Mode Mitigation of Seismic Irregular Structure

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Abstract - *This paper reports an analytical study that aimed to mitigate the torsional mode of irregular shaped Reinforced Concrete structures. Torsional irregularity is one of the major causes of severe damage and collapse of structures during an earthquake. It is due to that the irregular distribution of mass, stiffness and strengths may cause serious damage in asymmetry structural systems. During strong ground motion an asymmetrical building gets structural damage and failure due to the torsional behaviour. Structural Analysis software is used to conduct the modal analysis for getting the torsional modes of the seismic irregular structure. This project first concentrates in understanding the complex behavior of structure under asymmetric form and a study on the influence of the torsional effects on the behaviour of structure is done by using modal analysis. Torsional rotation of the mode shape has been found and then the torsional effect is reduced by two different ways such as Adding Shear wall, Adding Bracing to the irregular RC structure. Thus the final torsional rotation of the Reinforced concrete structure are again being modal analysis and the results of various methods are compared with the basic structure that without any retrofitting technique.*

Key Words: Modal analysis, Mode shape, Torsional irregularity, Asymmetric building, Shear wall, Bracing.

1. INTRODUCTION

Geometric irregularities, in floor plan of the buildings can result in accidental torsion of floors, this behaviour is also called as the torsional irregularity i.e, Center of mass does not coincide with the center of rigidity which may cause translational and torsional displacement of the floor. These torsional rotation can be reduced by the retrofitting techniques. Common retrofitting techniques are adding shear wall, adding infill wall, adding bracing, Wall thickening, mass reduction, Base isolation and strengthening of column and beams.

Sachin G. Maske.,et at al.(2002) conducted to analyse the asymmetric RC structure by using ETab software. In that analysis center of gravity (CG) and center of rigidity(CR) calculated, then that eccentricity makes a torsional effect to that structure. By this analysis which columns are getting affected by the torsional behaviour. The earthquake waves pass through the two lateral direction for analysing the torsion due to the dynamics effect by using Etab. The analysis and design of the structure is under guidelines of Indian standard code of practice IS-1893 (Part I: 2002).

M.F. Huang.,et at al.(2010) the linear-mode-shape (LMS) method was recently proposed to address some of the complications in the calculation of the generalised wind forces, which serve as the input to modal analysis for predicting wind-induced dynamic responses of tall buildings. The advanced linear-mode-shape (ALMS) method, a modification of the LMS method, is developed in this paper by introducing torsional mode shape corrections to take into account the partial correlation of torques over building height.

A Kadid et at al.(2011) investigated the seismic behavior of RC buildings strengthened with different types of steel braces, X-braced, inverted V braced, ZX braced, and Zipper braced. Static non linear pushover analysis has been conducted to estimate the capacity of three story and six story buildings with different brace-frame systems and different cross sections for the braces. It is found that adding braces enhances the global capacity of the buildings in terms of strength, deformation and ductility compared to the case with no bracing, and the X and Zipper bracing systems performed better depending on the type and size of the cross section.

Hadad S. Hadad.,et at al.(2014) conducted the experimental investigation on the effect of the different types of bracing on the lateral load capacity of the frame. The different types of bracing and the infill increased the initial stiffness of the bare frame by a reasonable value. The energy dissipation for the braced and infilled frames is always higher than that for the bare frame up to failure. Also, numerical modelling was carried out with the nonlinear software platform (IDARC). The numerical results obtained with the calibrated nonlinear model are presented and compared with the experimental results.

David Ugalde.,et at al.(2017) conducted the case study of damage due to the 2010 Chile earthquake. For reinforced concrete shear walls, these simplifications become even more relevant because of their many (virtually countless) possible cross-sections (e.g., T, L, or C shapes), some of them intricate. Realistic analysis of the seismic response of shear walls having non-rectangular cross-sections (i.e., nonplanar walls) involves a considerably degree of complexity, and is a topic of current researchIn tall building each leg of each non-rectangular wall was evaluated separately, which in Chile is a standard practice in the design process. It was found that the demand-to-capacity (D/C) ratio in many walls is greater than unity, which is inconsistent with the observed lack of damage.

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2. MODELLING AND ANALYSIS

Three types of irregular structures given in Table 1 modelled and modal analyzed in the Structural Analysis Software.

Table 1 Types of Model

Model name	Model Type
M	Geometric Irregular structure
SW	Geometric irregular structure with shear wall
BR	Geometric irregular structure with adding bracing

2.1 Geometric Irregular structure (M)

Four storey (G+3) geometric irregular RC framed structure was made up with Structural Analysis Software shown in Fig1 which consist of M25 grade concrete and Fe415 steel are used throughout the structure. Cross sectional dimensions of beams 0.3mx0.45m. Cross sectional dimensions of column 0.3mx0.3m and Slab thickness is 0.18m. Floor to Floor height of 3m, Length of the each bay is 6m, Live load of 4 KN/m^2 on all floors. Dead Load of the structure automatically calculated by 25 KN/m^3 density of reinforced cement concrete in addition to the dead load of the beam, column, and slab assumed some dead loads was acting on the beam which is uniformly disturbed to represent the infill brick walls for improving the accuracy of the results.

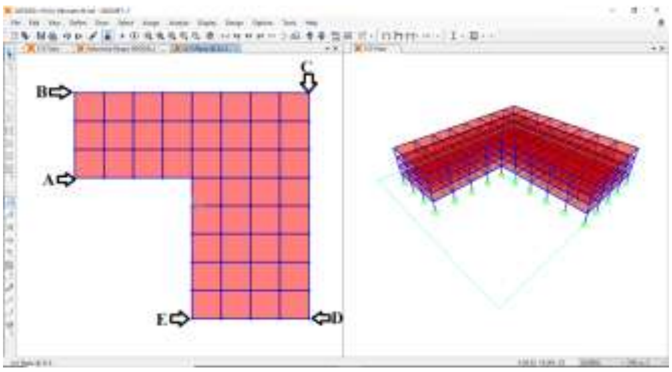

Fig. 1 2D and 3D view of the structure

Modal analysis performed for this structure. To simplify the analysis the maximum number of mode is reduced to 3, because first 3 modes gives almost 99% of participation of static load which is shown in the table 2.

Table 2 Modal Load Participation Ratios (M)

OutputCase	Item	Static	Dynamic
		Percent	Percent
MODAL	UX	98.6639	87.4853
MODAL	UY	98.6637	87.4865

Mode shape frequency and their corresponding eigen values can be calculated by the modal analysis in SAP 2000. That is tabulated in the table 3.

Table 3 Modal Periods and Frequencies (M)

Output Case	Step Type	Step Num	Period	Frequency	Eigenvalue
			Sec	Cyc/sec	rad2/sec2
MODAL	Mode	1	0.979422	1.02101035526578	41.15475591915
MODAL	Mode	2	0.979099	1.02134693662377	41.1818941489297
MODAL	Mode	3	0.905081	1.10487349010606	48.1930978401661

Our main objective of this project is analyzing the torsional effect on the geometric irregular structure. In SAP 2000 vertically upward direction represented as Z axis. So the torsional effect is represents rotation about Z axis (RZ). Modal participation on the RZ are tabulated in table 4. Which shows Mode shape 3 gives the maximum participate in RZ that means mode shape 3 gives maximum torsional effect on this geometrical irregular shape structure.

Table 4 Modal Participation Factors in RZ direction

Output Case	Step Type	Step Num	RZ	ModalMass	ModalStiff
			KN-m	KN-m-s2	KN-m
MODAL	Mode	1	-70.944915	1	41.15476
MODAL	Mode	2	1.385566	1	41.18189
MODAL	Mode	3	1117.061995	1	48.1931

Center of gravity and center of rigidity are located different point in that geometric irregular structure so that some torsion could occur. Effective way of calculating the torsional rotation in torsional mode shape is the measure the maximum outer joint displacement/rotation of any floor because length of the bay is much larger hence radius of the outer edge significantly increased thus the torsional stress also increased. It is much dangerous in the building so that we only considered about that. Outer edge joints are named as the A, B, C, D and E in the Figure 1.

Figure 2,3 shows the 2D and 3D torsional effect on the mode 3 by measuring the rotation by right click of the outer edge joint A,B,C,D and E. where in the all joints the maximum rotation about Z direction is the -0.00111 radian, negative sign indicates the maximum rotation about Z axis (RZ /R3) along clockwise direction.

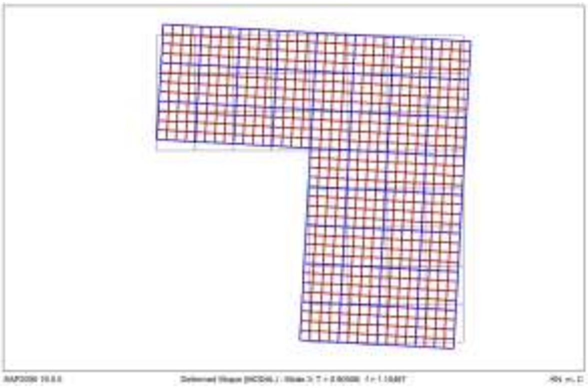

Fig. 2 Maximum 2D torsional rotation on mode 3

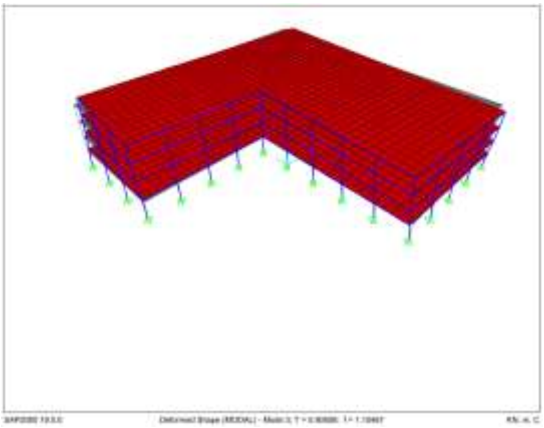

Fig. 3 Maximum 3D torsional rotation on mode 3

2.2 Geometric irregular structure with shear wall (SW)

In that model 3 L shaped shear wall is added with the previous geometric irregular structure to mitigate the effect of torsional in the modal analysis. That Shear wall contains M30 grade concrete and Fe415 steel with two layered of reinforcement with 25 mm cover on each side. Total thickness of the shear wall 200mm. L shaped Shear wall fixed through over entire height of the structure as shown in the Fig 4.

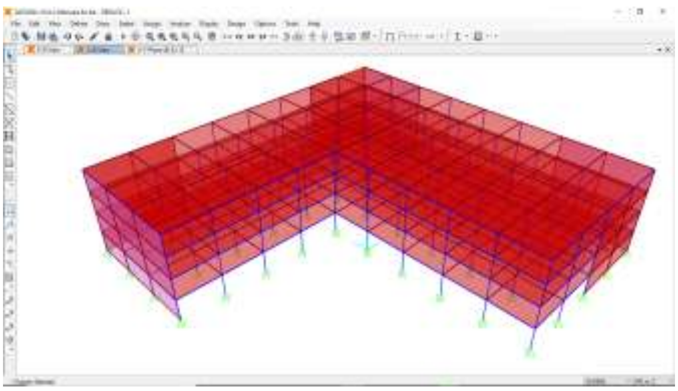

Fig. 4 3D view of geometric irregular structure with shear wall

Commonly in the steel structure angle section is good in torsion, because line of the axis of load cause torsion pass through or parallel through the shear center. From the previous research L shaped shear walls gives good results. L shaped Shear wall provided on the three outer corner of the geometric irregular structure. It provided on the basis of effective and economical use of shear wall that is maximum radius (Between shear center and that point) of the irregular shape building occurs at B, C and E points of the Figure 1. In Modal analysis of the geometric irregular structure with shear wall reduce the maximum number of modes to 3. Then perform the modal analysis which gives the modal load participation of almost 93% to simplify the modal analysis shown in table 5.

Table 5 Modal Load Participation Ratios (SW)

Output Case	Item	Static	Dynamic
		Percent	Percent
MODAL	UX	94.8048	77.9786
MODAL	UY	92.8484	71.597

In that modal analysis there is mode 2 gives some torsional effect on the structure other modes does not experienced any torsion which is clearly shown in the animated video. That deformed shape of the structure as shown in the fig 5.

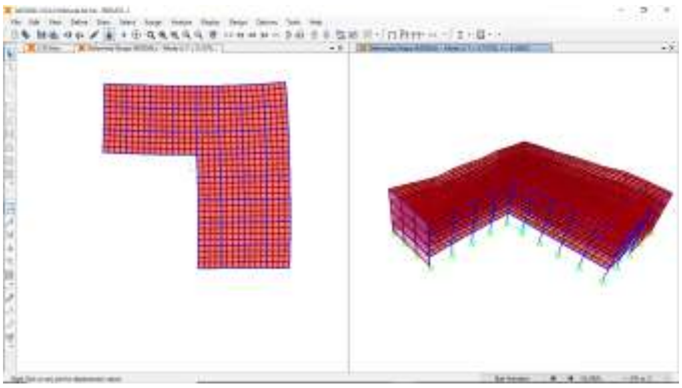

Fig. 5 2D and 3D view of Deformed shape mode2

In that case shear wall gives the lateral stiffness to the irregular structure thus the eccentricity between CG and CR reduced. So torsional mode rotation minimize very much, some torsion near the CG is only occur shown in fig 5 it is not much vulnerable to the structure.

2.3 Geometric irregular structure with adding bracing (BR)

In that model additional to the model of geometric irregular structure [Fig 1] bracings are added in it. X shaped concrete bracing which are connected with all the outer most of the column because outer most area got much affected by the torsional effect. Bracing are 0.3mx0.3m cross section M25, grade concrete and Fe415 steel are used [Fig 6].

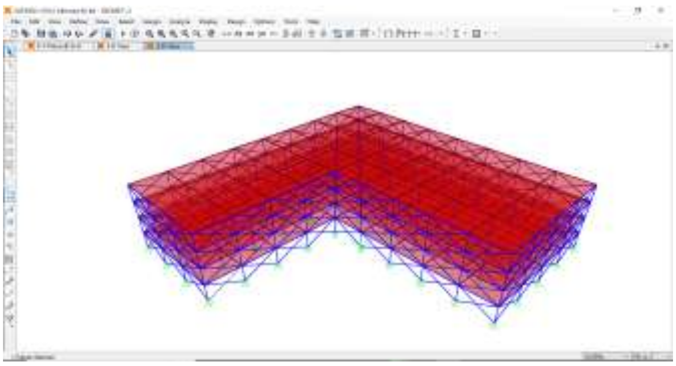

Fig. 6 3D view of braced geometric irregular structure

Modal analysis carried out in that structure and reduce the maximum number of modes into 3 because of simplify the analysis which gives the modal participation of load up to 98% shown in the table 6.

Table 6 Modal Load Participation Ratios (BR)

Output Case	Item	Static Percent	Dynamic Percent
MODAL	UX	97.7026	86.4592
MODAL	UY	98.0185	88.1398

By table 7 maximum modal participation of the rotation about y axis is occurs in mode shape 3. So mode 3 only got torsional behavior, we can analyse only the mode shape 3 to simplify the procedure.

Table 7 Modal Participation Factors (BR)

Output Case	Step Type	Step Num	RZ	Modal Mass	Modal Stiff
			KN-m	KN-m-s2	KN-m
MODAL	Mode	1	-264.6841	1	817.71556
MODAL	Mode	2	-215.62843	1	901.05696
MODAL	Mode	3	1157.21357	1	1939.74735

Fig 7 clearly shows the torsional rotation of the braced geometric irregular structure.

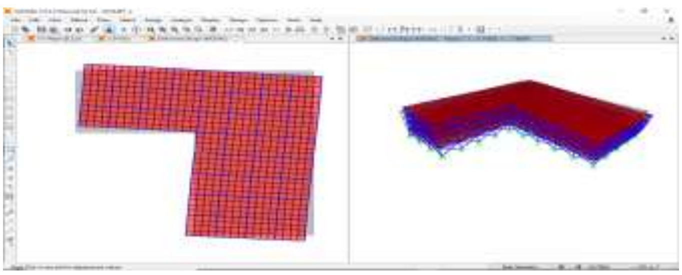

Fig. 7 Deformed shape of the braced model mode 3

3. RESULTS AND DISCUSSIONS

In this paper modelled three different types of the structures such as Geometric irregular structure (M), Geometric irregular structure with Shear wall (SW), Geometric irregular structure with adding bracing (BR) in the SAP2000. Our main objective of this paper is mitigate the torsional mode from the structure. The torsional mode occurs at the frequency of 1.1048, 6.3482 and 7.0095 cycles per second in respectively Geometric irregular, shear walled, braced structure. Table8 shows the rotation of the structures at A, B, C, D and E shown in the figure 1.

Table 8 Displacements of the points (Rotation about Z axis)

Model Name	A(radian)	B(radian)	C(radian)	D(radian)	E(radian)
M	-0.00111	-0.00111	-0.00111	-0.00111	-0.00111
SW	-0.00046	-9.133E-06	0.00011	-0.00034	3E-05
BR	-0.00072	-0.00046	-0.00048	-0.00044	-0.00067

By the table 8 Shear wall greatly reduce the torsional mode shape. After that bracing mitigate the torsional mode of the structure. Figure 8 shows that the minimum rotation obtained by adding shear wall to the structure.

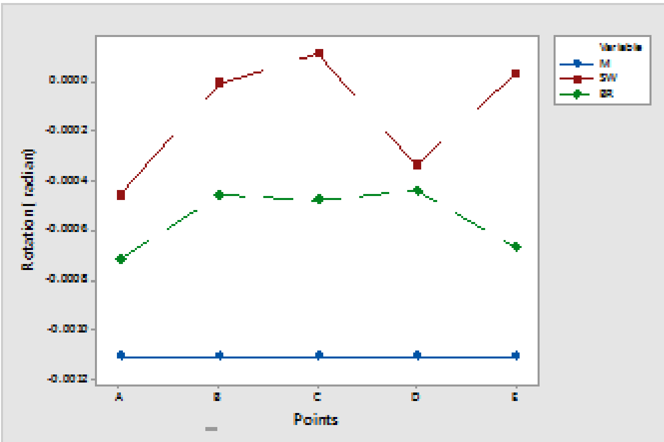

Chart 1 Rotation about z axis at the different point

4. CONCLUSION

It is concluded from this investigation that providing shear wall to the corner frame in the irregular structures in plan significantly reduce the twisting of the Reinforced Concrete structures. The second option to avoid twisting of RC Structure is incorporating X-Bracing at the perimeter of the structures. Since almost 90% participation is achieved in first three modes and analyzing the structures for first three modes is sufficient.

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BIOGRAPHIES

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