Seismic Retrofitting of RC Building by Using Different Bracing Systems

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ABSTRACT

The Buildings, which appeared to be strong enough, may crumble like houses of cards during earthquake and deficiencies may be exposed. Experience gain from the recent earthquake of Bhuj, 2001 demonstrates that the most of buildings collapsed were found deficient to meet out the requirements of the present day codes. In last decade, four devastating earthquakes of world have been occurred in India, and low to mild intensities earthquakes are shaking our land frequently. It has raised the questions about the adequacy of framed structures to resist strong motions, since many buildings suffered great damage or collapsed. Under such circumstances, seismic qualification of existing buildings has become extremely important. Seismic qualification eventually leads to retrofitting of the deficient structures

A nonlinear static pushover analysis using the displacement coefficient method, as described in FEMA 356 is carried out on an existing hostel building in Babasaheb Naik College of Engineering, Pusad. Built in 1987, the subject hostel building is a four-story, rectangular structure.

1. INTRODUCTION

1.1 General

A large number of existing buildings in India are severely deficient against earthquake forces and the number of such buildings is growing very rapidly. This has been highlighted in the past earthquake. Retrofitting of any existing building is a complex task and requires skill, retrofitting of RC buildings is particularly challenging due to complex behavior of the RC composite material. The behavior of the buildings during earthquake depends not only on the size of the members and amount of reinforcement, but to a great extent on the placing and detailing of the reinforcement. There are three sources of deficiencies in a building, which have to be accounted for by the retrofitting engineer:

(i) Inadequate design and detailing
(ii) Degradation of material with time and use
(iii) Damage due to earthquake or other catastrophe.

The three sources, suggest a retrofit scheme to make up for the deficiencies and demonstrate that the retrofitted structure will be able to safely resist the future earthquake forces expected during the lifetime of the structure. In particular, the seismic rehabilitation of older concrete structures in high seismicity areas is a matter of growing concern, since structures vulnerable to damage must be identified and an acceptable level of safety must be determined **[1]**.

Thus, the structural engineering community has developed a new generation of design and seismic procedures that incorporate performance based structures and is moving away from simplified linear elastic methods and towards a more non-linear technique. Recent interests in the development of performance based codes for the design or rehabilitation of buildings in seismic active areas show that an inelastic procedure commonly referred to as the pushover analysis is a viable method to assess damage vulnerability of buildings. Basically, a pushover analysis is a series of incremental static analysis carried out to develop a capacity curve for the building. Based on the capacity curve, a target displacement which is an estimate of the displacement that the design earthquake will produce on the building is determined. The extent of damage experienced by the structure at this target displacement is considered representative of the damage experienced by the building when subjected to design level ground shaking. Many methods were presented to apply the nonlinear static pushover (NSP) to structures. These methods can be listed as:

(1) Capacity Spectrum Method (CSM) (ATC)
(2) Displacement Coefficient Method (DCM) (FEMA-356)
(3) Modal Pushover Analysis (MPA).

The approach has been developed by many researchers with minor variation in computation procedure. Since the behavior of reinforced concrete structures may be highly inelastic under seismic loads, the global inelastic performance of RC structures will be dominated by plastic yielding effects and consequently the accuracy of the pushover analysis will be influenced by the ability of the analytical models to capture these effects. In general, analytical models for the pushover analysis of frame structures may be divided into two main types: (1) distributed plasticity (plastic zone) and (2) concentrated plasticity (plastic hinge). Although the plastic hinge approach is simpler than the plastic zone, this method is limited to its incapacity to capture the more complex member behavior that involve severe yielding under the combined actions of compression and bi-axial bending and buckling effects **[1]**.

1.2 Seismic Retrofitting.

All buildings those are constructed, before the modern regulations came up for the design of buildings in seismic areas, those which are constructed before thirty years or those constructed recently but not properly designed, constructed or maintained can be considered as a possible candidates for retrofitting. These buildings may be damaged by earthquake action. It is not always possible to strengthen the existing buildings to the level corresponding to modern seismic codes due to economic reasons. The building should be retrofitted to achieve the required performance level. Although engineering safety is the prime criterion, other criteria such as social, cultural, financial, historical, artistic, and political should also be considered **[13]**.

Existing building can become seismically deficient when

a) Seismic design code requirements are up graded since the design of these buildings is with an older version of the code,

b) Seismic design codes used in their design are deficient,

c) Engineering knowledge makes advances rendering insufficient the previous understanding used in their design, and

d) Designers lack understanding of the seismic behavior of the structures.

Indian buildings built over the past two decades are deficient because of items (b), (c) and (d) above. The last revision of the Indian seismic code in 1987 IS 1893 (1984) is deficient from many points of view, and engineering knowledge has advanced significantly from what was used. Also the seismic design was not practiced in most buildings being built **[2].**

2. OBJECTIVES OF THE PROJECT

a) To analyse the response of existing RC building subjected to seismic loading by pushover analysis using SAP2000.
b) To suggest a retrofit scheme to existing RC building as per seismic analysis.
c) To identify the suitable retrofitting technique for resisting the seismic loads efficiently and effectively.
d) To compare response of conventional rc building and the building having energy dissipating devices subjected to seismic loads.

3. MODELING AND ANALYSIS OF BUILDING.

4.1 Modeling and Analysis of Building.

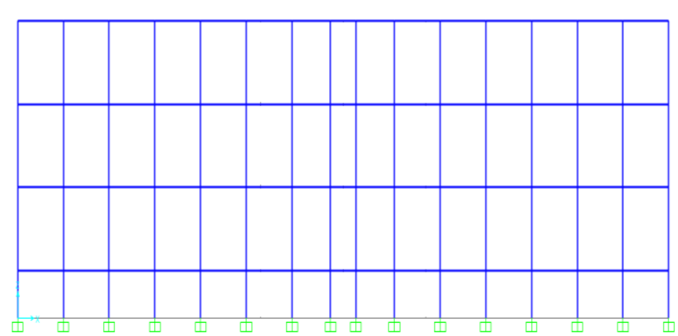

Fig. 4.1 Elevation of Building

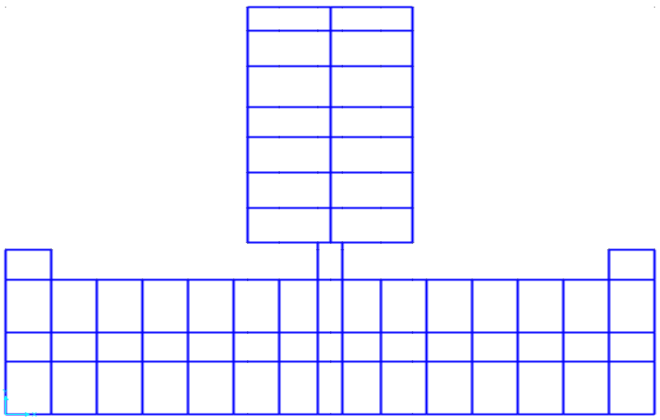

Fig 4.2 Plan of building

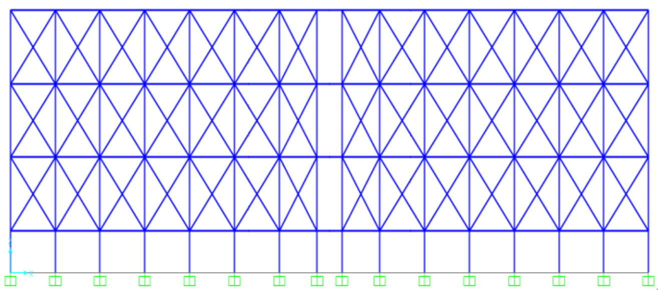

Fig 4.3 Elevation of X Braced Building

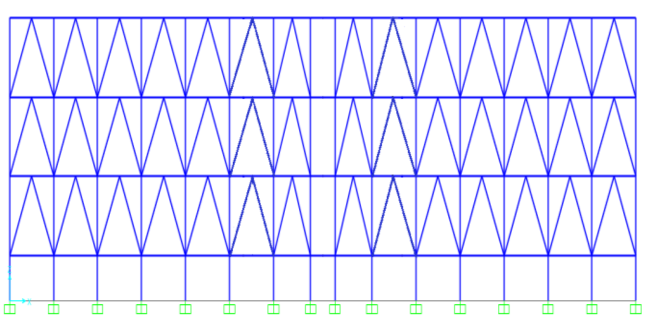

Fig 4.4 Elevation of Inverted V Braced Building

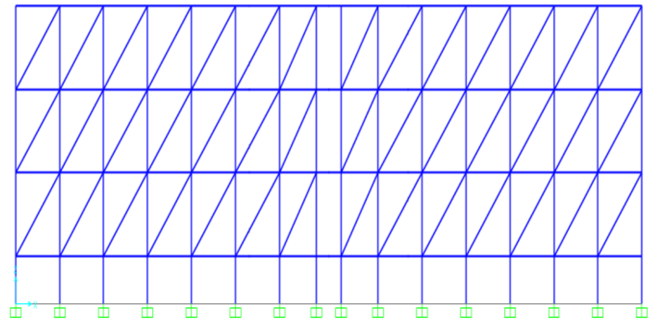

Fig 4.5 Elevation of Inclined Tensile Braced Building

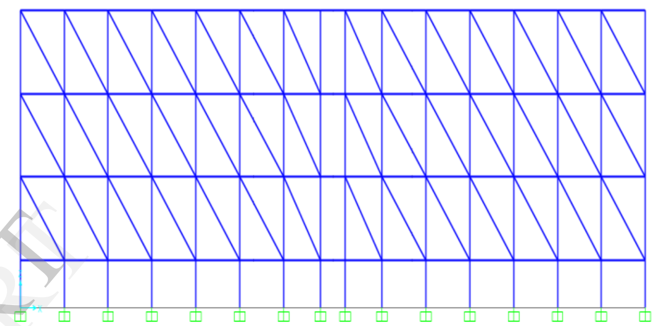

Fig 4.6 Elevation of Inclined Compression Braced Building

4.2 Building Description

i)	Zone	V
ii)	Zone factor	0.36
iii)	Response reduction factor	5
iv)	Important factor	1
v)	Soil condition	Medium
vi)	Height of building	12.50 m
vii)	Wall thickness	
	External	230 mm
	Internal	115 mm

viii)	Weight density of Brick Masonry	20 kN/m3
ix)	Weight density of RC material	25 kN/m^3
x)	Thickness of slab	120 mm
xi)	Floor to floor height	3.5 m
xii)	Plinth height above ground level	2.0 m
xiii)	Size of columns	230 mm x 450 mm
xiv)	Size of beams	230 mm x 400 mm
xv)	Size of brace	ISMC 250
xvi)	Type of bracing system	X- bracing Inverted V bracing Inclined bracing
xv)	Grade of steel	Fe-415
xvi)	Grade of concrete	M20
xvii)	Floor finish	1.0 kN/m^2
xviii)	Imposed load	4.0 kN/m^2

5. RESULTS AND DISCUSSION

5.1 General

In the present study, non-linear response of existing RC frame building using SAP 2000 under the loading has been carried out. The objective of this study is to see the variation of load-displacement graph and check the maximum base shear and displacement of the frame.

After running the analysis, the pushover curve is obtained as shown in figures.

A table also obtain which gives the coordinates of each step of the pushover curve and summarizes the number of hinges in each state (for example, between IO, LS, CP or between D and E). This data is shown in following table.

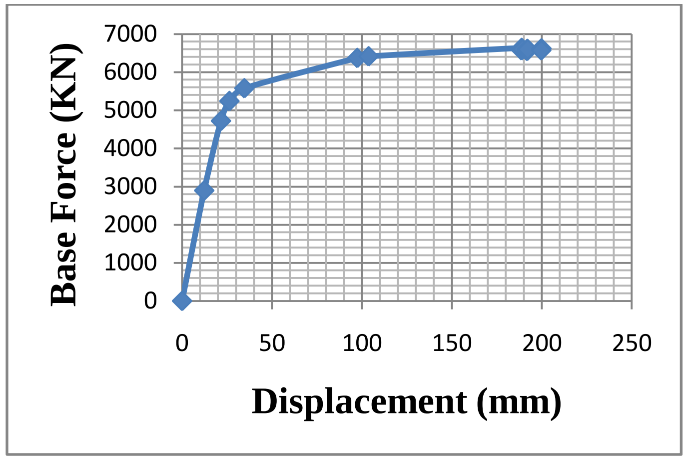

Fig. 5.1 Pushover Curve of an Existing Building in X direction

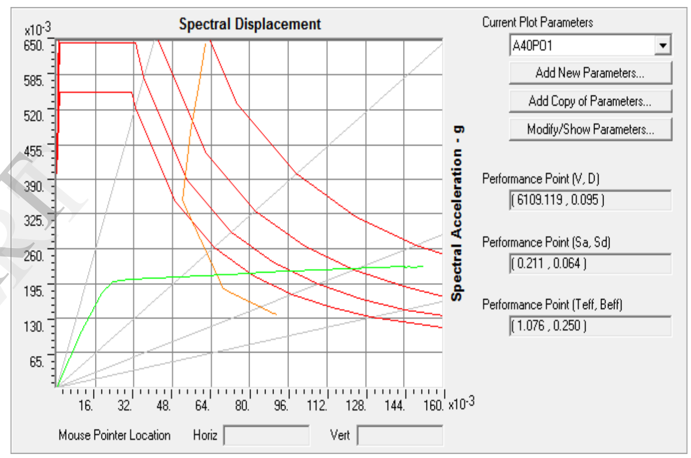

Fig. 5.2 Capacity Spectrum Curve of an Existing Building in X direction

Table 5.1 Tabular data for pushover curve in X direction

Steps	Displacement (mm)	Base Force (KN)	A to B	B to IO	IO to LS	LS to CP	CP to C	C to D	D to E	Beyond E	Total
0	0	0	1164	0	0	0	0	0	0	0	1164
1	12	2897	1164	0	0	0	0	0	0	0	1164
2	22	4724	986	178	0	0	0	0	0	0	1164
3	26	5244	837	327	0	0	0	0	0	0	1164
4	35	5579	714	450	0	0	0	0	0	0	1164
5	97	6373	532	357	275	0	0	0	0	0	1164
6	104	6417	476	406	282	0	0	0	0	0	1164
7	189	6637	444	83	435	201	0	1	0	0	1164
8	189	6573	449	77	436	201	0	0	1	0	1164
9	189	6593	451	81	428	203	0	0	1	0	1164
10	189	6599	438	82	436	207	0	0	1	0	1164
11	189	6602	437	82	427	217	0	0	1	0	1164
12	192	6611	445	77	420	220	1	0	1	0	1164
13	192	6556	445	78	421	218	0	0	2	0	1164
14	192	6589	445	78	421	218	0	0	2	0	1164
15	192	6602	445	78	421	218	0	0	2	0	1164
16	200	6625	443	79	422	218	0	0	2	0	1164
17	200	6575	422	80	411	247	0	0	4	0	1164

After Pushover analysis hinges formation in each stage of a building are calculated, also from fig.5.2 it is obvious that the demand curve tend to intersect the capacity curve near the event point, which means an elastic response and the security margin is greatly enhanced. Therefore, it can be concluded that the margin safety against collapse is high and there are sufficient strength and displacement reserves.

To improve the seismic performance of existing building, different bracing systems are proposed and the analysis is carried out for existing building with different combinations of bracing systems. The analysis results are demonstrated with the help of figures and charts. Finally, the comparative study is carried out based on different parameters such as lateral displacement, base shear.

After running the analysis of building with different bracing combinations, the pushover curve is obtained as shown in figure 5.3 to 5.9. Tables also obtain which gives the coordinates of each step of the pushover curve.

5.2 Pushover Curve of Building With Different Bracing System:

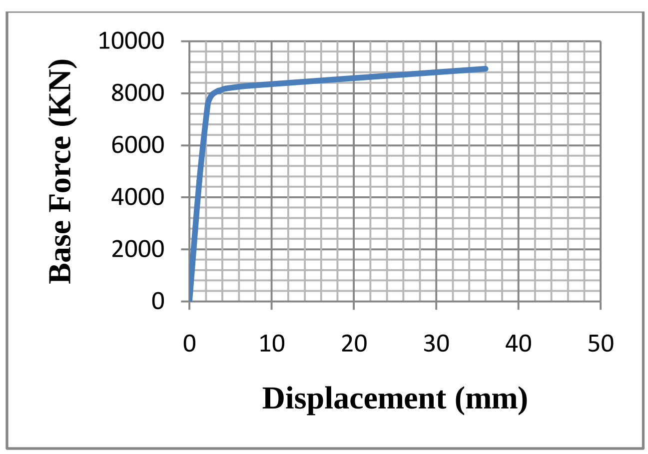

Fig. 5.3 Pushover Curve of X-Braced Building in X direction

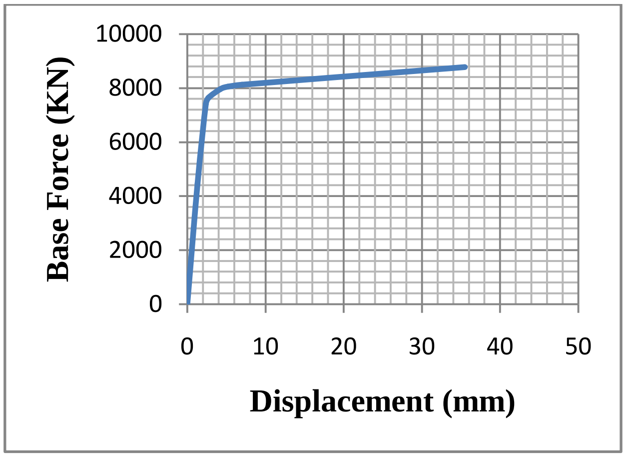

Fig. 5.4 Pushover Curve of Inverted V-Braced Building in X direction

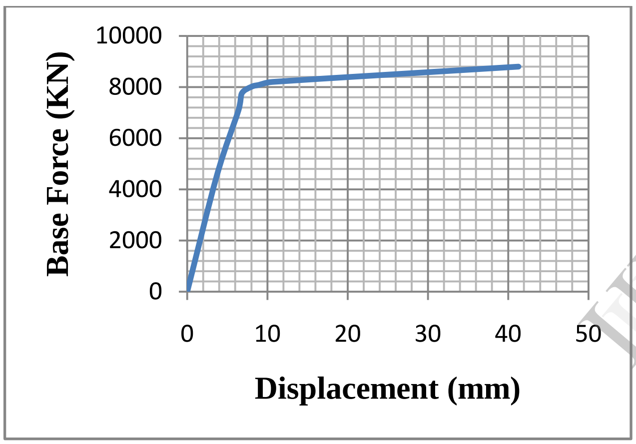

Fig. 5.5 Pushover Curve of Inclined Compression Braced Building in X direction

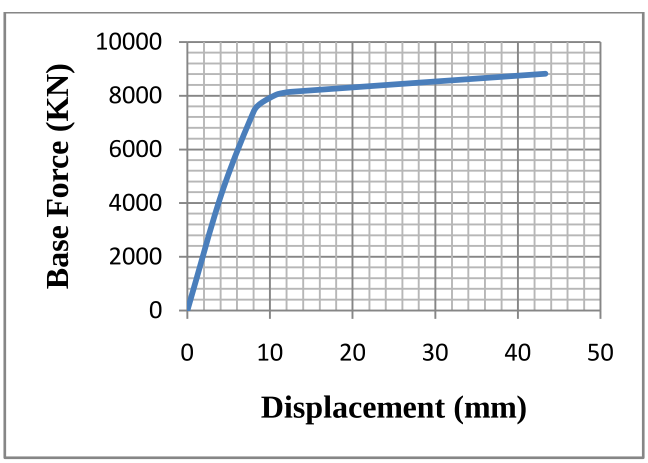

Fig. 5.6 Pushover Curve of Inclined Tensile Braced Building in X direction

5.3 Capacity Spectrum Curve of Building With Different Bracing Systems:

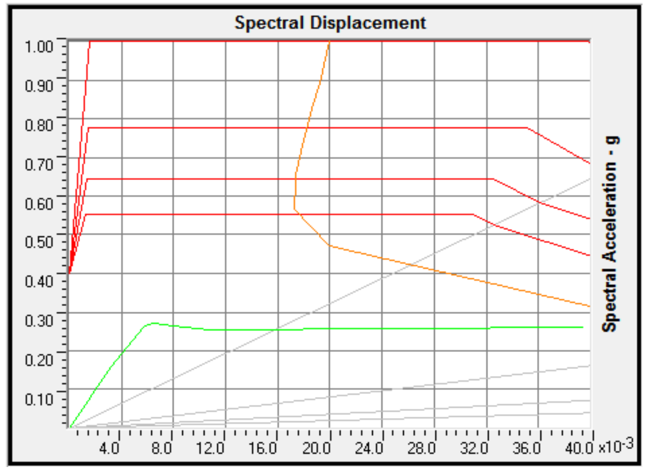

Fig. 5.7 Capacity Spectrum Curve of X-Braced Building in X direction

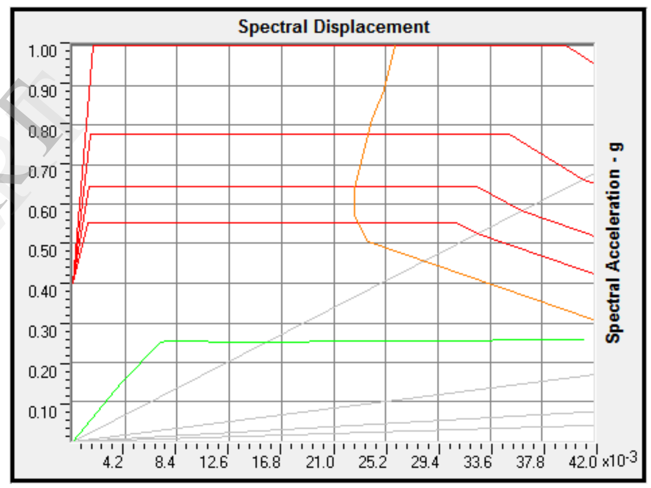

Fig. 5.8 Capacity Spectrum Curve of Inverted V-Braced Building in X direction

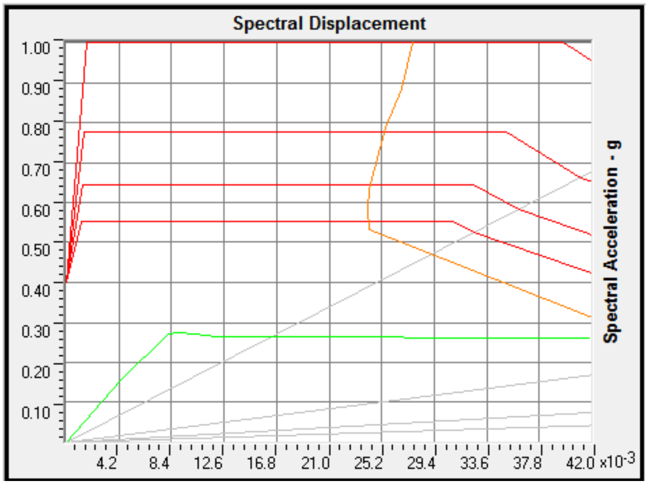

Fig. 5.9 Capacity Spectrum Curve of Inclined-Braced Building in X direction

Table 5.2 Tabular data for pushover curve of X-braced building in X direction

Steps	Displacement (mm)	Base Force (KN)	A to B	B to IO	IO to LS	LS to CP	CP to C	C to D	D to E	Beyond E	Total
0	0	0	1164	0	0	0	0	0	0	0	1164
1	1	4611	1162	2	0	0	0	0	0	0	1164
2	2	7537	1030	134	0	0	0	0	0	0	1164
3	2	7761	966	198	0	0	0	0	0	0	1164
4	3	7951	943	221	0	0	0	0	0	0	1164
5	4	8096	924	240	0	0	0	0	0	0	1164
6	4	8113	915	249	0	0	0	0	0	0	1164
7	4	8172	910	254	0	0	0	0	0	0	1164
8	7	8284	908	256	0	0	0	0	0	0	1164
9	36	8933	891	83	0	185	0	5	0	0	1164
10	36	8470	887	87	0	179	0	0	11	0	1164

Table 5.3 Tabular data for pushover curve of inverted V braced building in X direction

Steps	Displacement (mm)	Base Force (KN)	A to B	B to IO	IO to LS	LS to CP	CP to C	C to D	D to E	Beyond E	Total
0	0	0	1164	0	0	0	0	0	0	0	1164
1	1	4466	1162	2	0	0	0	0	0	0	1164
2	2	7417	1020	144	0	0	0	0	0	0	1164
3	3	7643	940	224	0	0	0	0	0	0	1164
4	4	7961	904	260	0	0	0	0	0	0	1164
5	5	8055	893	271	0	0	0	0	0	0	1164
6	7	8123	884	280	0	0	0	0	0	0	1164
7	36	8774	849	125	0	185	0	5	0	0	1164
8	37	8330	848	126	0	168	0	0	22	0	1164

Table 5.4 Tabular data for pushover curve of inclined compression braced building in X direction.

Steps	Displacement (mm)	Base Force (KN)	A to B	B to IO	IO to LS	LS to CP	CP to C	C to D	D to E	Beyond E	Total
0	0	0	1164	0	0	0	0	0	0	0	1164
1	4	4347	1162	2	0	0	0	0	0	0	1164
2	8	7414	985	179	0	0	0	0	0	0	1164
3	9	7708	917	247	0	0	0	0	0	0	1164
4	11	8011	892	272	0	0	0	0	0	0	1164
5	11	8089	874	290	0	0	0	0	0	0	1164
6	13	8140	865	299	0	0	0	0	0	0	1164
7	43	8811	838	136	0	184	0	6	0	0	1164
8	42	8523	836	137	0	175	0	2	14	0	1164

Table 5.5 Tabular data for pushover curve of inclined tensile braced building in X direction.

Steps	Displacement (mm)	Base Force (KN)	A to B	B to IO	IO to LS	LS to CP	CP to C	C to D	D to E	Beyond E	Total
0	0	0	1164	0	0	0	0	0	0	0	1164
1	4	4547	1162	2	0	0	0	0	0	0	1164
2	6	7101	982	182	0	0	0	0	0	0	1164
3	7	7750	923	241	0	0	0	0	0	0	1164
4	8	8011	866	298	0	0	0	0	0	0	1164
5	9	8089	870	294	0	0	0	0	0	0	1164
6	11	8201	863	301	0	0	0	0	0	0	1164
7	41	8799	827	139	0	190	0	8	0	0	1164
8	40	8896	824	145	0	176	0	3	16	0	1164

After Pushover analysis of different braced systems building, hinges formation in each stage of a building are calculated, from table 5.1 it can been seen that total number of yielding occurs in building without bracing in X direction at event B, IO, LS, and E respectively is 742 while from table 5.3 to 5.6 it can be seen that total number of yielding occurs in building with X-bracing, inverted V bracing, and inclined bracing in X direction is 277, 316, 328 and 340 respectively. Also from fig.5.9 and fig. 5.10 it is obvious that the demand curve is not intersecting the capacity curve which mean building is safe against collapse.

5.4 Plastic Hinges Mechanism.

Plastic hinge formation for the without braced building and building with different braced systems have been obtained at different displacement levels. The hinging patterns are plotted in figures 5.10, 5.11, 5.12 and 5.13. From figure 5.10 it can be seen that the plastic hinges formation starts with beam ends and base columns of lower stories, then propagates to upper stories and continue with yielding of interior intermediate columns in the upper stories.

Comparison of the figures 5.11, 5.12 and 5.13 reveals that the patterns of plastic hinge formation for the different braced building are quite similar. But since yielding occurs at events B, IO and LS respectively, the amount of damage in the three buildings will be limited

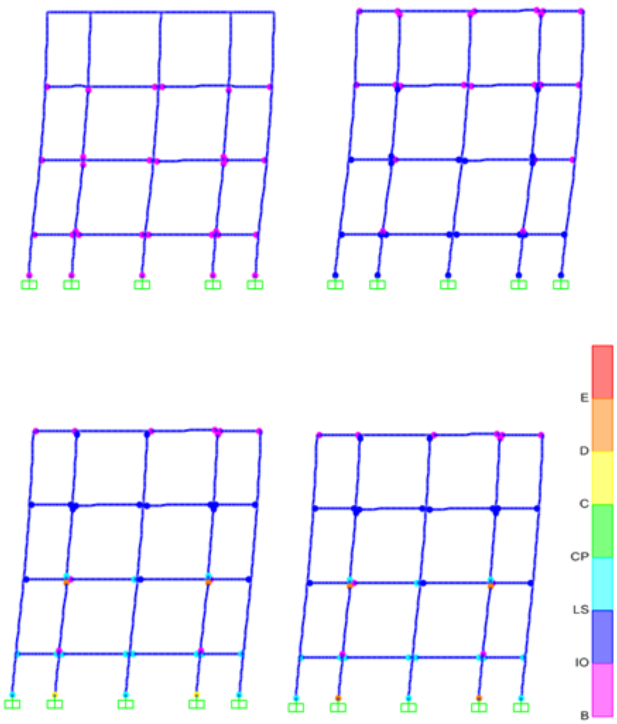

Fig. 5.10 Hinges Pattern of Without Braced Building at Different Pushover Steps

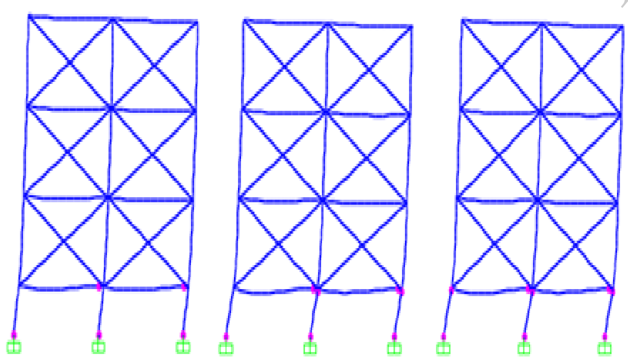

Fig. 5.11 Hinges Pattern of X-Braced Building at Different Pushover Steps

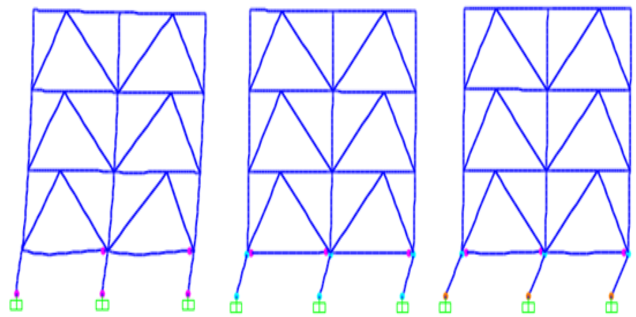

Fig. 5.12 Hinges Pattern of Inverted V Braced Building at Different Pushover Steps

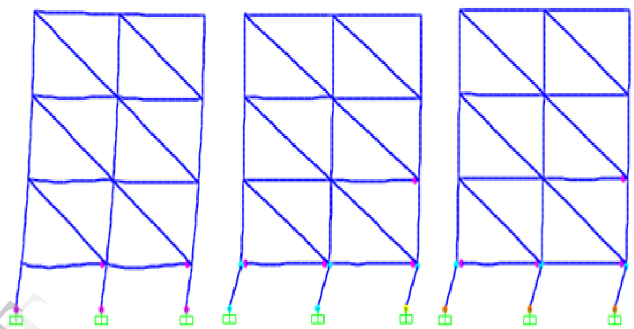

Fig. 5.13 Hinges Pattern of Inclined Braced Building at Different Pushover Steps

From figure 5.11 to figure 5.13 it can be seen that maximum plastic hinges are forming at the base storey because due to practical difficulty bracing cannot be provided below the ground level. Though the base force is increasing.

5.5 Lateral Displacement:-

The graphs are plotted taking pushover steps as the abscissa and displacement as ordinate for different bracing systems.

5.5.1 Comparison of displacement at various pushover steps of without braced building and building with different bracing system. The graphs for ISMC 250 are plotted in X direction as shown in fig. 5.17

From fig. 5.17 it can be seen that lateral displacement in braced buildings with bracing section ISMC 250 are reduced as compared to the without braced building in X direction.

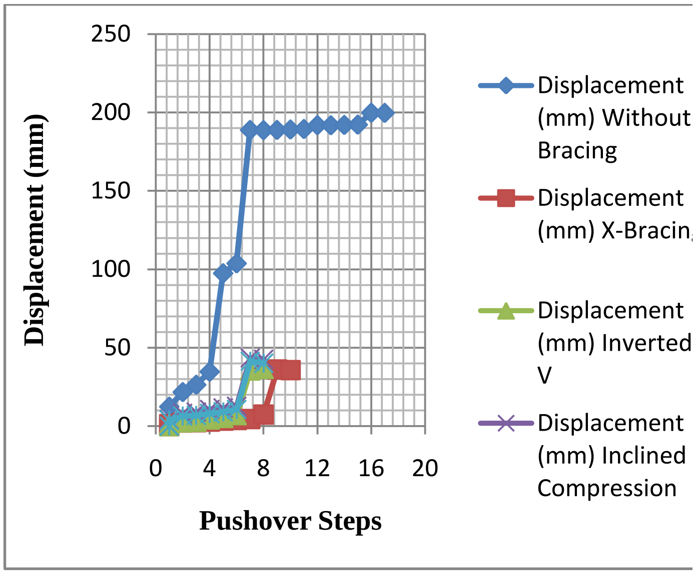

Fig. 5.11 Displacement of Floor at Various Steps in X-Direction

The displacement at last step at the top storey reduces by 82.17%, 81.7%, 78.76% and 79.79 for X bracing, inverted V bracing, inclined compression bracing and inclined tensile bracing respectively in X direction.

6. CONCLUSION

A. Introduction

For buildings that needed to be rehabilitated, it is easy to investigate the effect of different strengthening and retrofitting schemes. By using pushover analysis we can select the suitable strengthening and retrofitting schemes by changing member properties of weaker sections and carrying out the analysis again. For retrofitting pushover analysis provides better and economical solution as compared to other methods. The results of present study demonstrate that most of the plastic hinges are forming within beam element. In that case, we can restrengthen the structure by providing X-bracing systems which provides an excellent mechanism for energy dissipation.

Conclusion

Based on analysis results following conclusion are drawn

1. The joints of the structure have displayed rapid degradation and the inter storey deflections have increased rapidly in non- linear zone in structure without bracings. Severe damages have occurred at joints at lower floors whereas moderate damages have been observed in the first and second floors. Minor damage has been observed at roof level.
2. The behavior of properly detailed reinforced concrete frame building is adequate as indicated by the intersection of the demand and capacity curves and the distribution of hinges in the beams and the columns. Most of the hinges developed in the beams and few in the columns.
3. The results obtained in terms of demand, capacity and plastic hinges gave an insight into the real behavior of structures.
4. It is observed that inherent deficiencies in the detailing of the beam-column joints get reflected even after providing bracing systems in Y-direction, though the performance factors indicate significant improvement. There is a need to evolve suitable performance factors when the system shows a negative stiffness.
5. The floor displacement is maximum for without braced building frame as compared to braced building frame. In the braced building frame, floor displacement is minimum for X bracing, and nearly same for inclined bracing and inverted V bracing.
6. From above discussion it is concluded that in inclined bracing system deflection is nearly same as that of X-bracing and inverted V bracing and base shear is also nearly same, so from economic point of view we can provide inclined bracing system to the structure to resist the seismic forces without compromising with strength and stiffness of the structure.

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