Scientific Journal Impact Factor (SJIF): 1.711

e-ISSN : 2349-9745
p-ISSN : 2393-8161

International Journal of Modern Trends in Engineering and Research
www.ijmter.com

Inelastic Behaviour of R.C. Buildings Retrofitted With Brick Masonry Infill Walls

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Abstract - In new era of construction of multi-storied buildings with open ground storey is a common practice in India provided for functional and architectural reasons. Though calamitous collapse of R/C building having soft storey at ground floor is an age old Phenomenon. However nothing promising has been done to retrofit them. This may be primarily due to high cost of retrofitting techniques, which are in practice today. The main intend of this study is to demonstrate that addition of in filled walls in ground floor and strengthening of other in fill panels in typical low rise R/C building having soft storey at ground floor, provides an alternative cost-effective and perhaps most convenient retrofit solution.

Keywords: Masonry infilled wall, Mode shapes, Pushover curve, Push over analysis, Soft Storey.

I. INTRODUCTION

Construction of multi-storey residential buildings in Maharashtra, the rest of India, and indeed in much of rest of the world, are constructed of reinforced concrete frames, with openings in those frames infilled with unreinforced clay brick masonry. They impart the significant stiffness to the building which as a consequence, attracts strong earthquake forces.

Current design practices in India do not consider infill walls; lateral force resisting structural element. Thus, in common design practice, the presence of so-called non-structural infill walls is ignored. The structural part of the building (i.e. the bare reinforced concrete frame elements) is analyzed and its members are reinforced accordingly. Hence, one of the objectives of this study is to suggest guidelines for evaluating strength and stiffness of unreinforced infill panels. These guidelines are strictly based on FEMA-356 [5] and ATC 40[1].

A large number of buildings in India, suffering from soft storey deficiency, require immediate attention in terms of retrofitting. The main intend of this study is to demonstrate through linear elastic as well as pushover analysis of typical ten storey building that addition of properly designed new masonry infill walls in soft storey, and strengthening of infill walls at other store's provide simplest and cost-effective alternative for retrofitting of low strength RC building with soft storey.

1. Building Description for Analytical Study

The total three (G+9) models are modelled and analyzed. All models are subjected to response spectrum analysis and inelastic static analysis with the help of structural analysis programme 2000[4]. Plan dimensions of building was 22.60m x 12.80m.The inter-storey height of the ground floor level was 3.5m and the other inter-storey heights were 3.0m.Masonry infill walls have been modelled as crossed N-link element (Strut Model) [9].The equivalent width of strut is assumed to be six times the thickness of wall or as given by Stafford Smith.[10] Further details concerning the construction of the building model, the mechanical characteristics of the materials and the amount of reinforcement has been considered as per IS 456-2000[8] and IS1893:2002 [3] parameters those are considered in the performance analysis process is listed below, Building Type – Residential building, R.C.C. Residential (G+9) building i.e. ten storey, Raft foundation of 1.6 m depth. The area is considered under Seismic Zone III (Mumbai), Medium type of Soil.

II. RESPONSE SPECTRUM METHODOLOGY

The Finite Element Modeling is performed using the software package SAP 2000[4]. Three conditions are considered for the study; (i) bare frame model (ii) frame with infill walls on all floors except ground floor and (iii) frame with infill walls on all floors except ground floor and with some openings in the upper floor. Assuming a live load of 3 kN/m2 and a floor finish of 1 kN/m. Loads are calculated separately for bare frame analysis and for frame analysis considering the strength and stiffness of infill walls. Response spectrum method [2] of analysis based on the modal superposition is performed by using the design spectrum specified in IS 1893:2002[3]. Modal analysis types can be chosen between Eigenvector or Ritz vector [11]. Here Ritz vector can provide a better basis when used for Response spectrum as Ritz vector analysis seeks to find modes that are excited by a particular loading. For modal combination Complete Quadratic Combination option (CQC) is selected. Square Root of Sum of Squares option as directional combination and a scale factor of 9.8 [11], that multiplies each acceleration load which has units of acceleration, and should be consistent with the length units in use is selected. It is assumed that the buildings are situated in Zone- III of India on medium soil. Analysis is done using SAP 2000[4] for bare frame model and frame with infill walls on all floors except ground floor using Response spectrum method. A model with some openings in the upper floors, i.e., without infill walls is also analyzed.

III. PUSHOVER METHODOLOGY

The pushover analysis is relatively simple way to explore the design of a structure. It consists of pushing a mathematical model [6] of a building over a prescribed displacement in order to predict the sequence of damages in the inelastic range and to detect weak links. In this study, a nonlinear static pushover analysis is carried out in order to determine and compare the capacity and the demand curves of a reinforced concrete building.

Key elements of the pushover analysis [7]

- Plastic hinges

The default types include an uncoupled moment hinges, an uncoupled axial hinges, an uncoupled shear hinges and a coupled axial force and biaxial bending moment hinges.

- Control node

Control node is the node used to monitor displacements of the structure. Its displacement versus the base-shear forms the capacity (pushover) curve of the structure.

- Developing the pushover curve

This includes the evaluation of the force distributions. To have a displacement similar or close to the actual displacement due to earthquake, it is important to consider a force displacement equivalent to the expected distribution of the inertial forces. Different forces distributions can be used to represent the earthquake load intensity.

- Estimation of the displacement demand

This is a crucial step when using pushover analysis. The control is pushed to reach the demand displacement which represents the maximum expected displacement resulting from the earthquake intensity under consideration.

- Evaluation of the performance level

Performance evaluation is the main objective of a performance based design. A component or action is considered satisfactory if it meets a prescribed performance. The main output of a pushover analysis is in terms of response demand versus capacity.

IV. RESULTS AND DISCUSSIONS

In present work to study the inelastic behavior of the structure total three analytical models of ten storey RC frame buildings have been investigated for the performance of RC frames before and after retrofitted with Masonry infill. For investigating the performance of RC frames with Masonry infill wall have been modelled as crossed N-link element [9] (Equivalent Strut Model). All models are analyzed with the help of structural analysis program (SAP 2000) via elastic static analysis and inelastic static analysis .The study revealed that after application of Masonry infill wall (Equivalent Strut Model) the performance of the soft storey frame, bare frame has been enhanced. Results of performance of RC frames in the form of mode shapes, pushover curve, and capacity demand curve are presented in various Figures and Tables.

The absence of infilled walls in the ground floor resulted in the formation of soft story. This can be very easily explained by the graphs in the Figure 1 indicating the soft drift. The graphs were plotted for the column of ground floor for mode shape along X as well as Y-direction. The 0 kink at the first storey level in this graph clearly demonstrates large values of drift in first story of the soft storey structure. The graph analyses three different cases one for the bare frame; one for the original building and the last one for the retrofit building.

From the Figures 1-3 and tables 1-3 it is found that fundamental mode shape in X direction is more predominant than more shape in Y direction due to less moment of inertia available in X direction and the performance of the soft storey is worst than the bare frame and retrofit frame where as the retrofit frame performs well in X direction even if moment of inertia is less.

Table 1: Results of fundamental mode in X-Direction

Floor	***Retrofit frame***				***Soft storey frame***				***Bare frame***			
	Φ	***PF***	***sa***	***F str***	***Φ***	***PF***	***sa***	***F str***	***Φ***	***PF***	***sa***	***F str***
1	0.14	0.15	0.16g	60	0.5	0.58	0.33g	577	0.13	0.16	0.41g	234
2	0.26	0.28	0.16g	114	0.625	0.73	0.33g	736	0.28	0.35	0.41g	483
3	0.38	0.4	0.16g	125	0.7	0.81	0.33g	824	0.42	0.53	0.41g	724
4	0.5	0.54	0.16g	219	0.775	0.89	0.33g	912	0.55	0.7	0.41g	948
5	0.62	0.66	0.16g	272	0.89	1.03	0.33g	1048	0.68	0.86	0.41g	1173
6	0.72	0.77	0.16g	316	0.91	1.06	0.33g	1071	0.78	0.99	0.41g	1345
7	0.8	0.86	0.16g	351	0.93	1.08	0.33g	1095	0.87	1.1	0.41g	1500
8	0.88	0.94	0.16g	386	0.97	1.13	0.33g	1142	0.93	1.18	0.41g	1604
9	0.96	1.03	0.16g	422	0.99	1.15	0.33g	1165	0.97	1.23	0.41g	1673
Roof		1.3	0.16g	440		1.16	0.33g	1178		1.27	0.41g	1725

Where, PF is participation factor, Φ is the mode shape, Sa is the spectral acceleration, Fstr is the storey shear in kN.

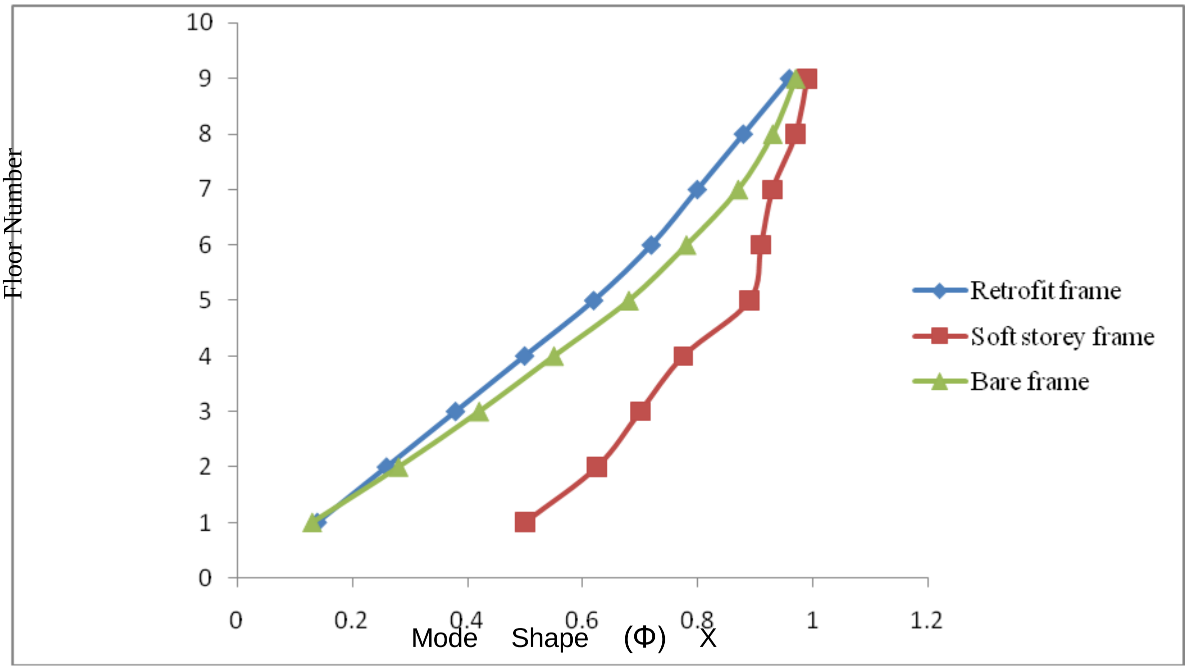

Figure 1: Mode shapes in X directions

From the Figure 4 and Tables 4-6 the formation of hinges over the structures indicate clearly that the frame without masonry infill panel will suffer great damages, the formation of hinges is especially in the first two levels from the ground level, means hinge forms mostly on ground and first floor where columns yielded at event E.

The third model having less amount of damage than all models in which the masonry panel at the lower level has been provided. In third model fully masonry infill frame, the hinge forms on all floors including the diagonal strut. For the model 3 there is a great improvement since column yielded at event LS, it indicating a safe design. For soft storey frame model, it will be better to provide the masonry infill panel otherwise alternative arrangement should be made for resisting the seismic force.

Table 2: Results of fundamental mode in Y-Direction

Floors	*Retrofit frame*				*Soft storey frame*				*Bare frame*			
	Φ	*PF*	*Sa*	*F str*	*Φ*	*PF*	*sa*	*F str*	*Φ*	*PF*	*sa*	*F str*
1	0.12	0.16	0.16g	58	0.32	0.4	0.33g	155	0.14	0.18	0.41g	255
2	0.25	0.32	0.16g	120	0.42	0.53	0.33g	268	0.28	0.35	0.41g	528
3	0.38	0.5	0.16g	183	0.52	0.66	0.33g	410	0.42	0.53	0.41g	792
4	0.51	0.54	0.16g	245	0.61	0.77	0.33g	565	0.55	0.7	0.41g	1038
5	0.63	0.82	0.16g	303	0.71	0.9	0.33g	770	0.65	0.83	0.41g	1226
6	0.75	0.97	0.16g	360	0.81	1.03	0.33g	996	0.78	1	0.41g	1490
7	0.84	1.09	0.16g	404	0.87	1.1	0.33g	1149	0.87	1.1	0.41g	1641
8	0.91	1.18	0.16g	438	0.92	1.17	0.33g	1285	0.94	1.18	0.41g	1773
9	0.96	1.25	0.16g	461	0.98	1.24	0.33g	1458	0.98	1.24	0.41g	1848
Roof		1.3	0.16g	467		1.27	0.33g	1392		1.27	0.41g	1833

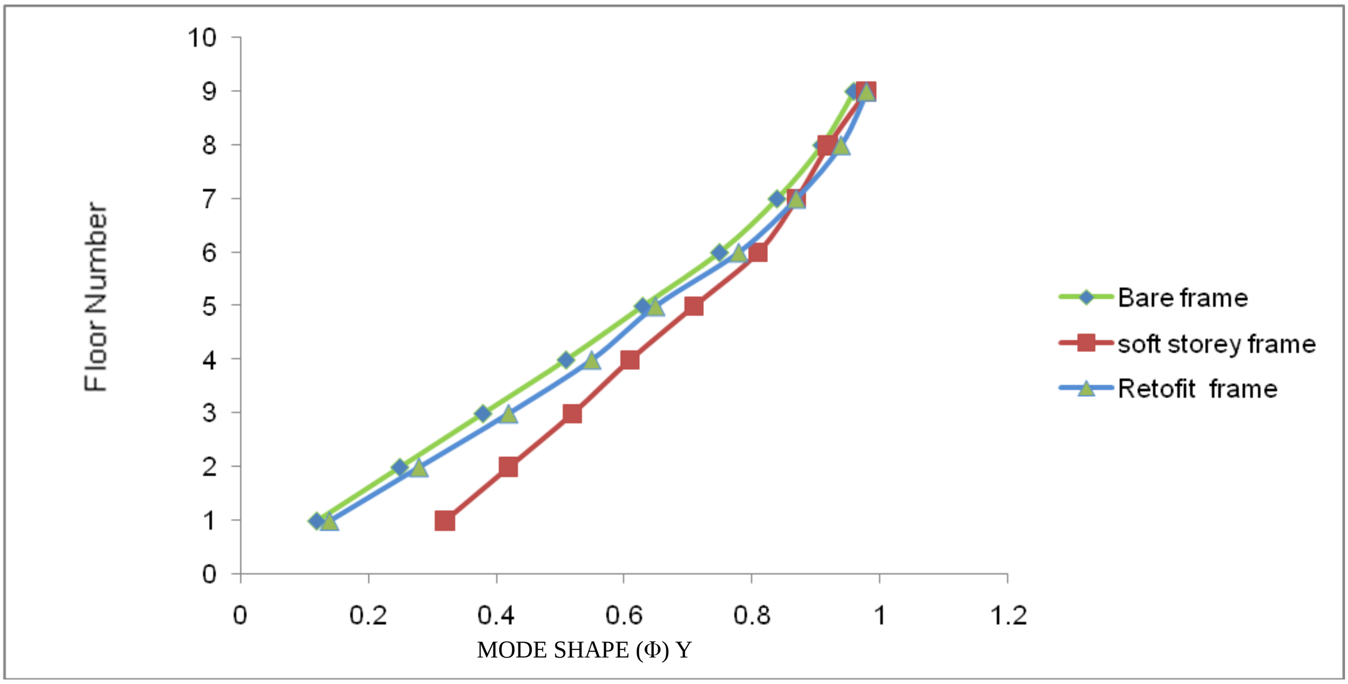

Figure 2 : Mode shapes in Y directions

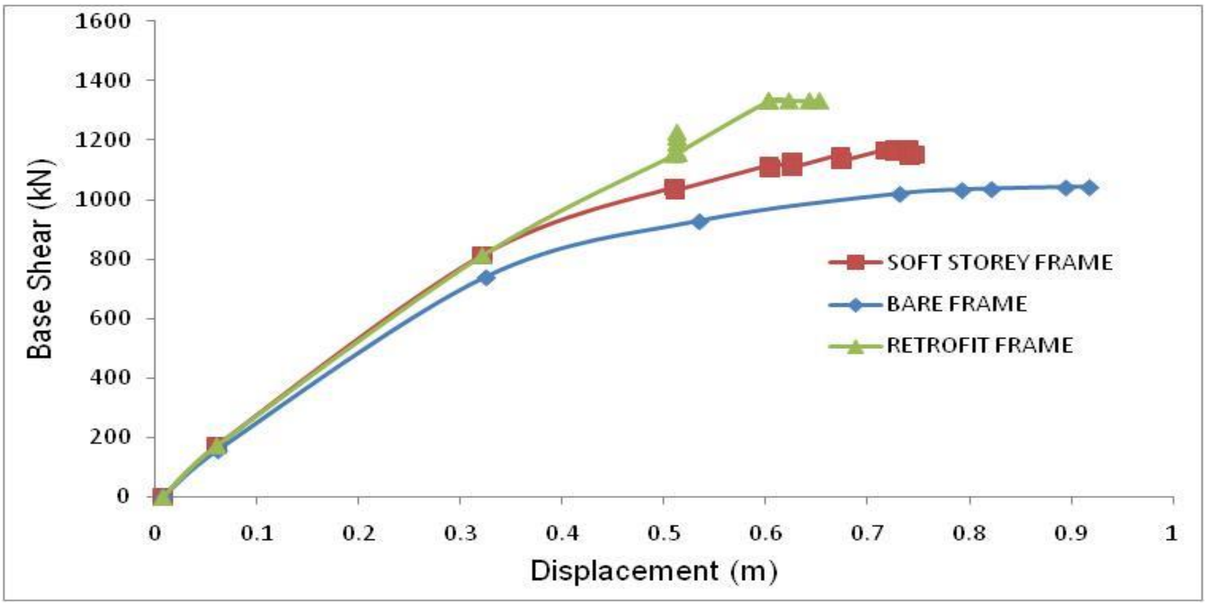

Figure 3: Pushover curve for all models

Table 3: Results of Base Shear and Displacement

Base Shear (kN)			*Displacement (m)*		
Bare Frame	***Soft Storey***	***Retrofit Frame (MI)***	***Bare Frame***	***Soft Storey***	***Retrofit Frame (MI)***
0	0	0	0.008	0.007	0.007
156.285	173.339	812.806	0.061	0.061	0.071
739.302	812.806	739.302	0.324	0.321	0.332
927.677	1041.895	927.677	0.534	0.510	0.520
1019.898	1030.276	1019.898	0.731	0.510	0.530
1032.656	1114.473	1167.672	0.792	0.603	0.626
1036.272	1105.097	1256.572	0.821	0.604	0.646
1041.613	1126.767	1315.446	0.894	0.626	0.686
1042.559	1108.226	1463.22	0.918	0.673	0.718

Figure 3: Performance point (●) for all Models

AtoB	*BtoIO*	*IOtoLS*	*LStoCP*	*CPtoC*	*CtoD*	*DtoE*	*BeyondE*	*Total*
1416	0	0	0	0	0	0	0	1416
1415	1	0	0	0	0	0	0	1416
1165	251	0	0	0	0	0	0	1416
1043	373	0	0	0	0	0	0	1416
911	505	0	0	0	0	0	0	1416

835	581	0	0	0	0	0	0	1416
813	603	0	0	0	0	0	0	1416
662	502	218	34	0	0	0	0	1416
660	498	194	64	0	0	0	0	1416
659	475	180	94	0	8	0	0	1416
659	475	180	94	0	0	8	0	1416
659	475	180	94	0	0	8	0	1416
659	475	179	95	0	0	8	0	1416
659	475	179	95	0	0	8	0	1416
659	475	179	95	0	0	8	0	1416
659	475	179	95	0	0	8	0	1416
659	461	187	93	0	0	16	0	1416
659	447	145	147	0	2	16	0	1416
659	447	145	147	0	0	18	0	1416
659	437	104	188	0	8	20	0	1416

Table 4: Results of non-linear hinges for Model 1

Table 5: Results of non-linear hinges for Model 2

AtoB	*BtoIO*	*IOtoLS*	*LStoCP*	*CPtoC*	*CtoD*	*DtoE*	*BeyondE*	*Total*
1416	0	0	0	0	0	0	0	1416
1415	1	0	0	0	0	0	0	1416
1200	216	0	0	0	0	0	0	1416
1144	272	0	0	0	0	0	0	1416
929	487	0	0	0	0	0	0	1416
668	494	190	64	0	0	0	0	1416
666	466	181	93	0	10	0	0	1416
666	466	181	93	0	0	10	0	1416
666	465	181	92	0	1	11	0	1416
666	465	181	92	0	0	12	0	1416
666	465	181	92	0	0	12	0	1416
666	465	181	92	0	0	12	0	1416
666	465	181	92	0	0	12	0	1416
666	464	178	96	0	0	12	0	1416
666	464	178	96	0	0	12	0	1416
666	450	190	94	0	4	12	0	1416
666	444	130	158	0	2	16	0	1416
666	444	130	158	0	0	18	0	1416

Table 6: Results of non-linear hinges for Model 3

AtoB	*BtoIO*	*IOtoLS*	*LStoCP*	*CPtoC*	*CtoD*	*DtoE*	*BeyondE*	*Total*
1416	0	0	0	0	0	0	0	1416
1415	1	0	0	0	0	0	0	1416
1199	217	0	0	0	0	0	0	1416
1152	264	0	0	0	0	0	0	1416
930	486	0	0	0	0	0	0	1416
862	554	0	0	0	0	0	0	1416
825	591	0	0	0	0	0	0	1416
676	500	206	34	0	0	0	0	1416
672	500	180	64	0	0	0	0	1416
671	457	187	93	0	8	0	0	1416
669	459	187	93	0	0	8	0	1416
669	459	178	94	0	8	8	0	1416
669	459	178	94	0	0	16	0	1416
669	449	118	162	0	2	16	0	1416
668	450	86	192	0	0	20	0	1416
668	450	82	188	0	8	20	0	1416
668	450	82	188	0	0	28	0	1416
668	450	82	188	0	0	28	0	1416
668	450	82	188	0	0	28	0	1416
668	450	82	188	0	0	28	0	1416
668	450	82	188	0	0	28	0	1416

V. CONCLUSIONS

- The pushover analysis is relatively simple way to explore the non linear behaviour of the buildings when subjected to lateral loads.
- The results obtained in terms of demand, capacity and plastic hinges gives an insight into the real behaviour of structures.
- Absence of in filled walls in the ground floor resulted in the formation of soft story. Adding shear walls on the ground floor share almost two –thirds of the lateral shear without undergoing severe damage.
- The behaviour of reinforced concrete frame building is adequate as indicated by the intersection of the demand and capacity curves when analysed with shear wall and the distribution of hinges in the beams and the columns. Most of the hinges developed in the beams and few in the columns but with limited damage.
- The overall ductility of the frame is dependent on the ductility of the beams and the ductility of the base column. If the base columns and the beams are capable of undergoing large deformation without any failure then the frame can undergo large deformations without any significant loss of vertical load carrying capacity of the frame. Hence for making the structure capable of undergoing large deformations it is necessary to ensure that the beams and the base column should have good ductility.
- The resulting inadequate stiffness, which is created due to absence of MI, causes less base share capacity of the soft storey.

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