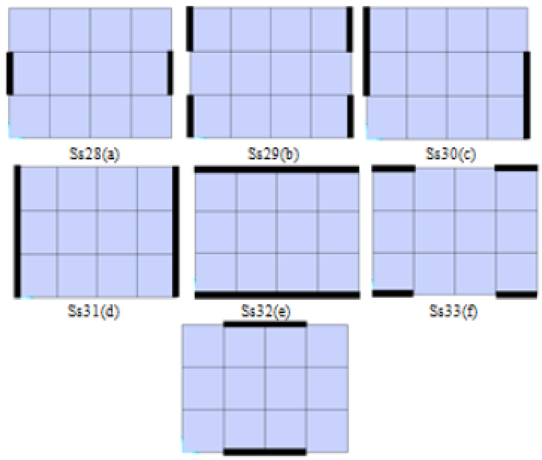
Model	Base shear (kN)	Column Torsion (kNm)	Column Moment (kNm)	Column Shear (kN)	Mode shape
S	417	1.75	43.4	26	Diagonal with torsion
Ss15	434	0.17	45.4	27.3	X translation
Ss16	462	4.17	18.3	7.3	Diagonal with torsion
Ss17	462	3.47	16.5	6.1	Diagonal with torsion
Ss18	462	3.52	21.7	8.8	Diagonal with torsion
Ss19	461	4.2	8.1	38.9	Diagonal with torsion
Ss20	430	0.25	39.4	23.8	X translation
Ss21	430	0.12	36.5	18.3	X translation
Ss22	430	0.3	45.2	27.4	X translation
Ss23	462	3.27	36.9	18.9	X translation with torsion
Ss24	462	3.43	37.9	19.7	X translation with torsion
Ss25	462	3.25	38.02	19.8	Diagonal with torsion
Ss26	462	2.96	37.8	19.8	Diagonal with torsion
Ss27	462	0.12	45.9	27.9	X translation

Case 3: Steel strips in combination

The building models were analysed with steel strips at random positions in order to study the torsional behavior of the building. The details of the models are given in Table 8.

Table 8: Model details

Ss28	Steel strips at middle bays of shorter side
Ss29	Steel strips at edge bays of shorter side
Ss30	Steel strips at corner edge of shorter side
Ss31	Steel strips at both shorter sides
Ss32	Steel strips at both longer sides
Ss33	Steel strips at edge bays of longer sides
Ss34	Steel strips at middle bays of longer sides



The models were analysed in SAP2000 by modal analysis and the results are shown in Table 9.

Table 9: Results of modal analysis

Model	Mode shape with time period (s)		
	1	2	3
S	T (1.59)	X (1.45)	T (1.07)
Ss28	X (1.35)	T (1.12)	T (0.69)
Ss29	X (1.32)	T (1.04)	T (0.62)
Ss30	X (1.33)	T (1.03)	T (0.61)
Ss31	X (1.31)	T (0.99)	T (0.57)
Ss32	X (1.26)	X (0.79)	Y (0.70)
Ss33	Yt (1.32)	X (0.88)	Yt (0.77)
Ss34	Yt (1.32)	X (0.90)	Yt (0.78)

From Table 9, it can be seen that torsion was completely eliminated in the first three modes when steel strips were provided through the full length of the building along the X-direction (as seen as shown in Figure 7). Seismic forces on this model induced pure translation in the X direction in the first two modes and Y direction in third mode.

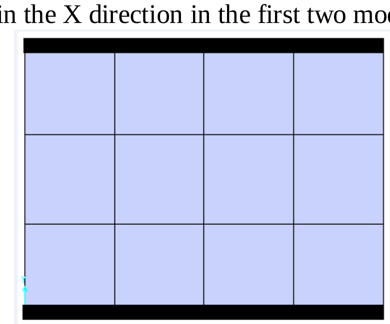


Fig 7: Plan view of model Ss32

Response spectrum analysis was also carried out for the building models with steel strips at random positions and the results are as shown in table 10. Ascertaining the results of modal analysis, the response spectrum analysis also showed that torsion was most reduced for model 32 with a reduction of column torsion, column moment and column shear by 90%, 22% and 23% respectively and the response changed to pure translation in the X direction.

Table 10: Results of response spectrum analysis

Model	Base shear (kN)	Column Torsion (kNm)	Column Moment (kNm)	Column Shear (kN)	Mode shape
S	417	1.75	43.4	26	Diagonal with torsion
Ss28	431	0.3	45	27.2	X translation
Ss29	441	0.6	36	21	X translation
Ss30	439	0.35	37	21	X translation
Ss31	447	0.09	34	20	X translation
Ss32	803	0.09	34	20	X translation
Ss33	686	0.18	6.9	116	X translation
Ss34	706	0.03	47.9	10.4	X translation

V. CONCLUSION

For a stiffness irregular building, the first prominent modes will be torsional.

To counter the effects of stiffness irregularity, balancing irregularity should be provided correspondingly.

Steel strips can be provided at suitable locations to increase the stiffness of the building.

a) Steel strips placed opposite to the stiffness irregularity balances the irregularity due to the reduced eccentricity between centre of mass and centre of stiffness, thereby restricting (92% reduction in column torsion) the irregular movement of the building.

b) Steel strips provided along the full length in one direction can eliminate torsion (95% column torsion) due to increased stiffness of the building balancing the irregularity.

4. Both of these methods are effective in restricting the irregular movement of the building. However buildings with steel strips provided completely along full length in one direction may prove to be uneconomical compared to those with steel strips opposite to the centre of rotation. Therefore the method of retrofitting can be chosen by the designer on cost trade off basis.

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