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Research Paper

Evaluation of Shear Wall-RC Frame Interaction of High-rise Buildings using 2-D Model Approach

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ABSTRACT

The usefulness of structural walls in the framing of buildings has long been recognized. It is generally preferred to use shear wall in combination with moment resisting frame. In the present study, an effort is also made to investigate the shear wall-RC frame interaction using 2-D modeling of 20, 30 and 35 storey RC frame building with shear wall. In equivalent simplified 2-D model, two exterior frames with shear wall modeled as single frame with double stiffness, strength and weight. The interior frames without shear wall are modeled as a single frame with equivalent stiffness, strength and weight. The modeled frames are connected with rigid link at each floor level. Using 2-D plane frame model the lateral force distribution between Exterior frame with shear wall and Interior frame without shear wall is investigated. From the analysis, it is observed that up to bottom seven/eight storey more than 50% load is taken by frame with shear wall and the lower most three storeys take about 75% of total storey shear.

1 Introduction

It is often advantageous to use a combination of shear wall and moment resisting frame in the same building. Since the earthquake performance of RC frame buildings with shear walls is often found to be better than that of buildings without shear walls, in recent years there has been emphasis on providing shear walls even in buildings whose configuration otherwise indicates frames, this leads to a combined system. This system is one of the most popular systems for resisting lateral loads in medium to high-rise buildings. The system has a broad range of application and has been used for buildings as low as 10 stories to as high as 50 stories or even taller. Figure 1 (a) illustrates the interactive behavior of a cantilever shear wall and a frame, both carrying the same load at a certain height. This causes the shear wall to suffer bending distortions and the frame experiences mainly translatory displacements. Only at the lower floors, do the two

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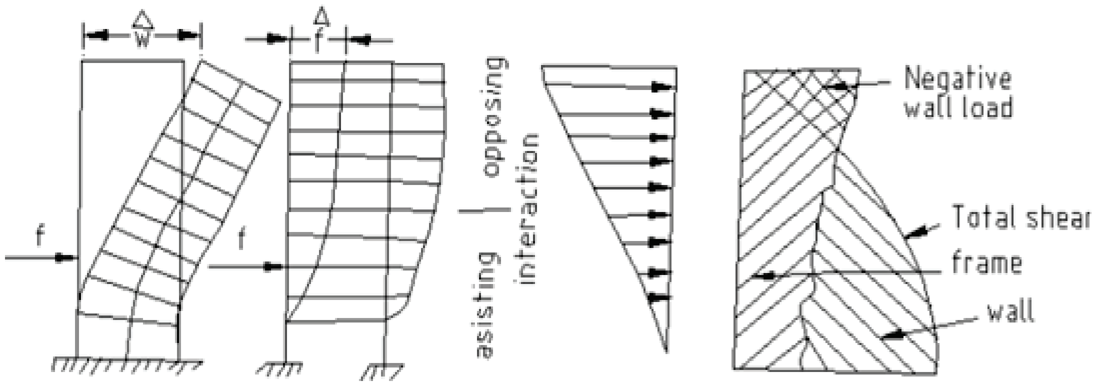
structures assist each other in carrying the external load as shown in figure. Generally, the shear walls are designed to resist the proportion of the specified seismic loads attracted by their elastic stiffness, the ductile frames must be designed to resist at least 25% of the total seismic load, even if their elastic stiffness relative to the shear walls is such that they attract a smaller force, as usually be the case. Due to this ductile frames back up the shear walls, when the shear walls are stressed beyond elastic limit. The typical distribution of the lateral load between a tall and a relatively slender shear wall and a frame is illustrated, in terms of shear force, in fig.1 (b).



Wall Frame Load Shear

Fig. 1. Interaction of shear wall and rigid jointed frame

Pique (1992) tried to find the best alternative for modeling beams ending at shear walls as linear elements with rigid arms for use in dynamic and static matrix structural analysis for earthquake loading. Fahjan et al. (2010) applied and studied the different approaches for linear and nonlinear modeling of the shear walls in structural analyses of buildings for RC building with shear walls. The analyses results of different approaches are compared in terms of overall behavior of the structural systems. Mergos and Beyer (2012) proposed a simplified method of incorporating shear-flexure interaction effect in equivalent frame models of flexure dominated RC walls. In particular, appropriate modifications to the constitutive V-γ law for the wall base section are proposed as a function of the corresponding flexural response. The suggested methodology is implemented in a finite element model consisting of two interacting spread inelasticity sub-elements representing inelastic flexural and shear response. Marzban (2012) used “Beam on Nonlinear Winkler Foundation” approach to investigate the inertial soil-foundation-structure interaction effects on the seismic performance of concrete shear wall frames. Hence, frames of 3, 6, 10 and 15 number of stories founded on soft, medium and hard soils were designed and modeled using OpenSees. The resulting pushover curves were studied through two code-based viewpoints of force-based design and performance-based design.

In the present study, a shear wall-RC frame interaction of 20, 30 and 35 storey RC frame building with shear wall is investigated using simplified equivalent 2-D modeling approach. The lateral force distribution between exterior frame with shear wall and interior frame without shear wall is also evaluated using simplified 2-D plane frame model.

2 Prototype Building and Study Parameters of Considered Structures

Typical 20, 30, and 35 storey reinforced concrete buildings have been chosen for the analysis. The floor plan of the building is shown in figure 2. The building consists of an assembly of cast in place reinforced concrete beams, columns and shear wall. The dimensions of the building components are designed for the most critical load combination using the relevant Indian Standards IS:456 and IS:1893. The building is considered to be located in zone-V and importance factor=1.The building parameters are defined as, Building plan dimension= 25m x 25m, No. of bays in X and Y direction = 5 @ 5 m each, Concrete Grade= M30, Steel Grade = Fe 415 MPa, Slab thickness = 150 mm, height of each storey = 3.5m, live load on floors = 5 kN/m^2, Shear wall thickness = 200 mm, 250 mm and 275 mm for 20, 30, and 35 storey reinforced concrete buildings respectively. Table 1 shows the dimensions of beams and columns for considered building. The shear wall is provide at the mid bay of each exterior frames. Consider buildings having shear walls as well as moment resisting frames to resist lateral load in the same direction. The analysis should ensure compatibility of deformation in the walls and the frames such that the rigid floor diaphragm condition is satisfied. However, on their own the walls and the frames tend to have an entirely different deformation profile; since these combined systems forced to deform with a similar deformation profile by the floor diaphragm, interaction forces exist between the walls and the frames.

Table1. Dimensions of Beams and Columns

Height of Buildings	Storeys	Column size	Beam size
20- storey	1 to 10	900 mm x 900mm	300 mm x 600 mm
	10 to 20	600 mm x 600mm	300 mm x 600 mm
30- storey	1 to 15	1000 mm x 1000mm	300 mm x 600 mm
	16 to 30	700mm x 700 mm	300 mm x 600 mm
35- storey	1 to 15	1100 mm x 1100 mm	300 mm x 600 mm
	16 to 25	750 mm x 750 mm	300 mm x 600 mm
	26 to 35	600 mm x 600 mm	300 mm x 600 mm

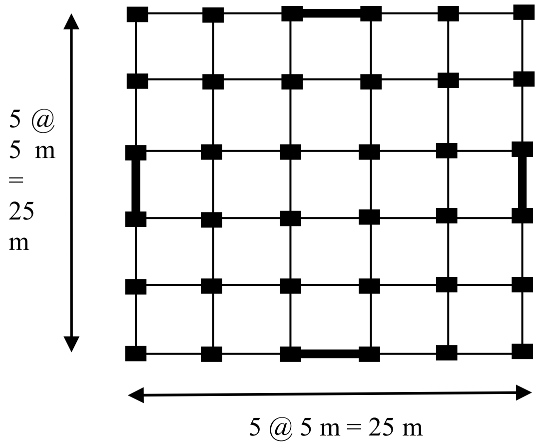


Fig.2 Plan of considered building

3 2-D Modeling of Considered Building

The considered buildings consist of parallel arrangement of four identical interior frames and two exterior frames with shear wall in the direction of motions (X-direction or Y-direction). A two dimensional plane frame model has been used for determination of lateral forces in the SMRF with and without shear wall assuming no torsion effect. The mathematical model connects all the plane frames in the direction of motion by assuming the same horizontal displacement in a floor.

In 2-D model as shown in figure 3, two exterior frames with shear wall may be modelled as single frame with double stiffness, strength and weight. The shear wall is modelled as a wide column connected to the adjacent columns of the RC frame with rigid link. Four identical interior frames without shear wall are modelled as a single frame with fourth time stiffness, strength and weight. The modelled exterior frame and interior frame are connected with rigid link at each floor level. The lateral forces at each storey of respective building are calculated as per seismic coefficient method (IS: 1893:2002) and are applied on the combined 2-D plane frame model. Modelling and analysis of frames have been carried out using SAP 2000. The lateral forces taken by two exterior frames with shear wall and four interior frames without shear wall are evaluated.

4 Lateral Force Analysis for Considered Building

Fig. 3 shows the 2-D plane frame model of 20-storey building with shear wall for evaluating the shear wall-RC frame interaction.

Table 2, 3 and 4 shows the lateral load shared by exterior frame with shear wall and interior frame without shear wall of 20 storey, 30 storey and 35 storey building respectively. Figure 4, 5 and 6 shows the lateral force sharing/distribution between exterior frame with shear wall and interior frame without shear wall of 20 storeys, 30 storeys and 35 storeys building respectively.

In case of 20 storey building, it is observed that at storey level 8 to 9 and 12 to 14 almost 50% of the lateral loads are resisted by the RC frame and remaining 50% are resisted by the shear wall. The variation in the load distribution patterns at storey level 11 is due to the change in structural dimensions of columns at 11th storey onwards. In case of 30 storey building, it is observed that at storey level 7 to 12 and 16 to 20 almost 50% of the lateral loads are resisted by the RC frame and remaining 50% are resisted by the shear wall. The variation in the load distribution patterns at storey level 16 is due to the change in structural dimensions of columns at 16th storey onwards. In case of 35 storey building, variation in the load distribution patterns at storey level 16 and 26 is due to the change in structural dimensions of columns at 16th and 26th storey onwards.

Table 2 Shear wall-frame interaction for 20-storeyed building

No. Of storey	INTERIOR FRAME		EXTERIOR FRAME		Storey shear (kN)
	Storey shear	**% of total**	Storey shear	**% of total**	
20	456.9186	107.2	-30.68856	-7.2	426.23
19	804.4363	93.45	56.38371	6.55	860.82
18	906.0677	72.435	344.80232	27.565	1250.87
17	1003.241	62.75	595.54928	37.25	1598.79
16	1045.025	54.8	861.95496	45.2	1906.98
15	1137.543	52.23	1040.4067	47.77	2177.95
14	1218.542	50.48	1195.3682	49.52	2413.91
13	1279.104	48.87	1338.2562	51.13	2617.36
12	1347.36	48.28	1443.3604	51.72	2790.72
11	1145.779	39.02	1790.6106	60.98	2936.39
10	1846.473	60.17	1222.2871	39.83	3068.76
9	1605.899	50.39	1581.0409	49.61	3186.94
8	1587.342	48.39	1692.968	51.61	3280.31
5	1366.338	39.71	2074.4523	60.29	3440.79
7	1537.471	45.87	1814.3293	54.13	3351.8
6	1466.921	43.09	1937.3985	56.91	3404.32
4	1231.498	35.55	2232.6318	64.45	3464.13
3	1056.044	30.37	2421.2161	69.63	3477.26
2	847.7865	24.34	2635.3135	75.66	3483.1
1	694.4728	19.93	2790.0872	80.07	3484.56

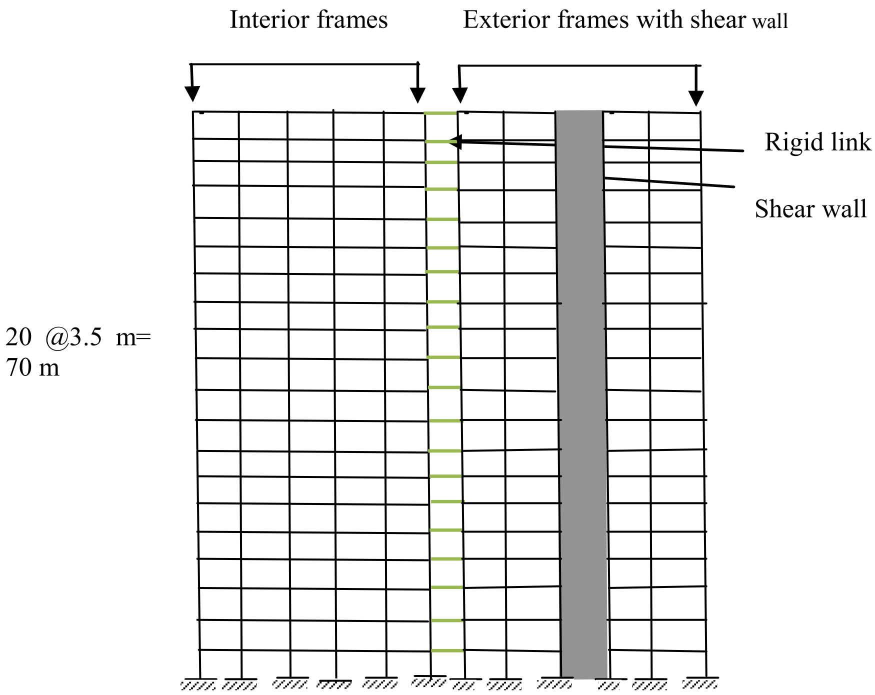


Fig. 3. 2-D plane frame model of 20 storey shear wall building

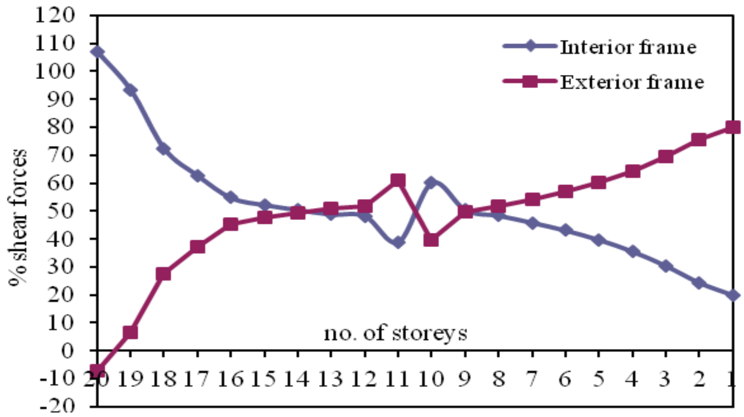


Fig. 4. Interaction between frame with shear wall and without shear wall for 20-storey building

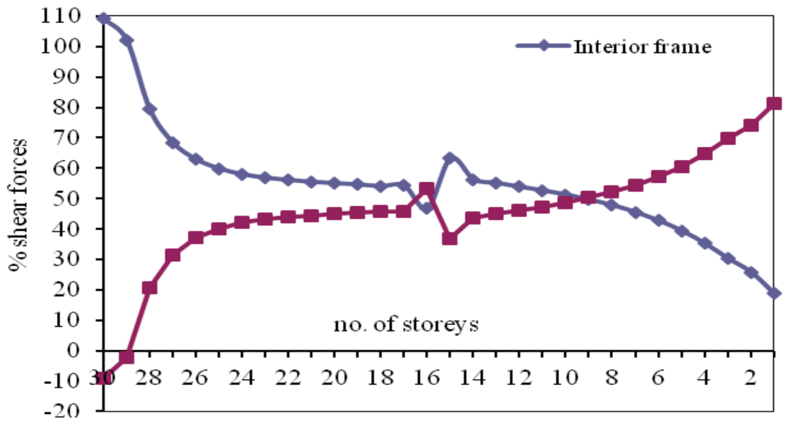


Fig. 5. Interaction between frame with shear wall and without shear wall for 30-storey building

Table 3 Shear wall-frame interaction for 30-storeyed building

No. Of storey	INTERIOR FRAME		EXTERIOR FRAME		Storey shear (kN)
	Storey shear	**% of total**	Storey shear	**% of total**	
30	324.63	109.2	-27.3498	-9.2	297.28
29	633.269	102.16	-13.3894	-2.16	619.88
28	731.064	79.41	189.5557	20.59	920.62
27	821.338	68.43	378.9221	31.57	1200.26
26	918.507	62.93	541.0626	37.07	1459.57
25	1016.87	59.84	682.4469	40.16	1699.32
24	1113.56	57.99	806.7054	42.01	1920.27
23	1206.61	56.83	916.5811	43.17	2123.19
22	1294.34	56.06	1014.509	43.94	2308.85
21	1375.3	55.5	1102.714	44.5	2478.01
20	1448.35	55.04	1183.1	44.96	2631.45
19	1512.94	54.62	1256.994	45.38	2769.93
18	1564.61	54.06	1329.6	45.94	2894.21
17	1629.05	54.21	1376.022	45.79	3005.07
16	1449.23	46.7	1654.043	53.3	3103.27
15	2020.75	63.17	1178.155	36.83	3198.9
14	1853.62	56.32	1437.609	43.68	3291.23
13	1858.34	55.13	1512.496	44.87	3370.84
12	1852.41	53.87	1586.258	46.13	3438.67
11	1840.47	52.65	1655.2	47.35	3495.67
10	1816.74	51.28	1726.042	48.72	3542.78
9	1779.37	49.69	1801.571	50.31	3580.94
8	1726.46	47.81	1884.628	52.19	3611.09
7	1655.36	45.55	1978.806	54.45	3634.17
6	1561.95	42.78	2089.177	57.22	3651.13
5	1443.19	39.4	2219.723	60.6	3662.91
4	1293.83	35.25	2376.616	64.75	3670.45
3	1113.8	30.31	2560.891	69.69	3674.69
2	947.452	25.77	2729.118	74.23	3676.57
1	689.445	18.75	2987.595	81.25	3677.04

Table 4 Shear wall-frame interaction for 35-storeyed building

No. Of storey	INTERIOR FRAME		EXTERIOR FRAME		Storey shear (kN)
	Storey shear	**% of total**	Storey shear	**% of total**	
35	286.9491	111.1	-28.6691	-11.1	258.28
34	536.5217	100.54	-2.88166	-0.54	533.64
33	621.902	78.42	171.138	21.58	793.04
32	701.5034	67.65	335.4566	32.35	1036.96
31	788.0041	62.25	477.8659	37.75	1265.87
30	876.012	59.18	604.2381	40.82	1480.25
29	963.1404	57.31	717.4396	42.69	1680.58
28	1044.958	55.96	822.3721	44.04	1867.33
27	1138.663	55.79	902.3173	44.21	2040.98
26	1080.521	49.07	1121.479	50.93	2202
25	1549.788	65.74	807.6624	34.26	2357.45
24	1480.767	59.05	1026.883	40.95	2507.65
23	1547.406	58.49	1098.184	41.51	2645.59
22	1597.943	57.65	1173.857	42.35	2771.8
21	1645.765	57.01	1241.035	42.99	2886.8
20	1687.28	56.41	1303.82	43.59	2991.1
19	1722.175	55.82	1363.055	44.18	3085.23
18	1746.516	55.1	1423.204	44.9	3169.72
17	1781.224	54.89	1463.856	45.11	3245.08
16	1583.386	47.81	1728.444	52.19	3311.83
15	2116.543	62.65	1261.817	37.35	3378.36
14	1936.488	56.23	1507.382	43.77	3443.87
13	1919.592	54.84	1580.758	45.16	3500.35
12	1706.464	48.09	1842.016	51.91	3548.48
11	1683.203	46.9	1905.717	53.1	3588.92
10	1838.338	50.75	1784.002	49.25	3622.34
9	1790.765	49.07	1858.645	50.93	3649.41
8	1728.947	47.1	1941.853	52.9	3670.8
7	1650.382	44.76	2036.798	55.24	3687.18
6	1552.189	41.96	2147.021	58.04	3699.21
5	1431.493	38.61	2276.077	61.39	3707.57
4	1285.784	34.63	2427.136	65.37	3712.92
3	1123.697	30.24	2592.233	69.76	3715.93
2	872.4433	23.47	2844.827	76.53	3717.27
1	652.4388	17.55	3065.161	82.45	3717.6

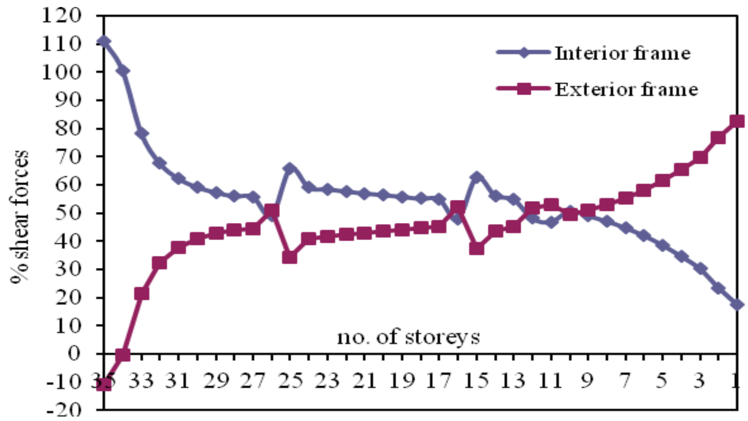


Fig. 6. Interaction between frame with shear wall and without shear wall for 35-storey building

From analysis results of all considered RC frame, it is observed that the entire lateral load at top 2 to 3 storey is taken by RC frame only and the contribution of shear wall in resisting lateral force at top is almost negligible. Where as at storey level 1 to 3 from bottom more than 75% of the lateral load is taken by shear wall and remaining 25% lateral load is resisted by the RC frame. At intermediate storey levels, almost 40 % of lateral load is resisted by frame with shear wall, whereas remaining 60% load is resisted by frame without shear wall. Shear wall and RC frame assist each other in carrying the external load at the lower and intermediate floors. However, as the storey/height decreases, the higher forces are resisted by exterior frame with shear wall as compared to internal frame without shear wall. A shear wall and frame, both are carrying the same load at a certain intermediate height but at the lower height/storey, the shear wall carries higher % of loads as compared to the RC frame. The distribution of lateral forces between RC frame and shear wall is also varying with the height of the buildings. It is observed that up to bottom eight storey more than 50% of lateral load is taken by frame with shear wall and at lower most three storey more than 75% of total storey shear is taken by frame with shear wall.

5 Conclusions

In the present study, shear wall-RC frame interaction of 20, 30 and 35 storey RC frame building with shear wall is investigated using simplified equivalent 2-D modeling of respective frames. From the analysis of 2-D model of building having RC frame with shear wall, it is observed that shear wall and RC frame assist each other in carrying the external load at the lower and intermediate floors. From analysis results of all considered RC frame, it is observed that the entire lateral load at top 2 to 3 storey is taken by RC frame only and the contribution of shear wall in resisting lateral force at top is almost negligible. Where as at storey level 1 to 3 from bottom more than 75% of the lateral load is taken by shear wall and remaining 25% lateral load is resisted by the RC frame. At intermediate storey levels, almost 40 % of lateral load is resisted by frame with shear wall, whereas remaining 60% load is resisted by frame without shear wall. However, as the storey/height decreases, higher forces are resisted by exterior frame with shear wall as compared to internal frame without shear wall. Shear wall and frame, both are carrying the same load at a certain intermediate height but at the lower height/storey, the shear wall carries higher percentage of lateral loads as compared to the RC frame.

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