Seismic Evaluation and Retrofitting of RC Building by Using Energy Dissipating Devices

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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

In the proposed investigation a performance based evaluation and retrofit of an existing hostel building in Babasaheb Naik College of Engineering, Pusad. Built in 1987, the subject hostel building is a four-story, rectangular structure. A nonlinear static pushover analysis using the displacement coefficient method, as described in FEMA 356, is used to evaluate the seismic performance of the existing building. A seismic retrofit using energy dissipating device based on pushover analysis is proposed for the life-safety target performance of the existing building.

I. 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 safety 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].

1.3 Seismic Design

RC frame building would become massive if they were to be designed to behave elastically without incurring damage, and hence the project may become economically unviable. On the contrary, the building must undergo damage necessarily to be able to dissipate the energy input to it during the earthquake. Thus, as per the seismic design philosophy, (a) under occasional strong shaking, structural damage is acceptable. Therefore, structures are designed philosophy, (a) under occasional strong shaking, structural damage is acceptable, but collapse is not, and (b) under semi occasional moderate shaking, structural damage is limited oven though non-structural damage is not acceptable. Therefore, structures are designed only for a fraction of the force that they would experience if they were designed to remain elastic during the expected strong ground shaking and thereby permitting damage under minor shaking refer figure 2.1 Thus, seismic design balances reduced cost and acceptable damage, thereby making the project viable [2]
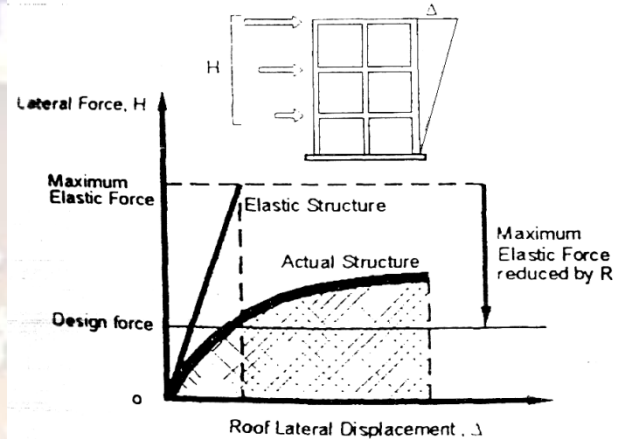
Fig. 1.1 Basic Strategy of Earthquake Design

1. 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.

II. PUSHOVER ANALYSIS

Once the target performance of a structure has been determined by the engineer after having met the requirements of the building and design codes. There are different methods of analysis which provides different degree of accuracy. Based on the type of external action and behavior of structure the seismic analysis methods are classified as

Table 3.1: Types of analysis methods

Static		Dynamic	
Linear	**Nonlinear**	**Linear**	**Nonlinear**
Seismic coefficient	Pushover analysis	Response spectrum	Time history

method	method	method	method

Nonlinear static analysis is an improvement over the linear static or dynamic analysis in the sense that it allows the inelastic behavior of the structure. The method assumes a set of static incremental lateral load over the height of the structure. The method is relatively simple to be implemented, and provides information of the strength, deformation and ductility of the structure and the distribution of demands.

1.1 3D Pushover Analysis
In this analysis method, earthquake load is applied on the model in an incremental basis. Earthquake load distribution is selected for which analysis is required. For this load distribution an initial load step is selected 3 D static analysis is done for this initial load step and checking for plastic moment capacity of elements to reach. If no element reaches plastic moment capacity, then load applied increase and analysis is done for new load. When in any element, plastic moment capacity is reached, plastic hinge is introduced in that element now. New analysis is done on this structure with new earthquake distribution (since earthquake load distribution will depend on structural properties. We can also continue with same distribution of earthquake load).and checking plastic moment capacity in other elements. And when plastic moment capacity is reacted, plastic hinge is introduced in that element.

At each step, load required for each event to occurred is noted down (event is the formation of plastic hinge in any element) same procedure is repeated until plastic mechanism is formed in the entire structure that leads to collapse of structure. Now collapse load is calculated which's nothing but load required for final event to occur.

3.2 Advantages of Pushover Analysis

1) It allows us to evaluate overall structural behaviors and performance characteristics.
2) It enables us to investigate the sequential formation of plastic hinges in the individual structural elements constituting the entire structure.
3) When a structure is to be strengthened through a rehabilitation process, it allows us to selectively reinforce only the required members maximizing the cost efficiency
4) The pushover analysis provides good estimate of global and local inelastic deformation demands for structures that vibrate primarily in the fundamental mode.

3.3 Limitations of Pushover Analysis

1) Deformation estimates obtained from a pushover analysis may be grossly inaccurate for structures where higher mode effects are significant.
2) In most cases it will be necessary to perform the analysis with displacement rather than force control, since the target displacement may be associated with very small positive or even a negative lateral stiffness because of the development of mechanisms and P-delta effects.
3) Pushover analysis implicitly assurances that damage is a function only of the lateral deformation of the structure, neglecting duration effects, number of stress reversals and cumulative energy dissipation demand
4) The procedure does not take into account for the progressive changes in modal properties that take place in a structure as it experiences cyclic non-linear yielding during earthquake.
5) Most critical is the concern that the pushover analysis may detect only the first local mechanism that will form in an earthquake mechanism that will form in an earthquake and may not expose other weakness that will be generated when the structures dynamic characteristics change after formation of first local mechanism.

III. MODELING AND ANALYSIS OF BUILDING
### 4.1 Introduction to SAP 2000
The software used for the present study is SAP 2000. It is product of Computers and Structures, Berkeley, USA. SAP 2000 is used for analyzing general structures including bridges, stadiums, towers, industrial plants, offshore structures, buildings, dam, silos, etc. It is a fully integrated program that allows model creation, modification, execution of analysis, design optimization, and results review from within a single interface. SAP 2000 is a standalone finite element based structural program for analysis and design of civil structures. It offers an intuitive, yet powerful user interface with many tools to aid in quick and accurate construction of models, along with sophisticated technique needed to do most complex projects.

SAP 2000 is objecting based, meaning that the models are created with members that represent physical reality. Results for analysis and design are reported for the overall object, providing information that is both easier to interprets and consistent with physical nature.

The SAP 2000 structural analysis programme offers following features-
- Static and Dynamic Analysis
- Linear and Nonlinear Analysis
- Dynamic seismic analysis and Static push over analysis
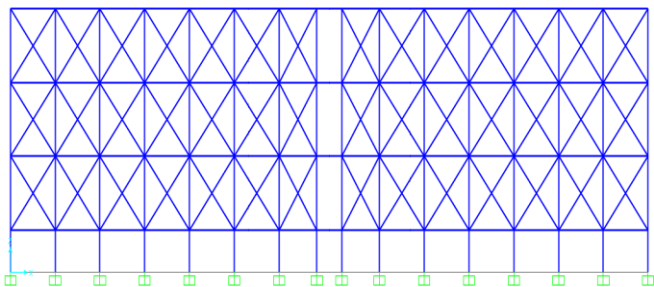- Geometric Nonlinearity including P-Δ effect

- Frame and shell structural elements
- 2-D and 3-D plane and solid elements

Nonlinear link and support analysis

4.2 Modeling and Analysis of Building
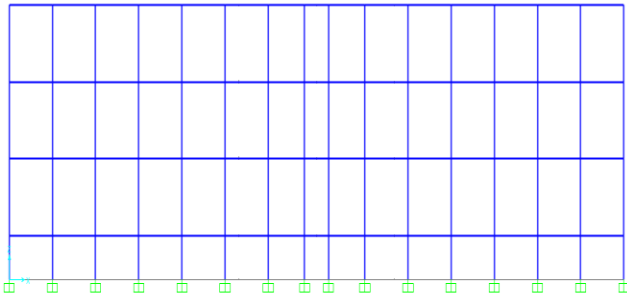
Fig. 4.1 Elevation of Building
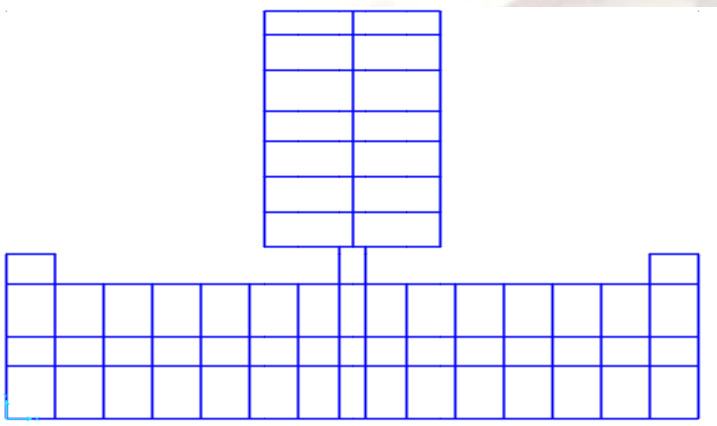
Fig 4.2 Plan of building

Fig 4.3 Elevation of X Braced Building

|		
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
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

**4.3 Building Description**

IV. 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.
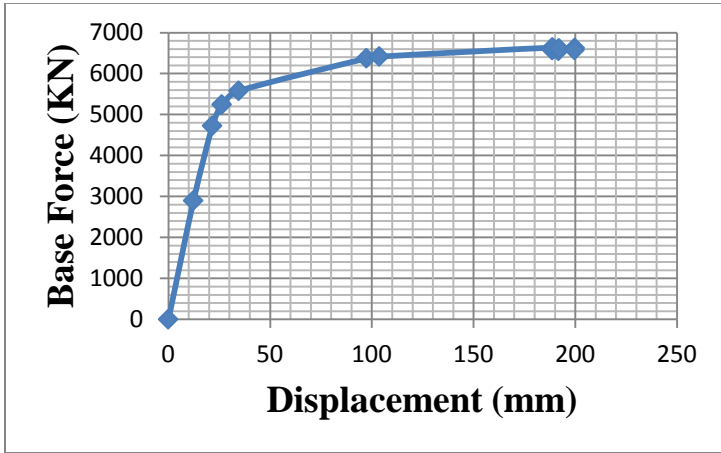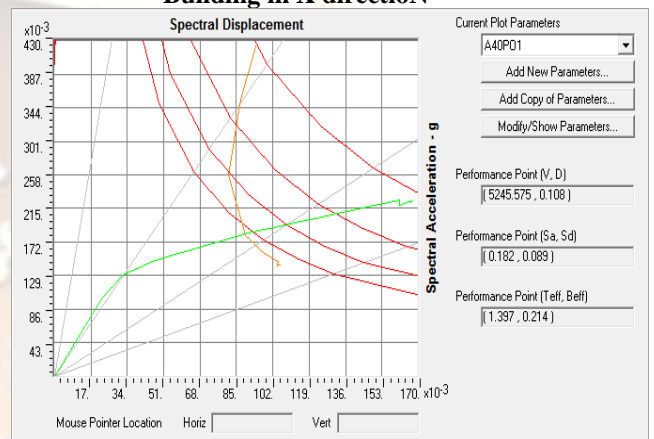
Fig. 5.1 Pushover Curve of an Existing Building in X direction
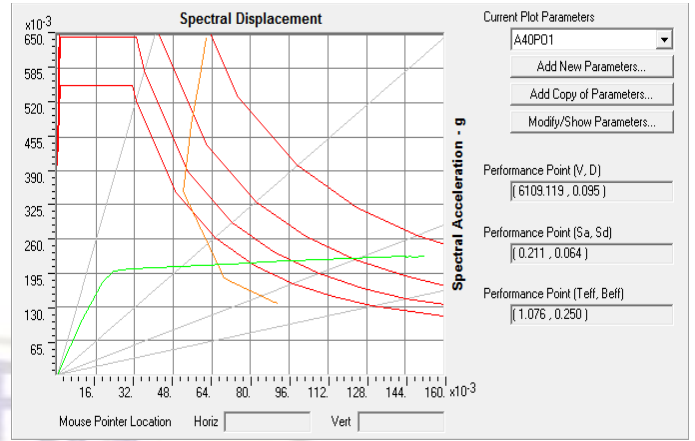
Fig. 5.3 Capacity Spectrum Curve of an Existing Building in X directioN
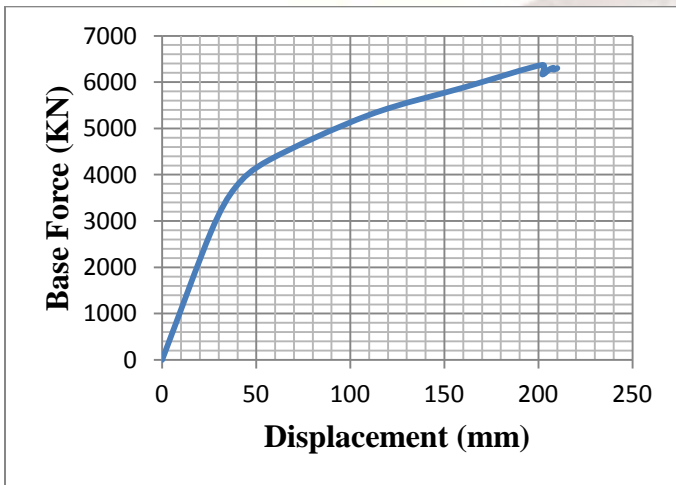
Fig. 5.2 Pushover Curve of an Existing Building in Y direction

Fig. 5.4 Capacity Spectrum Curve of an Existing Building in Y 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

Table 5.2 Tabular data for pushover curve in Y 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	26	2771	1150	14	0	0	0	0	0	0	1164
2	39	3728	960	204	0	0	0	0	0	0	1164
3	57	4319	858	306	0	0	0	0	0	0	1164
4	110	5290	730	242	192	0	0	0	0	0	1164
5	161	5891	714	150	300	0	0	0	0	0	1164
6	202	6370	686	85	217	159	0	17	0	0	1164
7	202	6163	696	85	233	134	0	0	16	0	1164
8	206	6280	702	48	264	134	0	0	16	0	1164
9	208	6308	703	25	293	125	0	2	16	0	1164
10	208	6267	695	26	293	132	0	0	18	0	1164
11	210	6300	700	22	297	130	0	2	13	0	1164
12	192	6393	708	19	297	100	0	0	40	0	1164

After Pushover analysis hinges formation in each stage of a building are calculated, also from fig.5.3 and fig. 5.4 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, X-bracing systems is proposed and the analysis is carried out for existing building with X-bracing system. 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 5.5 to 5.8. Tables also obtain which gives the coordinates of each step of the pushover curve.
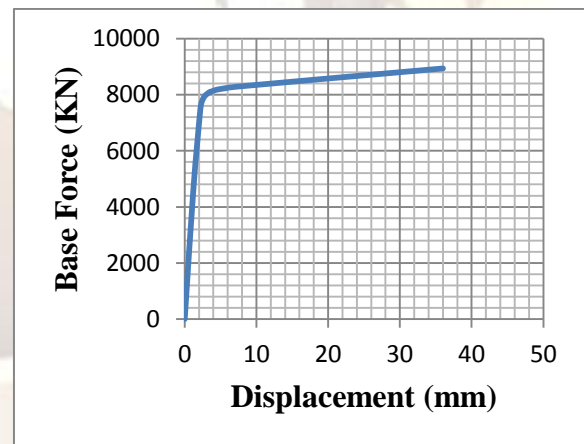

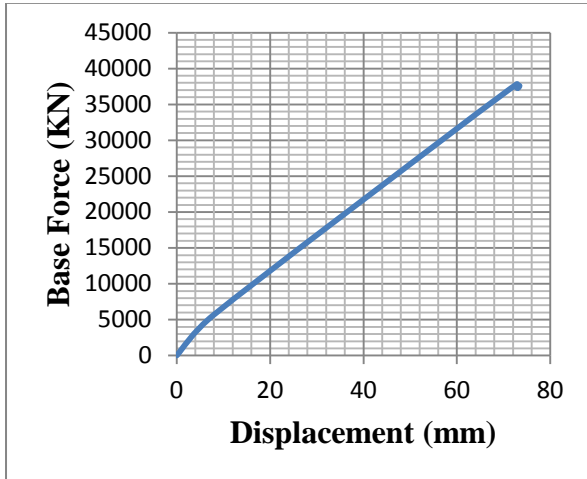**Fig. 5.5 Pushover Curve of X-Braced Building in X direction**

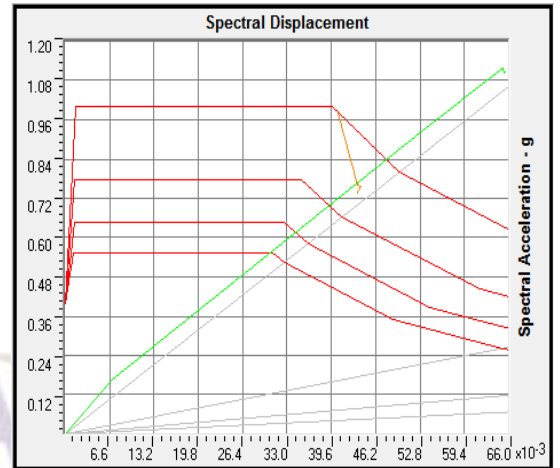**Fig. 5.6 Pushover Curve of X-Braced Building in Y direction**

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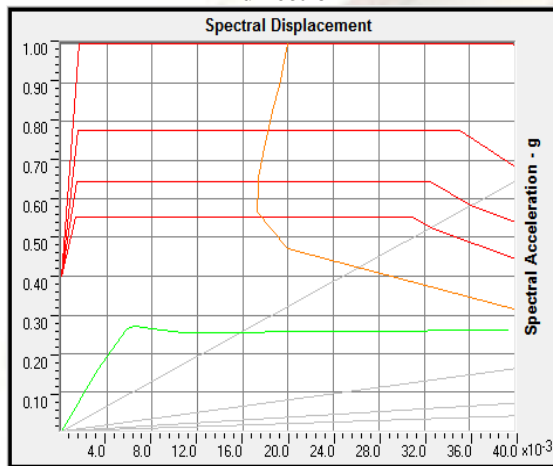

Fig. 5.7 Capacity Spectrum Curve of X-Braced Building in X direction

Table 5.3 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 5.4 Tabular data for pushover curve of X-braced building in Y 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	8	5646	1163	1	0	0	0	0	0	0	1164
2	60	31370	994	8	138	24	0	0	0	0	1164
3	73	37814	991	23	0	133	0	17	0	0	1164
4	73	37298	989	25	0	123	0	0	27	0	1164
5	73	37573	986	27	0	115	0	8	28	0	1164
6	73	37279	981	33	0	114	0	0	36	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 it can be seen that total number of yielding occurs in building with X-bracing, bracing in X direction is 277. Also from fig.5.7 it is obvious that the demand curve is not intersecting the capacity curve which mean building is safe against collapse.

From table 5.2 it can been seen that total number of yielding occurs in building without bracing in Y direction at event B, IO, LS, and E respectively is 456 while from table 5.4 it can be seen that total number of yielding occurs in building with X-bracing in Y direction is 183. Also from fig.5.8 it is obvious that the demand curve tend to intersect the capacity curve near the event point, as the performance point is obtained in Y direction is at very lateral stage as compared to without braced building which means some sort of an elastic response and the security margin is to be enhanced in Y direction.

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 5.13, 5.14, 5.15 and 5.16. From figure 5.13 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 5.14, 5.15 and 5.16 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
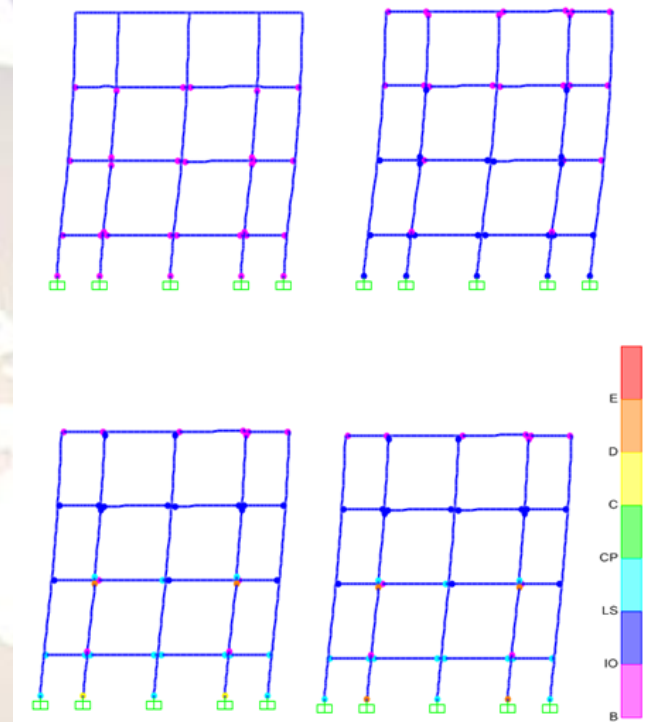
Fig. 5.9 Hinges Pattern of Without Braced Building at Different Pushover Steps
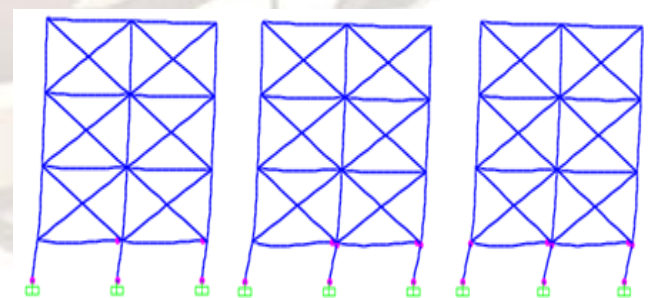
Fig. 5.10 Hinges Pattern of X-Braced Building at Different Pushover Steps

From figure 5.10 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.
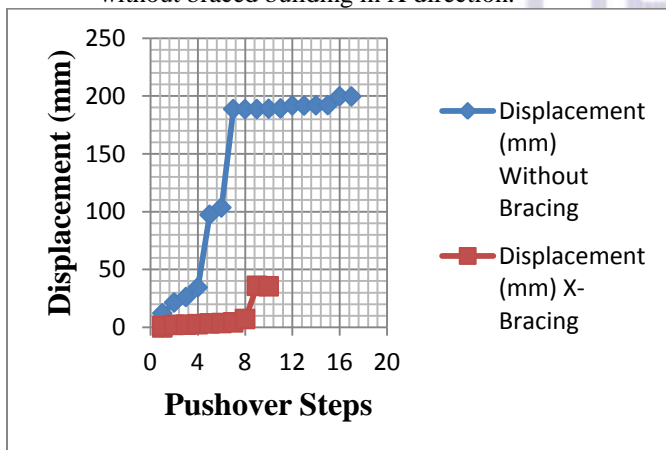

Fig. 5.11 Displacement of Floor at Various Steps in X-Direction

The displacement at last step at the top storey reduces by 82.17, for X bracing in X direction.

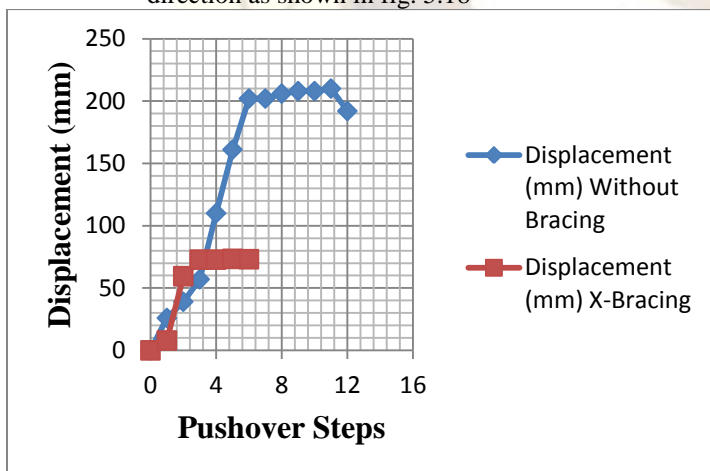The graphs for ISMC 250 are plotted in Y direction as shown in fig. 5.18

Fig. 5.12 Displacement of Floor at Various Steps in Y-Direction

The displacement at last step at the top storey reduces by 61.93% for X bracing in Y direction.

V. 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 X-braced building frame.

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