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Seismic Evaluation and Comparative Study of Various Retrofitting Techniques of RC Building

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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. 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 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. In this paper, we describe the formatting guidelines for ICEETCSE-2015 Submission.

Keywords: Seismic evaluation, nonlinear pushover analysis, hollow block slab building, retrofit systems.

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. 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, 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. 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).

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

It is not always possible to strengthen the existing buildings to the level corresponding to modern seismic codes due to economic reasons. 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. [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. 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.

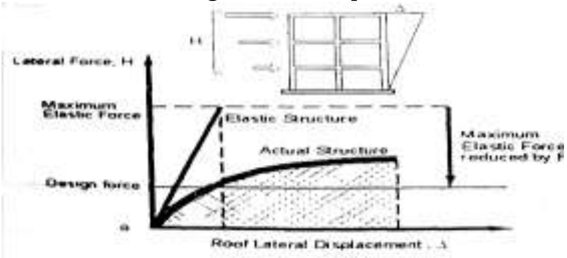

Fig. 1: Basic Strategy of Earthquake Design

II. 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.

III. 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 1. Types of analysis methods

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

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.

3.1 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 And when plastic moment capacity is reacted, plastic hinge is introduced in that element.

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

IV. 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.

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

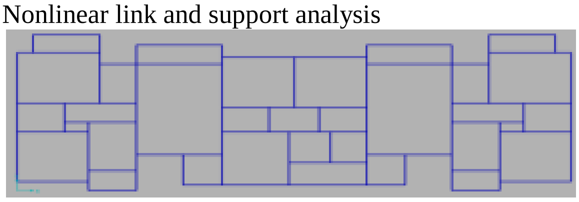

Fig. 2. Plan of 6 Storey Building

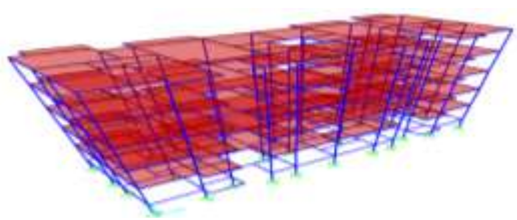

Fig. 3. Isometric View of Building

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 17.50 m
vii. Wall thickness
viii. External
ix. 230 mm
x. Internal 115 mm
xi. Weight density of Brick masonry 20kN/m^3
xii. Weight density of RC material 25 kN/m^3
xiii. Thickness of slab 125 mm
xiv. Floor to floor height 3.2 m
xv. Plinth height above ground level 1.5m
xvi. Size of brace ISMC 250
xvii. Grade of steel Fe-415
xviii. Grade of concrete M20
xix. Floor finish 1.0 kN/m^2
xx. Imposed load 3.5 kN/m^2

Table 2. Size of Beam and Column

SIZE OF BEAMS (mm)	SIZE OF COLUMN (mm)
230 X 450	230 X 380
230 X 350	230 X 400
230 X 300	230 X 450
150 X 450	230 X 500
115 X 450	

V. 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.
This data is shown in following table.

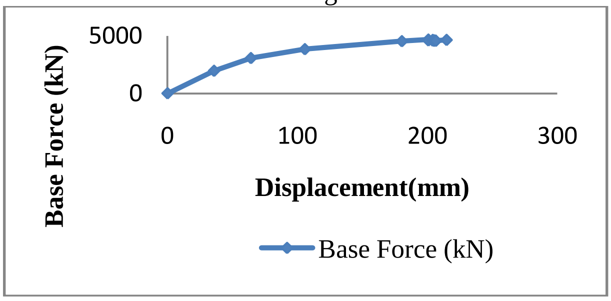

Fig. 4. Pushover Curve of an Existing Building in X direction

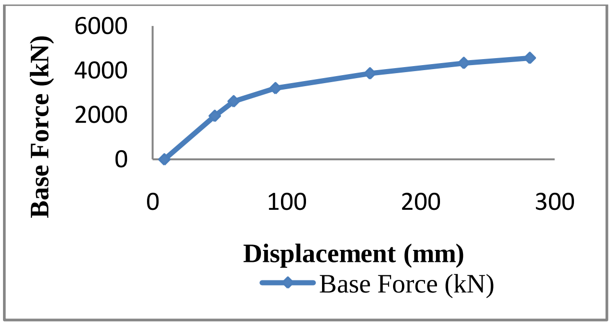

Fig. 5. Pushover Curve of an Existing Building in Y direction

Table 3. Data for pushover curve in X direction

Step	Displacement (mm)	Base Force (kN)	Levels of Hinge Formation								
			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	1584	0	0	0	0	0	0	0	1584
1	36	1958	1582	2	0	0	0	0	0	0	1584
2	64	3066	1467	117	0	0	0	0	0	0	1584
3	106	3840	1371	206	7	0	0	0	0	0	1584
4	181	4535	1291	160	122	11	0	0	0	0	1584
5	201	4674	1274	142	143	24	0	1	0	0	1584
6	201	4606	1274	141	143	25	0	0	1	0	1584
7	204	4642	1272	140	143	27	0	1	1	0	1584
8	204	4589	1272	140	143	27	0	0	2	0	1584
9	205	4605	1272	140	139	30	0	1	2	0	1584
10	205	4588	1272	139	139	30	0	1	3	0	1584
11	205	4561	1272	139	138	31	0	0	4	0	1584
12	207	4582	1272	139	136	32	0	1	4	0	1584
13	207	4568	1272	139	136	32	0	0	5	0	1584
14	215	4645	1265	131	139	43	0	1	5	0	1584

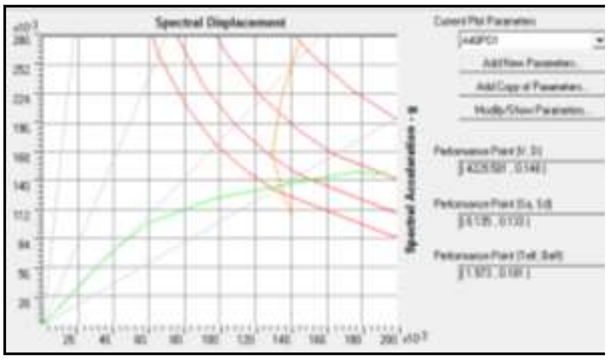

Fig. 6. Capacity Spectrum Curve of an Existing Building in X direction

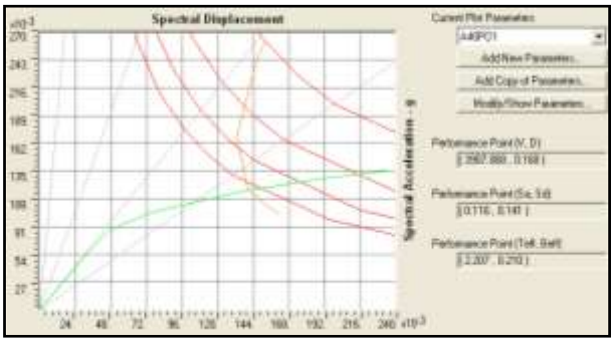

Fig. 7. Capacity Spectrum Curve of an Existing Building in Y Direction

Table 4. Data for pushover curve in Y direction

Step	Displacement (mm)	Base Force (kN)	Levels of Hinge Formation								
			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	9	0	1584	0	0	0	0	0	0	0	1584
1	46	1957	1583	1	0	0	0	0	0	0	1584
2	60	2613	1513	71	0	0	0	0	0	0	1584
3	92	3202	1417	154	13	0	0	0	0	0	1584
4	162	3870	1312	178	86	8	0	0	0	0	1584
5	232	4337	1242	162	125	39	0	16	0	0	1584
6	282	4565	1190	194	121	38	0	41	0	0	1584

After Pushover analysis hinges formation in each stage of a building are calculated, also from figures 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 systems are proposed and the analysis is carried out for existing building with shear walls at different locations, different bracing combinations of bracing systems and building with friction damper. 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.

5.2 Plastic Hinges Mechanism

Plastic hinge formation for the without retrofitted building and building with different types of retrofitting have been obtained at different displacement levels. The hinging patterns are plotted in figures 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 reveals that the patterns of plastic hinge formation for the different retrofitted building are quite similar except that the building with shear walls. But since yielding occurs at events B, IO and LS respectively, the amount of damage in the three buildings will be limited.

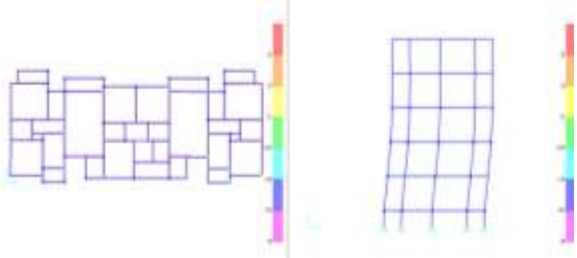

Fig. 8. Hinges Pattern of Without Retrofitted Building at Different Pushover Steps

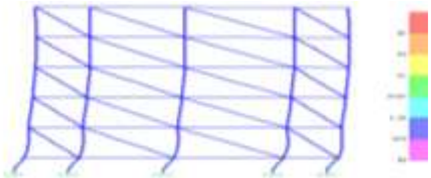

Fig. 9. Case (I) Inclined Compression Bracing

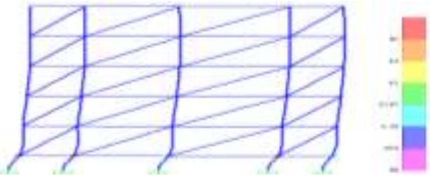

Fig. 10. Case (II) Inclined Tensile Bracing

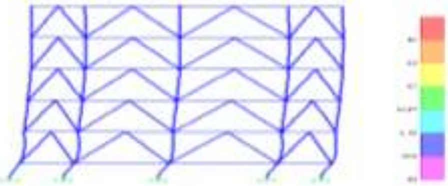

Fig. 11. Case (III) Inverted V Braced Building

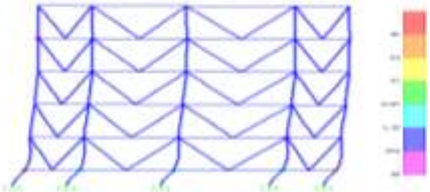

Fig. 12. Case (IV) V Braced Building

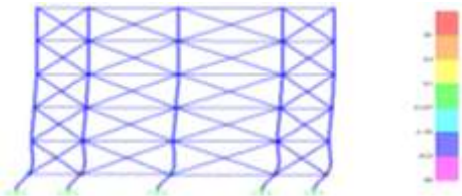

Fig. 13. Case (V) X Braced Building

5.3 Lateral Displacement

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

5.3.1 Comparison of displacement at various pushover steps of without Retrofit building and building with different retrofit scheme

The graphs for shear walls at different locations are plotted in X and Y direction as shown in figures. From the graphs it can be seen that lateral displacement was reduced in buildings with shear walls as compared to the building without shear wall.

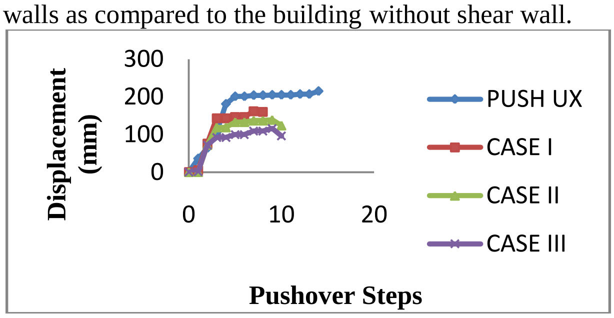

Fig. 14. Displacement of Floor in Building with Shear Walls at Various Steps in X Direction

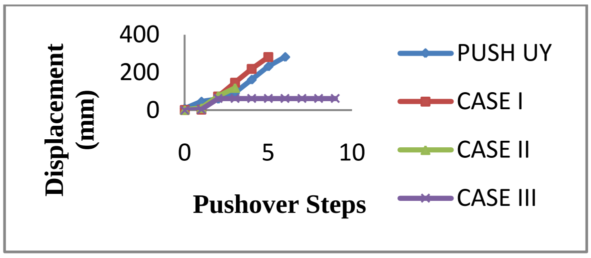

Fig. 15. Displacement of Floor in Building with Shear Walls at Various Steps in Y Direction

The graphs for ISMC 250 are plotted in X and Y direction as shown in figures. From the graphs it can be seen that lateral displacement in braced buildings with bracing section ISMC 250 are reduced as compared to the without braced building.

VI. CONCLUSION

6.1 General

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 re-strengthen the structure by providing different retrofit schemes which provides an excellent mechanism for energy dissipation.

6.2 Concluding Remarks

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 shear walls, bracings and friction damper. 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 shear walls, bracings and damper 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 retrofitted building frame as compared to retrofitted building frame. In building using shear walls, floor displacement is minimum for shear wall placed at corner then at intermediate and compare to maximum when shear wall at lift. In the braced building frame, floor displacement is minimum for X bracing, then for inverted V bracing and nearly same for inclined bracing. In building using damper floor displacement is minimum compared to both shear wall and bracing system.
6. From above discussion it is concluded that in X bracing system deflection is nearly same as that of friction damper and base shear is also nearly same, so from economic point of view we can provide X bracing system to the structure to resist the seismic forces without compromising with strength and stiffness of the structure.

6.3 Future Scope

1. An inclusion of shear failure limits in the performance criteria may lead to a better and more comprehensive understanding of the building’s behavior.
2. Non-linear time history analysis can be used for the structure to have a more accurate assessment of the structure’s capacity and understanding a more realistic demand scenario.
3. With recent advancement in material technology, more study can be focused on material qualities used in dampers like their strength, durability, high vertical stiffness, low horizontal stiffness and high energy dissipating capacity.
4. Modelling the RCC frame in SAP2000 software gives good results which can be included in future research.

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