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SEISMIC ANALYSIS OF RC SHEAR WALL FRAME BUILDINGS WITH AND WITHOUT OPENINGS IN SHEAR WALL

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ABSTRACT

The reinforced concrete shear wall is one of the most commonly used lateral load resisting system in high rise buildings. Because of its high inplane stiffness and strength, it can resist large horizontal forces and support gravity load simultaneously. During seismic excitation, they contribute in absorbing moments and shear forces and reduces torsional response. Often in practical scenario shear walls, large in dimensions are provided with an opening area in the middle or side of the wall to serve various architectural purpose, which ultimately results into substantial decrease in strength of the wall and have an adverse effect on seismic response of frame shear wall structure. The scope of this study is to compare the effect of shear wall with and without opening in RC frame shear wall structure in multistorey buildings. To carry out the analytical investigation, the structures are modelled in finite element software SAP2000.v.17.1.1.Three different types of analysis is carried out i.e. linear static, non linear static and non linear dynamics. The parameters that are compared are storey displacement, time period, base shear, maximum displacement, target displacement, energy dissipation and equivalent stiffness. For the accomplishment of this purpose the work is done in two parts. In the first part five different 10 storey shear wall RC frame models are considered with no opening area to variable size of openings area of 7%, 13%, 27% & 40% respectively. In the second part four different 10 storey shear wall RC frame models are considered with an opening area of 13% and horizontal opening eccentricity of (e_h=0,e_h=0.5m,e_h=1.0m & e_h=1.5m) respectively from centre of Shear wall.The comparison of these models for different parameters are presented here.

Keywords: Openings, SAP2000, Response spectrum, Time history, Pushover, base shear, target displacement, equivalent stiffness, energy dissipation.

I. INTRODUCTION

Many destructive earthquakes have been reported in past historical records that have devastated different parts of the world in different times. Earthquake is one of the nature's greatest hazards to the properties and human lives. It poses a unique engineering design problem for civil engineers. An intense earthquake constitutes severe loading to which most of the structures may possibly be subjected.

Buildings are designed to serve the needs of an intended occupancy. One of the important design requirements is the provision of an appropriate internal layout of buildings. Once the functional layout is established, one must develop a structural system that satisfies the strength criteria while satisfying the architectural layouts. The primary purpose of all kinds of structural systems used in the building is to support gravity loads. Besides these gravity loads, buildings are also subjected to lateral loads caused by wind, blasting or earthquake. An introduction of shear wall represents a structurally efficient solution to stiffen a building structural system laterally because the main function of a shear wall is to increase the rigidity for lateral load resistance. The reinforced concrete shear wall has high in plane stiffness and strength which can be used to simultaneously resist large lateral load and support gravity load.

To serve various architectural purposes such as doors and windows, we need to provide openings in large concrete shear wall at different locations. The size and location of openings may vary from architectural and functional point of view. This piercing of shear wall influences its behaviour, such as changing its force transfer mechanism, deducting its strength and stiffness, and decreasing its ductility level. Relative stiffness of shear walls is important since lateral forces are distributed to individual shear wall according to their relative stiffness. Therefore it ultimately affects the seismic response of frame shear wall structure. The scope of this paper is to study the effects of opening in shear wall in frame shear wall structure by comparing different parameters such as base shear, maximum displacement, target displacement, energy dissipation and equivalent stiffness by three different types of analysis i.e. Response spectrum analysis, Pushover analysis and Time History analysis.

II. PREVIOUS RESEARCH

Many researchers have investigated the effect of opening in concrete shear wall.

Lin and Kuo (1988),had conducted finite element analysis and experimental work to study the ultimate strength of shear wall with openings under lateral load. In the test program, the different amount and pattern of reinforcement were arranged around the openings. The test results indicated that the shear strength contributed by diagonal reinforcement around opening reached 40% of its yield strength, while the shear strength contributed by rectangular arrangement reached 20% of its yield strength.

Yanez, Park and Paulay (1992), studied on seismic behaviour of reinforced concrete walls with square openings of different size and arrangement under reversed cyclic loading. From experimental results, it was concluded that appropriately designed walls with staggered openings can have the same behaviour and ductility as walls with regular openings.

Elnashahi and Pinho(1998), tested a coupled shear wall at real scale. In their work, the load capacity and stress distribution around the openings were analyzed by conducting three-dimensional (3D) nonlinear push overanalyses on typical shear wall dominant building structures. They investigated the pattern of cracks, and the connection between wall and slab; the research showed significant contribution for increasing the global lateral resistance, by the interaction between wall-to-wall and wall-to-slab.

Khatami and Mortezaei (2012),studied the effect of openings in concrete shear walls under near fault earthquake ground motion. For this challenge, two near-fault earthquakes were selected from different records of past earthquakes: Loma Prieta and Taiwan.

Satpute S G and D B Kulkarni(2013),has done a comparative study of reinforced concrete shear wall analysis in multi-storeyed building with openings in shear walls by nonlinear method of analysis by varying the opening size in shear wall. All procedures incorporated in the analysis was performance-based paying more attention to damage control. Analysis is carried out by using standard package SAP2000.

III. STRUCTURAL MODELLING

Eight building models with 10 storeys having same floor plan area of 25m X 12m dimensions are considered for this study. The floor plan is divided into 5 bays in x-direction and into 3 bays in y-direction. Centre to centre distance between two gridsare 5m in x-direction and 4m in y-direction as shown in figure 1. The storey height for the building is taken as 3m for all the floors.

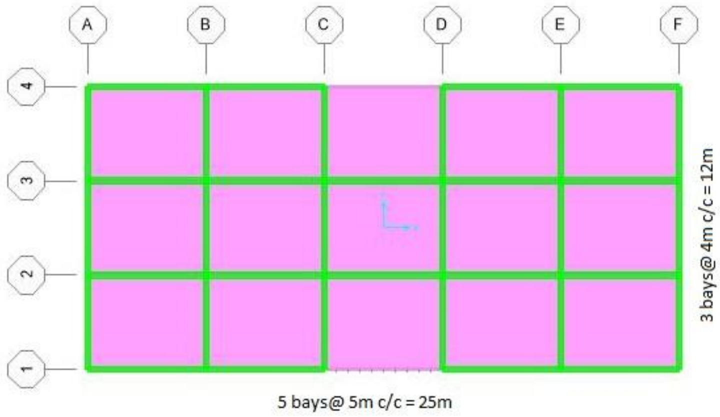


Figure1 Typical plan of building models of RC frame shear wall structures

The Research work is divided into two parts for the convenience of understanding the effect of opening sizes and locations discretely. In the first part, effects of horizontally centred opening of variable sizes from no opening to 7%, 13%, 27% & 40% of opening area of shear wall on RC shear wall frame structure is studied. In the second part of work size of opening is kept constant (i.e. 13% of opening area) but location of opening is changed in horizontal direction from 0.5m to 1.5m and the effects are studied.

Table1 Description of building models considered.

Model No.	Opening Size (m)	Opening Area (%)	Ecc.(eh) (m)
Model-1	-	0	0
Model-2	1 x 1	7	0
Model-3	1 x 2	13	0
Model-4	2 x 2	27	0
Model-5	2 x 3	40	0

Part-1

Model No.	Opening Size (m)	Opening Area (%)	Ecc.(eh) (m)
Model-3	1 x 2	13	0
Model-6	1 x 2	13	0.5
Model-7	1 x 2	13	1
Model-8	1 x 2	13	1.5

Part-2

All the eight RC shearwall frames models are designed for gravity loading as per IS: 456: 2000,IS: 875:1987 (part-1 & part-2). Lateral loads due to earthquake (EL) were calculated considering full dead load(DL) plus 25% of imposed load (IL), using seismic coefficient method given in IS1893 (Part 1): 2002.

PRELIMINARY DATA

1. Column size: 0.45 m × 0.45 m
2. Beam size: 0.23 m × 0.45 m
3. Slab thickness: 0.125 m
4. Shear wall thickness: 0.25 m
5. Grade of concrete for beams and columns= M30
6. Grade of concrete for slabs and shear walls= M25
7. Grade of Steel = Fe415
8. Unit weight of concrete (γ) = 25 kN/m^3

IV. RESULTS AND DISCUSSIONS

Analysis of eight 10 storey RC shear wall frame structures were carried out using software SAP2000.v.17.1.1 for three different types of cases i.e. linear static, non linear static and non linear dynamic. Results are shown below.

V. RESPONSE SPECTRUM ANALYSIS RESULTS

The results of the response spectrum analysis of all the building structures chosen are compared and discussed in this section.

Table2 Time Period, base shear and maximum displacement of frame-shear wall structures as size of opening increases.

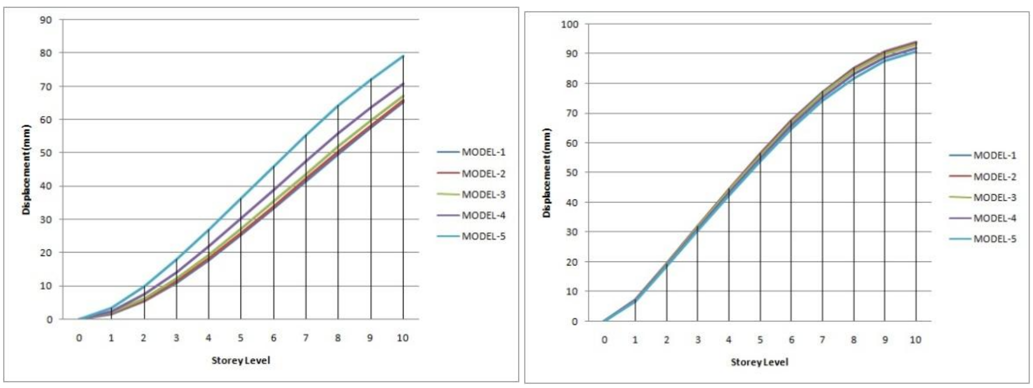
SL. NO.	PARAMETERS		MODEL-1	MODEL-2	MODEL-3	MODEL-4	MODEL-5
1	**Time Period(T)** (sec)	Mode-1	1.8796	1.8769	1.8743	1.86915	1.86447
		Mode-2	1.23737	1.24902	1.26756	1.3114	1.38129
		Mode-3	1.14447	1.15389	1.17077	1.21795	1.3101
2	**Base Shear** (KN)	in x-dir.	2336.813	2329.11	2321.4	2305.98	2290.57
		in y- dir.	1631.87	1626.48	1621.11	1610.34	1599.58
3	**Maximum Displacement** (mm)	in x-dir.	65.27	65.88	67.04	70.83	79.17
		in y- dir.	94.02	93.61	93.13	92.1	90.81

Table 3Time Period, base shear and maximum displacement of frame-shear wall structures as position of opening changes.

SL. NO.	PARAMETERS		**MODEL-3**	**MODEL-6**	**MODEL-7**	**MODEL-8**
1	**Time Period(T)** (sec)	Mode-1	1.8743	1.87432	1.87437	1.87459
		Mode-2	1.26756	1.27037	1.27999	1.30014
		Mode-3	1.17077	1.17619	1.19406	1.22986
2	**Base Shear** (KN)	in x-dir.	2321.4	2321.4	2321.4	2321.4
		in y- dir.	1621.11	1621.11	1621.11	1621.11
3	**Maximum Displacement** (mm)	in x-dir.	67.04	68.38	71.28	83.37
		in y- dir.	93.13	93.2	93.2	93.09

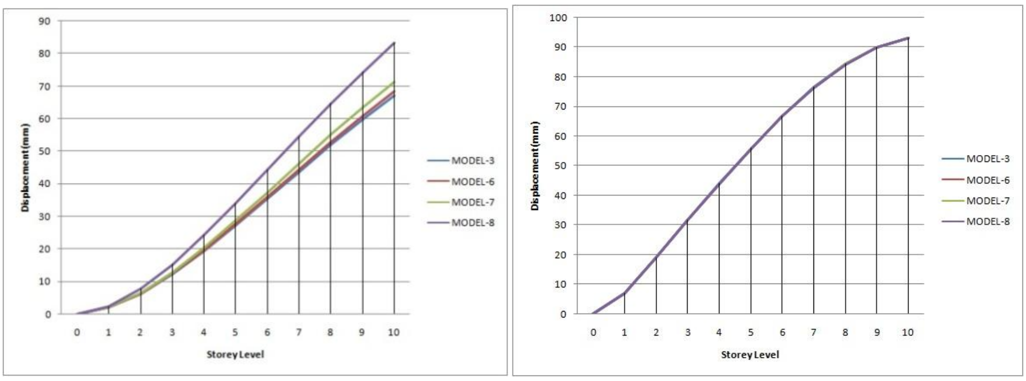
It can be inferred from the above comparisons that as the size of opening increases from 0% to 40% the time period remains almost same for first and second mode in which building has a displacement in y-direction and torsional direction respectively. However time period slightly increases in third mode in which building has a displacement in x direction as the size of openings increases. The same results for time period can be observed for the building models having 13% opening area and the horizontal eccentricity of opening changes from 0m to 1.5m.But in this case increase in time period is very less.

Base shear shows a decreasing pattern as the size of the opening increases in both the directions. This may be due to the decrease in gravity load due to reduction in size of shear wall. In second part there is no change in the value of base shear.



(a) (b)

Figure2 Storey displacementsof building in x & y direction respectively for different sizes of openings in shear wall.



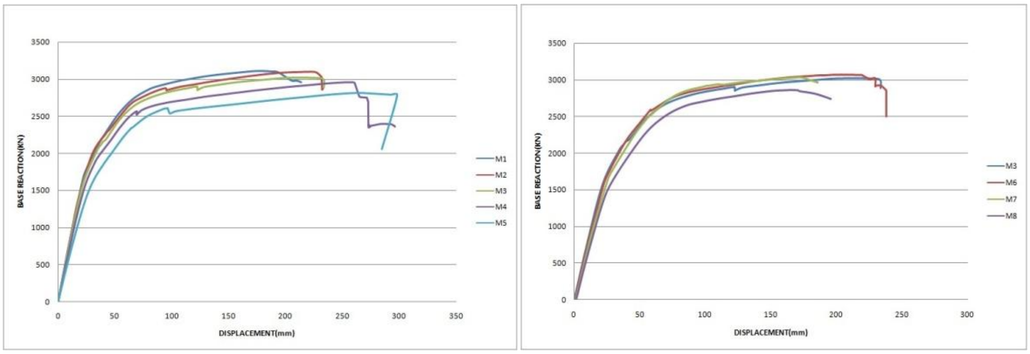
(a) (b)

Figure 3 Storey displacementsof building in x & y direction respectively for different horizontal position of openings in shear wall.

The maximum displacement of top storey of building structure increase in x-dir. as the size of opening increases. However this change is very low for opening area of shear wall up to 13%(i.e. 1m x 2m size).The increase in displacement is only about 3% when we provide an opening of area up to 13%.The displacement value increases to 8.5% when we provide an opening area of 27% and to 21% when we provide an opening area of 40%.Similarly the displacement value increases to 6% when we provide an opening area of 13% at a horizontal eccentricity of opening at 1m from centre of wall which further increases to 24% when we provide opening at 1.5m from centre of wall. The displacement in y-dir. shows no significant change for this case.

VI. PUSHOVER ANALYSIS RESULTS

A nonlinear pushover analysis of the selected building is carried out as per FEMA 356 forevaluating the structural seismic response.



Part-1Part-2

Figure 4 Pushover curve for different building models for part-1 and part-2 analysis in frame-shear wall structures.

Table 4 Target displacement, energy dissipated and equivalent stiffness of structure with the increase in opening area of shear wall (part-1).

Model No.	Percentage	Target displacement	Energy(Ed)	Equivalent stiffness
	opening	(mm)	kNm	kN/m
Model-1	0%	122.34	1935.9	24674.68
Model-2	7%	124.97	2057.4	23547.5
Model-3	13%	125.46	2102.2	22905.3
Model-4	27%	133.39	2148.3	20786.5
Model-5	40%	151.56	2482.2	17505.78

Table 5Target displacement, energy dissipated and equivalent stiffness of the structure with change in position of opening area in shear wall (part-2).

Model No.	Percentage	Eccentricity	Target displacement	Energy(Ed)	Equivalent stiffness
	opening	eh	(mm)	(kNm)	kN/m
Model-3	13%	-	125.46	2102.2	22905.3
Model-6	13%	0.5m	126.02	2016.4	23362.58
Model-7	13%	1.0m	127.99	1918.3	23209.26
Model-8	13%	1.5m	129.09	1530.8	21649.6

VII. TIME HISTORY ANALYSIS RESULTS

The results obtained by carrying out time history analysis for the PGA of 1.0577 m/s^2 from data taken from ground accelerationgiven by IS 1893 scaled for zone IV is shown below.

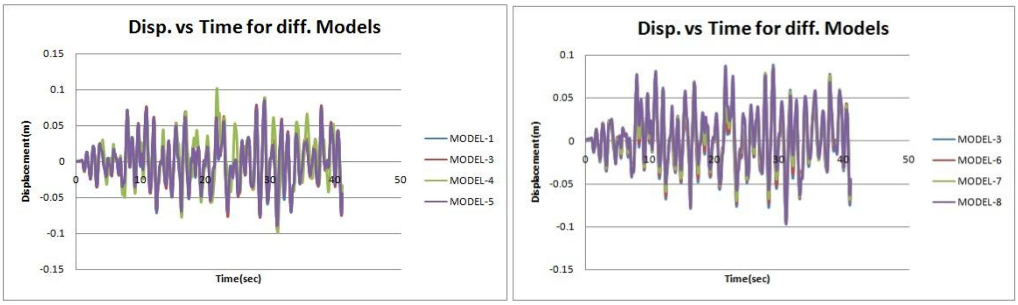
Table6Various parameters for time history analysis for increasing size of opening of shear wall.

Model No.	Opening	Acceleration	Displacement	Base shear
	area	(m/s2)	(mm)	(kN)
Model-1	0%	4.006	86.6	6567
Model-2	7%	4.393	87.2	6352
Model-3	13%	4.054	95.31	5611
Model-4	27%	4.735	98.52	5127
Model-5	40%	3.799	102.5	4084

Table7 Various parameters for time history analysis for different location of opening of shear wall.

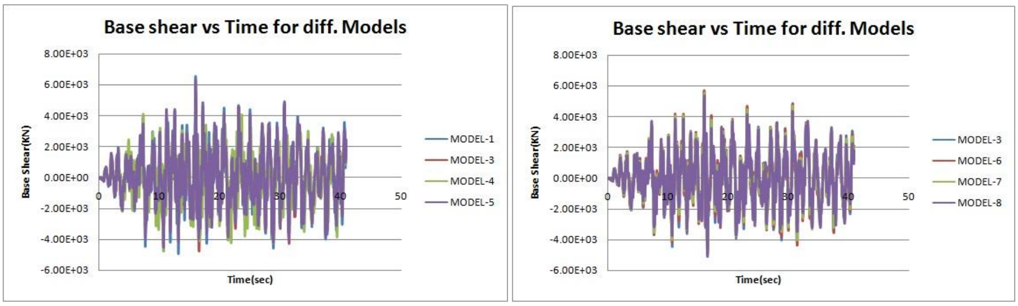
Model No.	Opening area	Horizontal Ecc.(m)	Acceleration (m/s2)	Displacement (mm)	Base shear (kN)
Model-3	13%	0	4.054	95.31	5611
Model-6	13%	0.5	4.675	92.8	5702
Model-7	13%	1	4.73	95.36	5537
Model-8	13%	1.5	4.8	97.31	5373

Plot between displacement versus time and base shear versus time for different building models are shown below.



Part-1 Part-2

Figure 5 Time history of displacement for different building modelsfor part-1 and part-2 analysis in frame-shear wall structures.



Part-1 Part-2

Figure 6 Time history of base shear for different building models for part-1 and part-2 analysis in frame-shear wall structures.

VIII. CONCLUSIONS

In this work, linear static analysis, non linear static analysis and non linear dynamic analysis is performed on a 10 storey building models to see the effects of openings in shear wall in RC shear wall frame structure. The following conclusions are drawn on the basis of numerical results obtained by software.

1. The response and stiffness of frame shear wallstructure is more affected by the size of opening than their locations in shear wall. However the response of the building is better when the openings are provided in the centre of the wall as compared to their horizontal eccentric positions.

2. The response and behaviour of frame shear wall structure remains almost similar for an opening up to 15% of shear wall areaas that of shear wall with no openings.

3. The values of seismic responses namely time period and maximum displacement are found in increasing order for all the three types of analysis.

4. The observed maximum displacement of top storey in case of response spectrum analysis is found 21% more in case of 40% opening area of shear wall than the shear wall without an opening. This change in maximum displacement of top storey is 24% in case of pushover analysis and 18% in case of time history analysis.

5. Similarly the displacement value increases to 6% when we provide an opening area of 13% at a horizontal eccentricity of 1.0m from centre of wall as compared to no horizontal eccentricity.This change in maximum displacement of top storey is 2.5% in case of pushover analysis and 2.1% in case of time history analysis.

6. The energy dissipated by the structure is found out to be increasing with increase in the size of the openings. The more energy dissipated by the structure the more it will be damaged by earthquake forces. The percentage increase in energy dissipation are 6.3%,8.6%,11%& 28% as the opening area in shear wall increases from 7%, 13%, 27% and 40% respectively.

7.The equivalent stiffness of the structure is observed to be in decreasing order for both the case, i.e. with increase in size of opening of shear wall and with increase in horizontal eccentricity of opening in shear wall. The decrease in equivalent stiffness is 4.6%, 7.2%, 15% and 29 % as we increase the size of opening in shear wall to 7%, 13%, 27%, and 40% respectively. Moreover the observed decrease in stiffness of frame shear wall structure as we increase the eccentricity of opening in horizontal direction to 1.0m and 1.5m are 0.65% and 7.3% respectively. This decrease is relatively low as compared with the increase in size of opening in shear wall in frame shear wall structure.

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