

PERFORMANCE BASED EVALUATION OF FRAMED REINFORCED CONCRETE SHEAR WALLS BY PUSHOVER ANALYSIS

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Abstract - *The structural safety for seismic loading is one of the most important factor along with building serviceability and potential for economic loss during major earthquakes. As trend is moving towards multi-storied structures, it is necessary for designers to provide adequate lateral strength and stability against the earthquake loads and wind loads. Hence in order to provide the lateral strength and stability shear walls are providing in the structures. The present work is based on comparing the bare frame with models having a reinforced concrete framed shear walls, which are modeled by using two different methods. The simplified shear wall which is single element throughout the building and refined model which is multi-layered membrane element. The shear walls are placed at different positions in the building along X and Y direction. The equivalent static and nonlinear static pushover analyses are carried out by using the software tool ETABS 2015 v.15.0.0. For the different load combinations available in IS 1893(part1): 2002 the displacements for different models are compared. The base shear, fundamental natural period and performance of the models are compared.*

Key Words: *shear wall, refined model, simplified model, displacement, reinforced concrete, Pushover analysis*

1. Introduction

In the present scenario construction of multi-storey buildings is very common thing. Therefore it is necessary to prevent them from damages due to the natural disasters like earthquake is very important factor. The structural safety for seismic loading is one of the most important factor along with building serviceability and potential for economic loss during major earthquakes. Seismic loading on any structure needs detailed information of structural behavior under large inelastic deformations. The behavior of seismic loads are different from wind loads or gravity loads, thus they require more detailed analysis to ensure acceptable seismic performance beyond the elastic range. When buildings under goes design ground motions, they are allowed to have some structural damages. This is due to almost all building codes permit inelastic energy dissipation in the structural systems.

Frames, shear walls and tubes are commonly used to resist the lateral loads. Now days shear walls and tubes more popular in multi-storey buildings in order to resist large lateral loads. In the present work framed shear walls are consider for analyses. Framed shear wall means infill panels are placed while constructing the frames or after the construction of the frames. If we placed the infill panels after the construction of the frames, then they carry little amount of gravity loads. But they can withstand for large amount of lateral loads due to the action of shear.

2. Literature

Indu. G and Amlan K. et.al[1] considered 4-story low rise building with shear wall located at the center of the building. The pushover analyses were carried out using the software SAP2000 for both models. Obtained pushover curves for both models were compared. The different type shear walls used in this study were as follows simple shear wall with equivalent column element and refined shear wall with wall panels having multi-layered membrane elements. They used the soften truss model to develop the shear hinge properties for simplified model with equivalent column element.

Z.W.Miao, X.Z.Lu et.al[2] analysed a shear wall which consist of multi-layer shell elements. Based on mechanics of composite materials shear wall is modeled and analysed. The shear wall is made up of many layers with various layer thicknesses. Layers are assigned with different materials like concrete and rebar. Then multi-layered shear wall is analysed for static pushover loads and cyclic loads.

Kubin et.al[3] used the finite element modelling method to model the shear walls. They considered the shear wall using shell elements with different mesh sizes and shear wall with frame element i.e mid-pier type for the analysis. The pushover analysis was carried out for both models and pushover curve is compared.

Kasliwal Sagar et.al[4] considered 16-story building with shear wall and modeled using both ETABS and SAP2000 software's. They carried out linear dynamic as well as nonlinear static analyses i.e response spectrum and pushover analysis respectively. By varying the position and number of shear wall the results for the building was obtained in both the softwares.

2.1 Problem formulation

An 8-story regular RC building with shear walls at different directions are considered for the equivalent static and pushover analyses. The 'I' shaped shear wall of clear length 2.5m is considered. The shear wall is provided at the center, along the X direction and Y direction on the both sides of the building in order to provide the symmetry. The moment resisting frame is provided where shear wall is present. The material safety factors and dead load and imposed live loads are assigned as per IS 456 and IS 875 respectively.

3. Computational modelling

ETABS 2015 15.0.0 software is used for 3 dimensional modelling of the buildings and analyses are carried out in same software. The advantage of this software is, using both material inelasticity and geometric nonlinearity it can easily predict the geometric nonlinear behavior of the frame elements for both static as well as dynamic loading conditions. In this software we can apply static loads i.e forces and displacements and also dynamic loads such as accelerations on the buildings. The software has capacity to carryout both linear and nonlinear static and dynamic analyses and also Eigen value analysis.

3.1 Modelling of the building

The frame elements used in the model i.e beam and columns are modeled using 3D frame elements and joints are considered as rigid joints. The end length offsets are assigned to the beam columns at the intersections. Slab effect is considered by assigning 'diaphragms' at each floor level. Here columns which have isolated footing below the plinth level are assigned with pinned restraints and the columns which are bound with shear walls are assigned at base with fixed restraints.

The dead loads of slab and other imposed loads on the slabs are transmitted to the supporting beams, and then they are transfer to columns then to the ground. The loads are assigned in such way that center of mass is coincide with centroid of the structure.

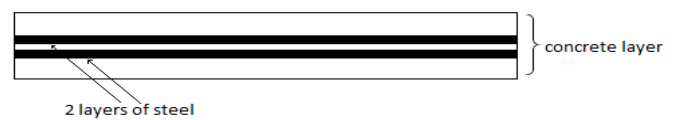
3.2 Modelling of the shear wall

The shear wall in building is modeled by the ETABS 2015 ultimate 15.0.0 software and then is analysed by the same software. Here two types of shear walls are modeled in two different buildings.

- Refined model shear wall : In this shear wall modeled using multi-layered membrane element.
- Simplified shear wall : Here it is modeled as single element throughout the building.

Refined model shear wall

To model this shear wall the layer model type option available in the ETABS 2015 software is used. Then provide the details for the layers such as number layer required, number of rebar layer and its sizes, spacing and also materials used for the layers etc. The multi-layer membrane element used in this study consists of one layer of concrete in which two layers of steel rebar is present (horizontal and vertical reinforcement). In order to resist the in-plane stress concrete layer is defined as membrane type. The mesh size used for this wall is 0.5m×0.5m. The refined model is bound with adjacent frame members. The typical section of refined model used is as shown in the fig below.



Simplified shear wall

This is modeled as single element throughout the building. This method of modelling decreases the computational time. Here wall panels are modeled as equivalent column elements with bounding columns. The beam and columns are connected by rigid links. In order to establish the nonlinearity, shear and flexure hinge are assigned to the column elements.

3.3 Data for the buildings

Table 1: The material properties for the building

NO	Description	Information
1	Plan dimension	24m × 18m
2	Thickness of slab	175 mm
3	Column size (width × depth)	500mm × 500mm
4	Beam size	300mm × 500mm
5	Beam size in LLRS	300mm × 600mm
6	Shear wall panel (clear length × thickness)	2500mm × 100mm
7	Grade of the concrete	M30
8	Grade of the steel used	Fe415
9	Live load	3 kN/m ² for middle floors and 1.5 kN/m ² for roof
10	Floor finish	0.75 kN/m ² ; No roof finish is considered.
11	Seismic zone	V
12	Importance factor(I)	1

13	Response reduction factor(R)	5
14	Type of soil below foundation level	Medium soil (type II)
15	Wall thickness	230mm for exterior walls and 100mm for interior walls

To introduce the non-linear behaviors for frame members flexural and shear hinges are assigned. The hinges properties are available in the ETABS nonlinear software as per ATC-40. For beam default flexure hinge M3 and shear hinge is assigned at both ends. For column default hinge PM2M3 which yields due to the interaction of axial force and bending moments is assigned at both ends and shear hinge is assigned at mid - height of the each column. The columns with are connected with shear wall is assigned by axial hinge at the middle, due to the presence of the axial forces in the adjacent shear wall panels.

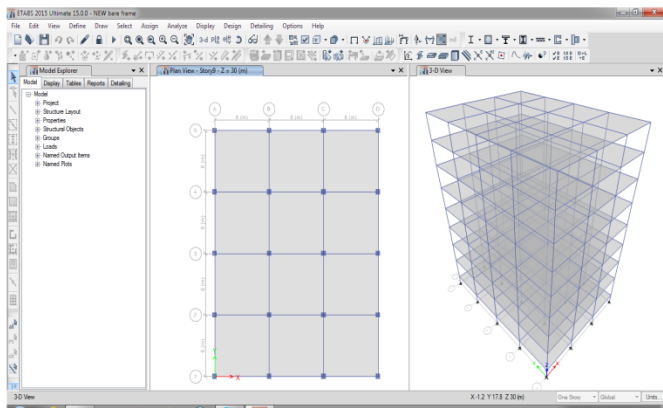


Fig -1: Plan and elevation of bare frame

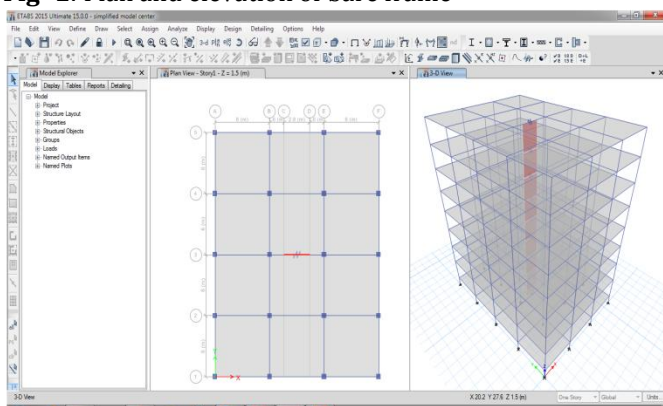


Fig -2: Plan and elevation of building with centrally located shear wall

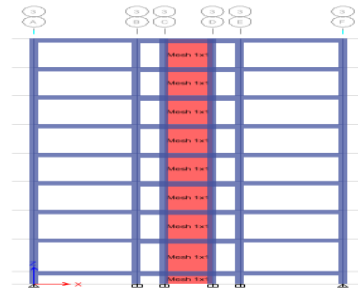


Fig -3: Elevation of refined model with centrally located shear wall

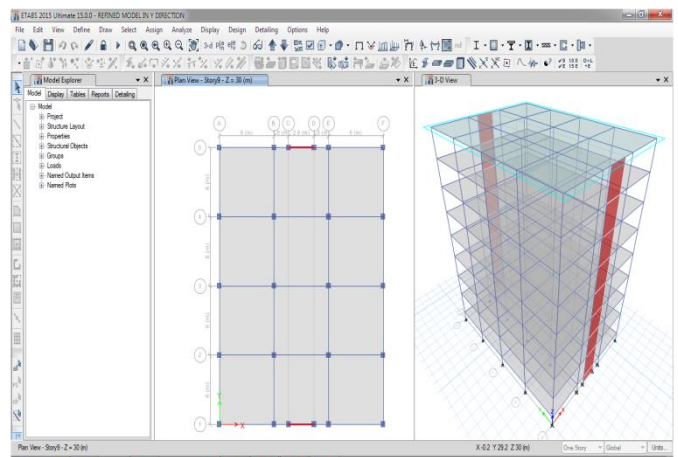


Fig -4: Plan and elevation of building with shear wall along Y direction

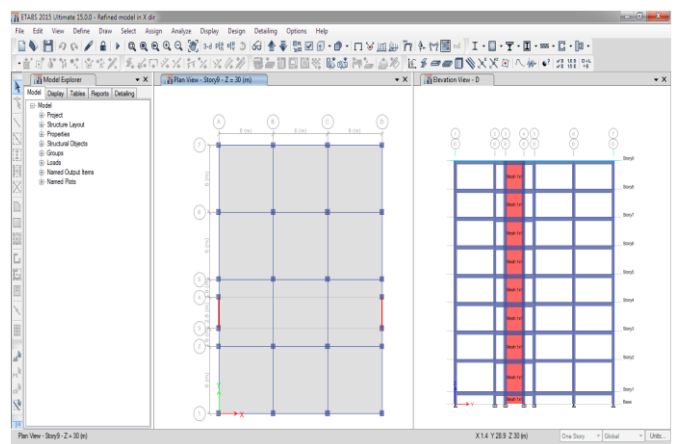


Fig -5: Plan and elevation of building with shear wall along X direction

4. Results and Discussions

Effect of shear wall on base shear, when it is provided at center and along edges of the building in X & y directions are given below. The results of simplified model and refined models are compared with bare frame.

Table 2 : Base shear values

Shear wall location	Bare frame	simplified model	refined model
At center	1464.24	1994.42	2159.11
Along Y direction	1464.24	2333.58	2690.56
Along X direction	1464.24	1492.67	1529.81

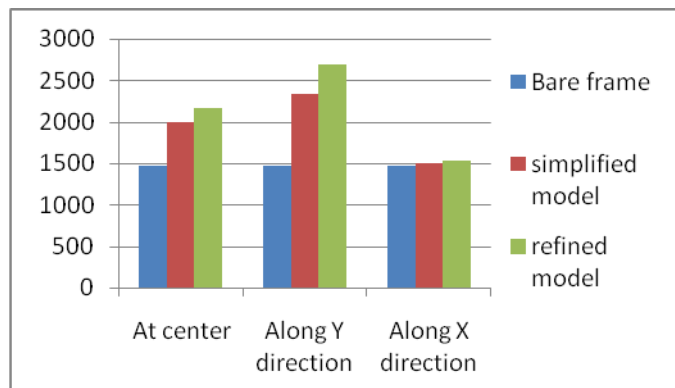


Chart -1: Chart for base shear values

Effect of shear wall on fundamental natural period, when it is provided at center and along edges of the building in X & y directions are given below.

Table 3: Fundamental natural period values

Shear wall location	Bare frame	simplified model	refined model
At center	2.128	1.559	1.455
Along Y direction	2.128	1.312	1.154
Along X direction	2.128	2.05	2.032

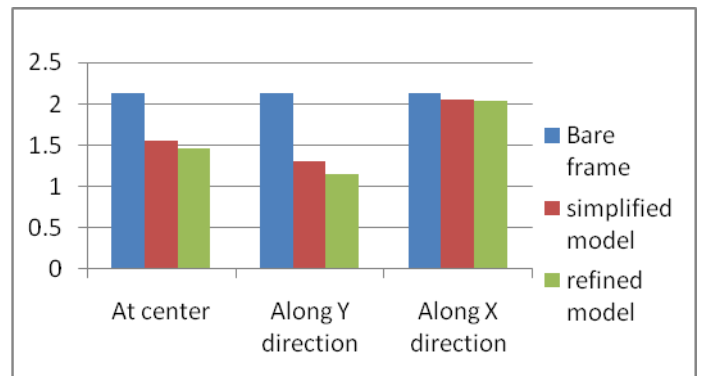


Chart -2: Chart for fundamental natural period

Effect of shear wall on displacement for various load conditions are given below.

Table 4: The displacement values for load case 1.5(DL+EQX) a for the bare frame and models with centrally located shear wall

story height in m	Displacement values in mm		
	bare frame	simplified model	refined model
0	0	0	0
1.5	3.8	1.9	1.1
5.5	16.6	9.4	7.2
9	27.2	17	14.1
12.5	37.4	24.9	21.9
16	47	32.9	29.9
19.5	55.7	40.6	37.7
23	63	47.6	44.9
26.5	68.4	53.5	51.2
30	71.6	58.3	56.4

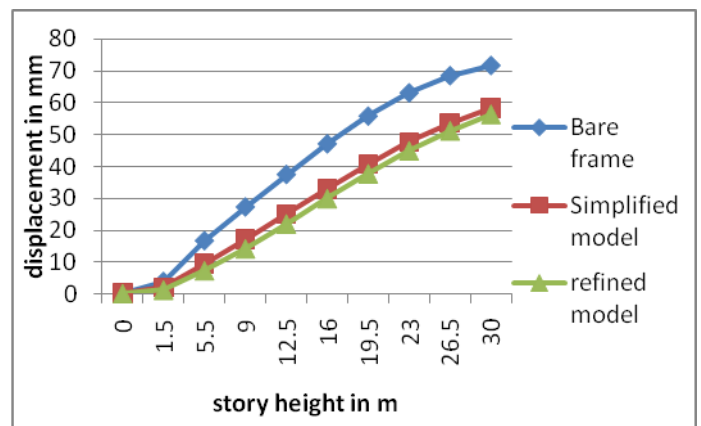


Chart -3: Chart for displacement for load case 1.5(DL+EQX)

From the above graph, the percentage of reduction in displacements of bare frame to simplified model and refined models for load case 1.5(DL+EQX) is 18.57% & 21.33% respectively. The percentage of variation between simplified and refined model is 3.25%.

Table 5: The displacement values for load case 1.2(DL+LL+EQX) for the bare frame and models with shear wall located along Y direction of the building

story height in m	Displacements in mm		
	bare frame	simplified model	refined model
0	0	0	0
1.5	3.4	1.2	0.6
5.5	14.8	6.3	4.3
9	24.3	11.8	8.9
12.5	33.4	17.7	14.2
16	41.9	23.8	20
19.5	49.6	29.9	25.9
23	56.1	35.5	31.6
26.5	60.9	40.6	37
30	63.8	44.8	41.8

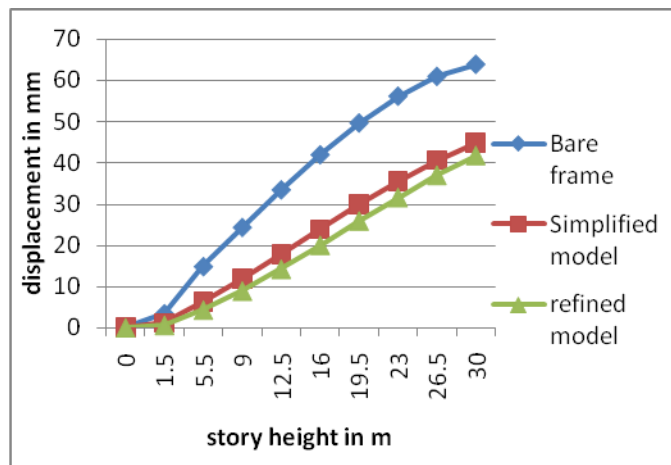


Chart -4: Chart for displacement for load case 1.2(DL+LL+EQX)

From the above graph, the percentage of reduction in displacements of bare frame to simplified model and refined models for load case 1.2(DL+LL+EQX) is 29.78% & 34.48% respectively. The percentage of variation between simplified and refined model is 6.69%.

PERFORMANCE POINT AND LOCATION OF HINGES

The base shear v/s the displacement values and performance point and target displacement values with location of hinges formed at life safety, collapse prevention

for bare frame and the buildings with centrally located shear wall is given below.

Table 6: The performance point and location of hinges of the bare frame for load case pushX

Step	Monitored Displ mm	Base Force kN	Location of Hinges				
			A-B	B-C	C-D	D-E	>E
0	0	0	1656	0	0	0	0
1	10	456.775	1656	0	0	0	0
2	19.4	884.042	1651	5	0	0	0
3	20.5	926.019	1616	40	0	0	0
4	21.3	938.692	1596	60	0	0	0
5	27	994.849	1571	85	0	0	0
6	37.4	1049.62	1566	90	0	0	0
7	52.8	1102.87	1536	120	0	0	0
8	62.8	1132.5	1536	120	0	0	0
9	73.5	1162.34	1511	145	0	0	0
10	85.1	1184.92	1506	150	0	0	0
11	95.1	1203.96	1506	150	0	0	0
12	100	1213.25	1506	150	0	0	0

A-IO	IO-LS	LS-CP	>CP	Total Hinges
1656	0	0	0	1656
1656	0	0	0	1656
1656	0	0	0	1656
1656	0	0	0	1656
1656	0	0	0	1656
1656	0	0	0	1656
1656	0	0	0	1656
1656	0	0	0	1656
1656	0	0	0	1656
1656	0	0	0	1656
1656	0	0	0	1656
1626	30	0	0	1656
1596	60	0	0	1656
1596	60	0	0	1656
1596	60	0	0	1656

Table 7: The performance point and location of hinges of the simplified model with centrally located shear wall for load case pushX

Step	Monitored Displ mm	Base Force kN	A-B	B-C	C - D	D -E	> E
0	0	0	1692	0	0	0	0
1	7	563.8135	1690	2	0	0	0
2	10.3	779.6155	1681	10	1	0	0
3	10.3	733.7213	1681	11	0	0	0
4	18.8	1202.3284	1647	45	0	0	0
5	22.1	1301.1872	1617	75	0	0	0
6	33.7	1454.6409	1582	109	0	0	1
7	44.8	1541.6329	1555	137	0	0	0
8	55.6	1608.8927	1538	154	0	0	0
9	72.8	1687.9899	1522	168	0	0	2
10	84.2	1737.6573	1518	174	0	0	0
11	94.3	1778.6002	1495	197	0	0	0
12	100	1798.4421	1495	197	0	0	0

A-IO	IO-LS	LS-CP	>CP	Total Hinges
1692	0	0	0	1692
1692	0	0	0	1692
1690	1	1	0	1692
1690	2	0	0	1692
1690	2	0	0	1692
1690	2	0	0	1692
1690	1	0	1	1692
1684	8	0	0	1692
1682	10	0	0	1692
1679	11	0	2	1692
1640	49	3	0	1692
1617	71	4	0	1692
1617	70	5	0	1692

Table 8: The performance point and location of hinges of the refined model with centrally located shear wall for the load case pushX

Step	Monitored Displ mm	Base Force kN	A-B	B -C	C - D	D -E	> E
0	0	0	1701	0	0	0	0
1	12.7	1162.1933	1700	1	0	0	0
2	16.2	1487.7236	1696	5	0	0	0
3	16.3	1480.9894	1696	5	0	0	0
4	16.5	1507.481	1695	5	0	0	1

A-IO	IO-LS	LS-CP	>CP	Total Hinges
1701	0	0	0	1701
1701	0	0	0	1701
1700	0	1	0	1701
1699	1	1	0	1701
1699	1	0	1	1701

5. CONCLUSIONS

Based on the results the following points are concluded.

1. Fundamental natural period for refined model is less compared to the fundamental natural period of bare frame and simplified model in all the cases mentioned.
3. The displacement for refined model having shear wall located centrally with load case 1.5(DL+EQX) is less compared to bare frame and simplified model.
4. The displacement for refined model having shear wall along Y direction with load case 1.2(DL+LL+EQX) is less compared to bare frame and simplified model.
5. The performance points obtained from the pushover analysis are within the collapse prevention for both refined model and simplified model in all cases. Hence the building is safe in all cases.
6. Results obtained from pushover method gives better results compared with linear static method as it considered the material nonlinearity and p-Δ effects.
7. Overall conclusion is that refined model gives better strength and stiffness compared to the other models and it can be used for the seismic retrofitting of the building.

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