STRONG COLUMN WEAK BEAM CONCEPT BY ANALYSING RCC MRF FRAME BY NON-LINEAR STATIC PROCEDURE

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ABSTRACT

From the former earthquakes, plastic hinges of columns are more protuberant than plastic hinges of the beam which stretches intensification to global structural weakening and leads to loss of countless lives. Entirely the structural mechanisms pass their forces through the column and it further transfers it with foundation and finally to the soil, thus we can visualize if the column collapses whole structure can collapse, this is the concept of the strong beam and weak column. Enhancing the moment-resisting capacity of the column as compare to beams this results in the formation of plastic hinges in the beams first and avoids the global damage as the beam will show flexure as an indication of beam failure and the individuals will have tolerable time to vacate from that structure. The study is undertaken to explore the further behavior of the structure and for this investigation three RC frames of 5, 8, and 12 storey height are considered for strong column weak beam concept for Seismic Zone V, Soil type II and all the guidelines are followed as per IS 1893:2016. For inspection of the recital of plastic hinges of beam and column, non-linear static analysis is accompanied in FEM based software ETABS and the hinges are studied and confirmed conforming to accepted norms given in FEMA 356 and further base shear and performance point are discussed with displacement are checked for all frames.

KEYWORDS: E-Tabs, Pushover Analysis, Moment Capacity Ratio, Performance Point, FEMA356

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INTRODUCTION

The realization of plastic hinges in beams aids to form the utmost anticipated and appropriate energy dissipating mechanism for structure in seismic circumstances. If the plastic hinges are moulded on mutual ends of the column formerly column is not able to extend the plasticity and breakdowns which can lead to global disaster. In preceding earthquakes identical effects had happened, column fails primarily in compression than beams in flexure prime to life intimidating disorder of people in buildings. The main and common failure noticed in the historical earthquakes that were the beam column-failure, story-failure, column-collapsing onward of the beam, and short column effect. The irregular building summonses enormous base shear and they are in grander risk, but the failure of consistent frames deprived of most significant structure irregularity is the chief concern in this work. The failure modes in all the past earthquakes are practically analogous and strong beam weak column derives out to be a major problem which central column to sway and these structures also have a deficiency of ductile detailing between beam and column connections. All international codal provisions recommended strong column weak beam structural design requirements and have a different value of β (beta) for distinctive design codes. The code provision recommended that the moment in the column should be β times stronger than beams.

$$\sum M_c \geq \beta \times \sum M_b \quad (1)$$

Table 1: Values of Moment Capacity Factor for Various International Codes

International Codes	Value of β
American Standard (ACI 318M-02)	1.2
New Zealand Standard (NZS3101:1995)	1.4
European Standard (NZS3101:1995)	1.4
Indian Standard (IS13920:2016)	1.4

Pushover analysis is the static non-linear analysis and is accomplished as per the guiding principle of FEMA-356, 440, and ATC40. This analysis can be operated on various packages like CSI-ETabs, SAP-2000, and Staad.Pro. The assignment of hinges can be manually or pre-available options in the software. Before assigning of hinges the structural performance is checked using linear dynamic analysis and is designed as per respective codes. Assessment of a structure under non-linear static analysis is for performance-based design which helps in designing the column and beams for the new structure and retrofits the earlier structure by checking the plastic hinge recognition criteria given by FEMA-356. Figure 1 shows the performance criteria of framing in which IO means Immediate Occupancy, LS means Life Safety CP means Collapse Prevention which comes in B to C which is a plastic zone in which the structure ductility yields for plastic behavior.

Figure 1: Shear Force vs Deformation.

A comparison of moment capacity ratio of beam and column was done by Yangbing Liu, Yuanxin Liao & Nina Zhen 2012 by varying the capacity ratio from 0.8 to 2.2 to improve the bearing capacity at node end of column and beam has suggested that with the decrease in ductility column loses its strength and $\beta = 1.2$ gives the first hinge on column base and $\beta = 1.6$ gives beam sway moment. Another research by Dooley & Bracci, 2001; Haselton et al., 2011; Ibarra & Krawinkler, 2005 shows that for tall buildings the present over strength factor of 1.2 is not sufficient to prevent the mechanism of plastic hinges and for 4 storey and more the over strength factor of 2 shows complete beam sway mechanism suggested by (Haselton et al., 2011; Ibarra & Krawinkler, 2005). B Shiva kumara Swamy, S K Prasad, Sunil N 2015 conclude in their research that the structure with least stiffness ratio by varying the dimension of beam and column are vulnerable to seismic excitation with the help of pushover analysis and the results are compared for different zones and soil type. A total of 15 structures of 12, 18, and 24 storey with varying capacity ratio from 1.2 to 2.0 was analyzed by Cagurangan (2015) and numerical modeling was done on openness and response of beams and column for incremental dynamic analysis was plotted on the research paper.

STRUCTURE GENERAL INFORMATION

The structural frame having G+5, G+8, and G+12 storey are considered for analysis under seismic zone 5 and medium soil condition, and all the design requirements are fulfilled as per IS456:2000 and IS1893:2016 and IS13920:2016. These frames are first designed for gravity loading and then the results of rebar percentage, column beam capacity ratio and

seismic results are verified and if the result is passed then further pushover analysis is done for the plastic capacity of the structure by assigning hinges in beam-column and performance is checked for all frames but in some cases, beam and column dimensions are not sufficient for some combination for seismic and gravity loading so the dimensions are modified to reduce the rebar percentage for economic purpose and maintaining the column beam capacity ratio and then pushover is done to check the damage and performance of 3 frames. These frames are without dual frame structure like a shear wall, dampers, struts which helps in dissipating energy or distributing seismic energy to check the actual performance of the frame.

METHODOLOGY WITH BUILDING DESCRIPTION

The frame consists of a plan area of 25 sq. m having 5 bays in each direction with a span of 5m and keeping the story height as 3m uniform on all the three structures viz. G+5, G+8, and G+12. The loading condition is adopted as per IS 875:1987 Part 1 for dead load and Part 2 for live load by assuming residential building. The seismic design parameters are adopted as per IS 1893:2016 and IS 13920:2016. Grade of concrete adopted for design is M25 and Fe415 as a grade of steel. Size of a beam fixed as per codal provisions as 300*350 mm and circular column of 450 mm diameter. Figure 2 depicts the 3D view of the selected model Figure 3, Figure 4, and Figure 5 represents a 3D view of 6, 9, and 13 storey buildings.

Figure 2: 3D View of G+5.

Figure 3: Plan View.

Figure 4: 3D View of G+8.

Figure 5: 3D View of G+12.

Beams are selected for hinges having parameter M3 (flexural case) and columns for P-M2-M3 at a distance of 0.1 and 0.9 from both ends. After assigning hinges the analysis was run only for dead and push cases with load combinations and results of Base shear vs. Displacement and performance points were located and frames are checked for that specific performance in which beams and column hinges was checked as per acceptance criteria in FEMA 356.

RESULTS AND DISCUSSIONS

Interpretation of G+5 Frame

Contrasting on the performance of 6 story building shown in Table 1 and Figure 8, the origin of hinges first observed at 49.20 mm displacement and maximum displacement noticed is 350.67 mm at 6870.68 kN base force and after that, it is

observed that base force starts dropping. Straining on the results of FEMA 440 curve in Figure 7, 6086.8kN is observed as performance point at 220.08mm displacement with ductility ratio of 2.60, T-secant as 1.762 s, T-effective as 1.649s and spectral acceleration is observed as 0.24 corresponding to the spectral displacement of 185.9mm.

Table 1: Base Shear vs Monitored Displacement for G+5 Building

Step	Monitored Displacement mm	Base Force kN	A-B	B-C	C-D	D-E	>E	A-IO	IO-LS	LS-CP	>CP	Total
0	0	0	2304	0	0	0	0	2304	0	0	0	2304
1	49.203	2431.166	2300	4	0	0	0	2304	0	0	0	2304
2	119.779	5107.6012	2134	170	0	0	0	2290	12	0	2	2304
3	138.681	5427.9434	2044	260	0	0	0	2214	58	0	32	2304
4	166.498	5699.4491	2008	296	0	0	0	2124	100	0	80	2304
5	175.735	5757.0018	2008	296	0	0	0	2120	96	0	88	2304
6	190.911	5907.4911	1964	340	0	0	0	2100	98	4	102	2304
7	196.797	5940.5036	1964	340	0	0	0	2092	106	4	102	2304
8	211.079	6055.2498	1924	380	0	0	0	2060	106	28	110	2304
9	221.27	6090.9295	1924	380	0	0	0	2044	118	32	110	2304
10	231.605	6192.6891	1908	396	0	0	0	2040	110	40	114	2304
11	284.39	6532.1036	1888	416	0	0	0	2020	78	56	150	2304
12	311.969	6630.8033	1888	416	0	0	0	2016	76	24	188	2304
13	330.074	6774.1355	1884	408	12	0	0	2016	76	12	200	2304
14	345.482	6854.5082	1876	412	16	0	0	2016	68	20	200	2304
15	348.384	6860.8295	1876	412	16	0	0	2016	68	20	200	2304
16	350.673	6870.6882	1872	408	24	0	0	2016	68	20	200	2304
17	350.769	6870.4183	1872	408	24	0	0	2016	68	18	202	2304
18	350.863	6871.0572	1872	408	24	0	0	2016	68	18	202	2304
19	350.875	6870.4538	1872	408	24	0	0	2016	68	18	202	2304
20	350.876	6870.469	1872	408	24	0	0	2016	68	18	202	2304
21	350.883	6867.7953	1872	408	24	0	0	2016	68	18	202	2304
22	350.979	6868.443	1872	407	25	0	0	2016	68	18	202	2304
23	350.98	6868.4995	1872	407	25	0	0	2016	68	18	202	2304

Figure 6: Spectral Acceleration vs Spectral Displacement for G+5 Story.

Figure 7: Detailed Results of FEMA 440 Graph Concerning the Demand Curve for G+5 Frame.

Figure 7: Variation of Base Shear vs Monitored Displacement for G+5 Frame.

Interpretation of G+8 Frame

Stressing on the performance of the 9 story building shown in Table 2 and Figure 11, the origin of hinges first observed at 95.15 mm displacement and maximum displacement noticed is 423.63 mm at 7790.28kN base force and after that, it is observed that base force starts dropping. Straining on the results of the FEMA 440 curve in Figure 10, 7407.5kN is observed as a performance point at 318.8mm displacement with a ductility ratio of 1.77, T-secant as 2.29 s, T-effective as 2.05 s. and spectral acceleration is observed as 0.2 corresponding to the spectral displacement of 261.51mm.

Table 2: Base Shear vs Monitored Displacement for G+8 Building

Step	Monitored Displ mm	Base Force kN	A-B	B-C	C-D	D-E	>E	A-IO	IO-LS	LS-CP	>CP	Total
0	0	0	3456	0	0	0	0	3456	0	0	0	3456
1	95.154	3014.3798	3452	4	0	0	0	3456	0	0	0	3456
2	213.638	6336.5685	3356	100	0	0	0	3436	12	0	8	3456
3	233.42	6798.4041	3276	180	0	0	0	3404	24	0	28	3456
4	233.43	6791.4421	3268	188	0	0	0	3404	24	0	28	3456
5	233.441	6788.489	3268	188	0	0	0	3404	24	0	28	3456
6	234.095	6801.8851	3268	188	0	0	0	3404	24	0	28	3456
7	234.106	6799.3535	3268	188	0	0	0	3404	24	0	28	3456
8	244.843	6972.7104	3220	236	0	0	0	3384	44	0	28	3456
9	252.319	7054.6829	3184	272	0	0	0	3384	40	0	32	3456
10	254.047	7063.6348	3172	284	0	0	0	3384	40	0	32	3456
11	258.278	7104.3111	3160	296	0	0	0	3384	38	0	34	3456
12	264.868	7140.9565	3144	312	0	0	0	3384	38	0	34	3456
13	268.978	7175.7174	3136	320	0	0	0	3384	36	0	36	3456
14	273.931	7196.2584	3132	324	0	0	0	3368	52	0	36	3456
15	276.978	7221.1857	3128	328	0	0	0	3352	68	0	36	3456
16	331.745	7465.0609	3040	416	0	0	0	3264	116	36	40	3456
17	390.307	7664.2907	3008	448	0	0	0	3180	128	48	100	3456
18	393.128	7681.2448	3000	456	0	0	0	3172	128	48	108	3456
19	418.546	7767.1875	2992	452	12	0	0	3148	124	40	144	3456
20	419.649	7767.4533	2990	454	12	0	0	3148	124	40	144	3456
21	419.697	7767.4553	2990	454	12	0	0	3148	124	40	144	3456
22	419.697	7767.456	2990	454	12	0	0	3148	124	40	144	3456
23	419.708	7761.6196	2990	454	12	0	0	3148	124	40	144	3456
24	422.751	7790.2699	2986	458	12	0	0	3148	124	40	144	3456
25	423.633	7790.2858	2986	458	12	0	0	3148	122	40	146	3456
26	423.643	7732.8721	2986	448	22	0	0	3146	124	40	146	3456
27	423.491	7722.5155	2986	447	23	0	0	3146	124	40	146	3456

Figure 8: Detailed Results of FEMA 440 Graph Concerning the Demand Curve for G+8 Frame.

Figure 9: Variation of Base Shear vs Monitored Displacement for G+8 Frame.

Figure 10: Spectral Acceleration vs Spectral Displacement for G+8 Story.

Interpretation of G+12 Frame

Incorporating the performance of 13 story buildings shown in Table 3 and Figure 14, the origin of hinges first observed at 195 mm displacement and maximum displacement noticed is 750.04 mm at 9140.72 kN base force and after that, it is observed that base force starts dropping. Straining on the results of FEMA 440 curve in Figure 13 7972.61kN is observed as performance point at 502.8mm displacement with ductility ratio of 1.90, T-secant as 3.31s, T-effective as 3.13s and spectral acceleration is observed as 0.15 corresponding to the spectral displacement of 411.35mm

Table 3: Base Shear vs Monitored Displacement for G+12 Building

Step	Monitored Displacement	Base Force	A-B	B-C	C-D	D-E	> E	A-IO	IO-LS	LS-CP	>C P	Total
	mm	kN										
0	0	0	4992	0	0	0	0	4992	0	0	0	4992
1	156	3254.6294	4992	0	0	0	0	4992	0	0	0	4992
2	195.725	4083.4057	4976	16	0	0	0	4992	0	0	0	4992
3	357.727	6769.3559	4768	224	0	0	0	4920	56	0	16	4992
4	410.854	7354.6083	4624	368	0	0	0	4884	48	0	60	4992
5	523.768	8113.8764	4476	516	0	0	0	4668	92	0	232	4992
6	688.624	8935.0623	4356	632	4	0	0	4560	104	12	316	4992
7	722.99	9089.6019	4328	648	16	0	0	4544	102	26	320	4992
8	741.406	9141.3774	4322	650	20	0	0	4544	96	28	324	4992
9	744.176	9144.1278	4322	650	20	0	0	4544	96	28	324	4992
10	746.925	9138.2765	4322	650	20	0	0	4544	96	28	324	4992
11	750.04	9140.7234	4322	650	20	0	0	4544	96	28	324	4992
12	747.963	9097.3919	4322	650	20	0	0	4544	96	28	324	4992

Figure 11: Detailed Results of FEMA 440 Graph Concerning the Demand Curve for G+12 Frame.

Figure 12: Spectral Acceleration vs Spectral Displacement for G+12 Story.

Figure 13: Variation of Base Shear vs Monitored Displacement for G+12 Frame.

CONCLUSIONS

Concluding the analytical results of non-linear static pushover analysis, the dimensions of beam and column highly influenced the design capacity of the structure and the concept of weak beam strong column is highly recommended for performance-based design. Straining on the code recommendation and the analytical results, there is a clear indication of the strong influence of moment capacity on the ductility of the column and further the frame follows the assorted array in which extremity node at ground level illustrates the formation of hinges and rest follows beam mechanism. Concluding the maximum displacement and corresponding base shear, the results show that the maximum displacement and base shear are directly related to several storey's, as in G+5 the maximum displacement is 350 mm corresponding to 6870 kN base force, similarly for G+8, displacement up to dropping of base shear 423 mm corresponding to 7790 kN base force and for G+12 frame it is 750 mm and 9140 kN base force which indicate an increase of maximum displacement and base shear as an increase in several stories.

Another aspect of the study depicts that the performance point observed for G+5, G+8, and G+12 frame as 6870.68kN, 7790.28kN, and 9140.72kN which surprisal shows a rapid increase in performance point but later increment is low. Contrasting on the displacement at performance point for G+5, G+8, and G+12 is 220.8, 318.8 and 502.8, which shows 44.38% increment in displacement from G+5 to G+8, and 57.71% increment in displacement from G+8 to G+12

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