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Pushover Analysis and Seismic Retrofitting Using Shear walls and Bracing System of Frame Structure

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Abstract - During last few years, we have faced terrifying earthquakes, Killari (September 29, 1993) and recently Bhuj earthquake (January 26, 2001). Where most human injuries and economic losses are caused by the failure of engineered structures, particularly buildings. Recent earthquakes, in which large economic losses have been suffered, confirm this noticeably. 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. Under such circumstances, seismic qualification of existing buildings has become extremely important. Seismic qualification eventually leads to retrofitting of the deficient structures. In this paper a seismic retrofit using shear wall and different bracing system based on the pushover analysis will be proposed for the life-safety target performance of the existing building. 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. The traditional methods of seismic retrofitting are reviewed and their weak points are identified. Repairs can lead to increased stiffness, strength, and failure-deformation.
Keywords - A nonlinear static pushover analysis, Shear walls, Bracing System, RC building, Seismic Retrofitting

1. INTRODUCTION

The need for evaluating the seismic adequacy of existing buildings has come into focus following the enormous loss of life and property during the recent earthquakes in India. After the Bhuj Earthquake (2001) considerable interest in this country has been directed towards the damaging effect of earthquakes and has increased the awareness of the threat of seismic events. Most of the mega cities in India are in seismically active zones and are designed for gravity loads only. A large number of existing buildings in India need seismic evaluation due to various reasons such as, non compliance with the codal requirements, updating of codes and design practice and change in the use of building. Hence evaluation of existing RC buildings in India is a growing concern. It is important to estimate the response of buildings under earthquakes from the viewpoint of life reservation and risk management. The adequacy and the performance of the building are checked with the codal provisions of IS 1893:2002[7]. A procedure for evaluating the seismic performance of existing building in India is proposed. The procedure is based on the capacity spectrum method (ATC 40) and is intended to provide practicing engineers with a methodology for determining the performance level of the building. The distribution of lateral forces used in pushover analysis is as given in FEMA 356 [6]. 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 [1].

2. PUSHOVER METHODOLOGY

The analysis is performed using the tool SAP2000. The pushover analysis follows the nonlinear static procedure. It essentially adopts the capacity spectrum method proposed by ATC-40 [5]. This method of evaluation considers two aspects, the performance of a structure during seismic event, and the capacity of the structure. The structure has been idealized as a 3D finite element model constructed with elastic frame elements having point plasticity at the possible plastic hinge locations. A lateral force distribution in accordance with IS 1893:2002 is applied to the analytical model. The force deformation relationship is defined as per the ATC-40 guidelines which follows the convention below [2].

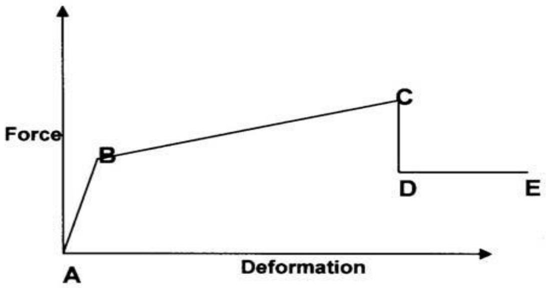

Figure 2.1Typical Force Deformation relationship

3. ELEMENT DESCRIPTION OF SAP2000

In SAP2000, a frame element is modeled as a line element having linearly elastic properties and nonlinear force displacement characteristics of individual frame elements are modelled as hinges represented by a series of straight line segments as shown in figure2.1. Point A corresponds to unloaded condition and point B represents yielding of the element. The ordinate at C corresponds to nominal strength and abscissa at C corresponds to the deformation at which significant strength degradation begins. The drop from C to D represents the initial failure of the element and resistance to lateral loads beyond point C is usually unreliable. The residual resistance from D to E allows the frame elements to sustain gravity loads. Beyond point E, the maximum deformation capacity, gravity load can no longer be sustained. Hinges can be assigned at any number of locations along the span of the frame element as well as element ends. The built-in default hinge properties for steel and concrete members are based on ATC-40 [5] and FEMA-273 [6] criteria. User-defined hinge properties can be based on default properties or they can be fully user-defined.

4. SEISMIC RETROFITTING

A performance based approach is used for the seismic retrofitting of the buildings considered in this study. The performance based design approach is based on matching various probable earthquakes with target performance levels (PLs). Three target PLs are used for the retrofitting design of the buildings as follows: (i) Immediate Occupancy (IO) PL where no damage is expected for minor levels of earthquake excitations, (ii) Life Safety (LS) PL where low or repairable structural and non-structural damage is expected for moderate earthquake excitations, and (iii) Collapse Prevention (CP) PL where irreparable or hardly repairable structural and nonstructural damage but no collapse is expected for major earthquake excitations [10]. The last revision of the Indian seismic code in 1987 IS 1893 (1984) [7] is deficient from many points of view, and engineering knowledge has advanced significantly from what was used.

5. PROBLEM FORMULATION

The 6 storey existing building is considered in this study. This structure is designed according to Indian Code IS1893:2002 and is located in Zone V and Imposed load taken as 3.5 kN/m^2. The material properties are M20 Grade concrete, Fe 415 steel for the yield strength of the longitudinal and transverse reinforcement. Considering shear wall of 250 mm thick and section ISMC 250 for bracings. The plan layout is shown in figure 5.1. The typical floor height is 3.2m.

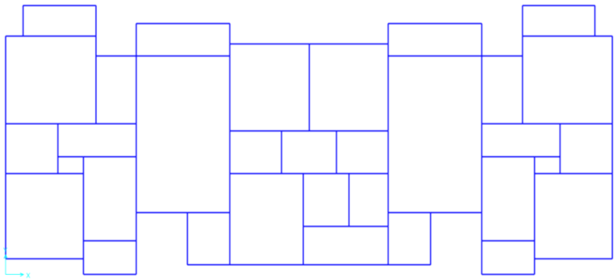

Figure 5.1 Plan of Building

5.1 Modeling Approach

The general finite element package SAP 2000 has been used for the analyses. A three-dimensional model of each structure has been created to undertake the non-linear analysis. The existing model shown in figure 5.2. Beams and columns are modeled as nonlinear frame elements with lumped plasticity at the start and the end of each element. SAP 2000 provides default-hinge properties and recommends PMM hinges for columns and M3 hinges for beams as described in FEMA-356.

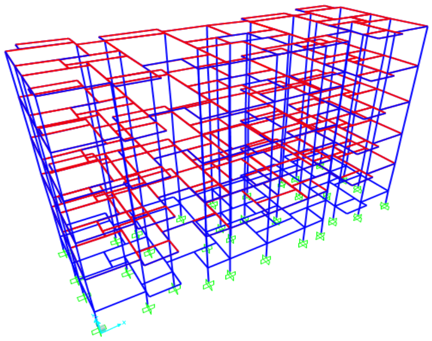

Figure 5.2 Isometric View of building

5.1.1 Retrofitting by Shear Walls

Pushover case: Building analyze by Static Nonlinear analysis without shear wall.
Case 1: The structure having shear wall at the lift duct of the building by using pushover analysis shown in figure a.

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Case 2**:** The structure having shear wall at the corners of the building by using pushover analysis shown in figure b.

Case 3**:** The structure having shear wall at the intermediate side of the building by using pushover analysis shown in figure. c.

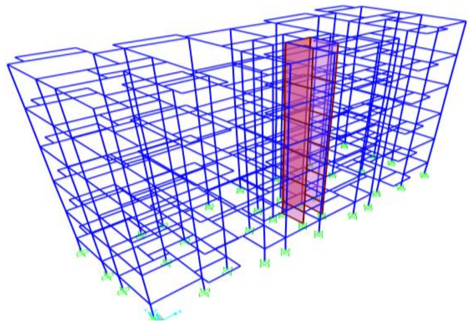

Fig. a

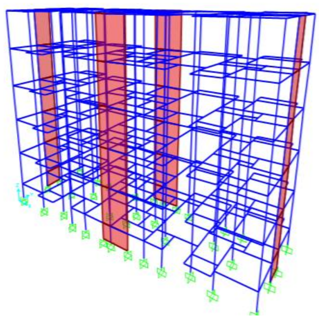

Fig. b

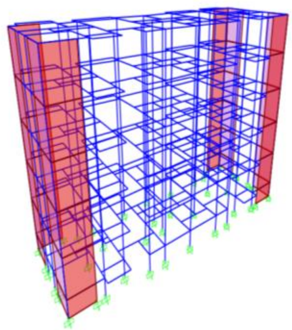

Fig. c

Figure a) Building with Shear Wall at Lift duct, b) Building with Shear Wall at Intermediate, c) Building with Shear Wall at Corners

5.1.2 Retrofitting by Bracing System

Pushover case**:** Building analyze by Static Nonlinear analysis without bracing system.

Case 1: Inclined compression braced building by using pushover analysis shown in figure a.

Case 2**:** Inclined tensile braced building by using pushover analysis shown in figure b.

Case 3**:** Inverted V braced building by using pushover analysis shown in figure c.

Case 4**:** V braced building by using pushover analysis shown in figure d.

Case 5**:** X braced building by using pushover analysis shown in figure e.

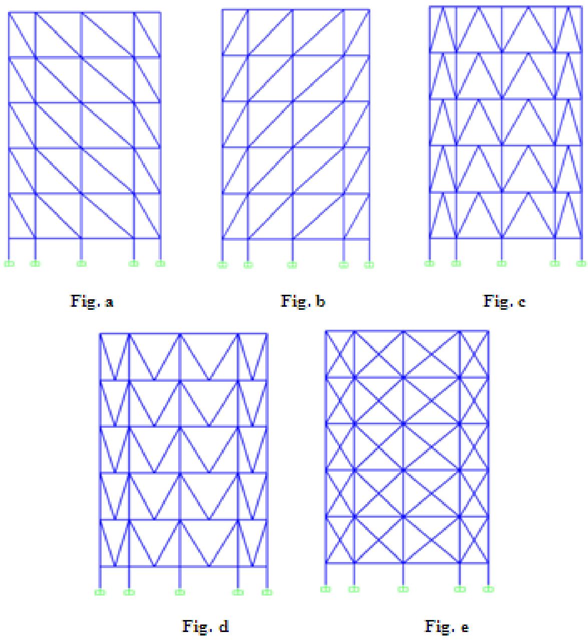

Figure a) Inclined Compression Braced Building; b) Inclined Tensile Braced Building, c) Inverted V Braced Building, d) V Braced building, e)X Braced Building

6. ANALYSIS RESULTS

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 which gives the performance point of the structure in both X and Y direction as shown in figures 6.1, 6.2, 6.3 & 6.4.

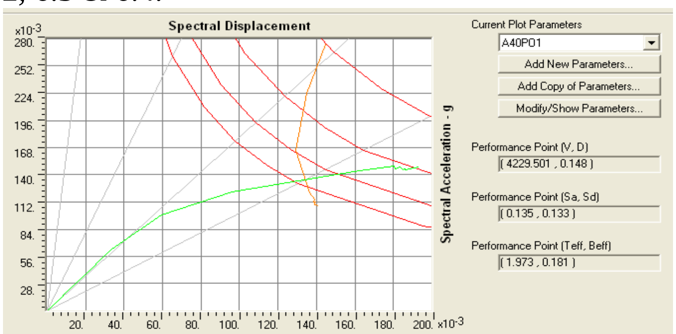

Figure 6.1 Capacity Spectrum Curve of an Existing Building in X direction

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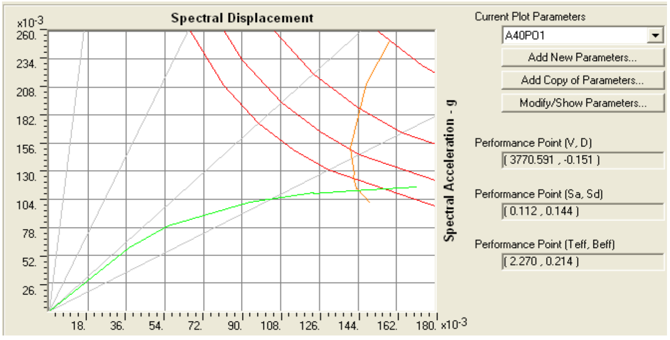


Figure 6.2 Capacity Spectrum Curve of an Existing Building in Y direction

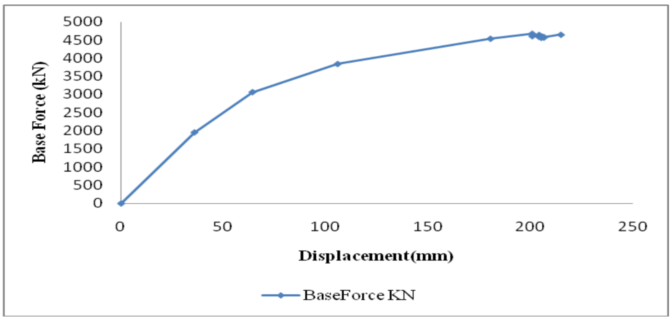


Figure 6.3 Pushover Curve of an Existing Building in X Direction

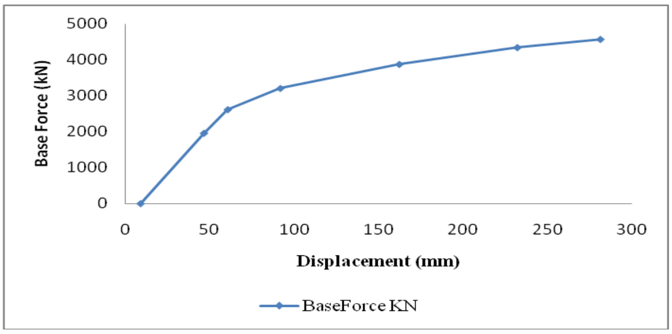
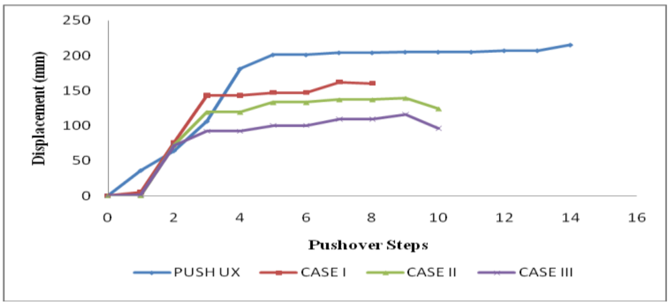


Figure 6.4 Capacity Spectrum Curve of an Existing Building in Y Direction

After Pushover analysis hinges formation in each stage of a building are calculated, also from figure 6.1 and figure 6.2 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 seen to exhibit abrupt changes in storey drifts, which is highly undesirable. To improve the seismic performance of existing building, shear walls and bracing system are proposed and the analysis is carried out for existing building with shear walls at various directions and different types of bracing system. The analysis results are demonstrated with the help of figures and charts. After running the analysis of building with shear walls and bracing system gives the coordinates of each step of the pushover curve as shown in tables and graphs.

Table 6.1: Data for pushover curve of building using shear walls at various locations in X direction.

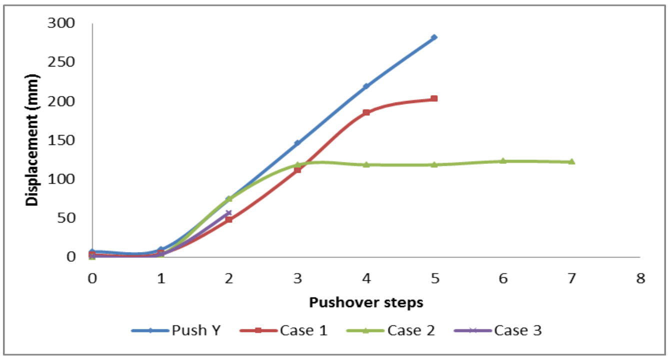
Steps	Push X	Case 1	Case 2	Case 3
0	0	0	0	0
1	36	5	0	1
2	64	76	72	72
3	106	143	119	92
4	181	143	119	92
5	201	147	133	100
6	201	147	133	100
7	204	162	137	109
8	204	160	137	109
9	205	--	139	116
10	205	--	124	96
11	205	--	--	--
12	207	--	--	--
13	207	--	--	--
14	215	--	--	--



Displacement of Floor at Various Steps in X Direction

Table 6.2: Data for pushover curve of building using shear walls at various locations in Y direction.

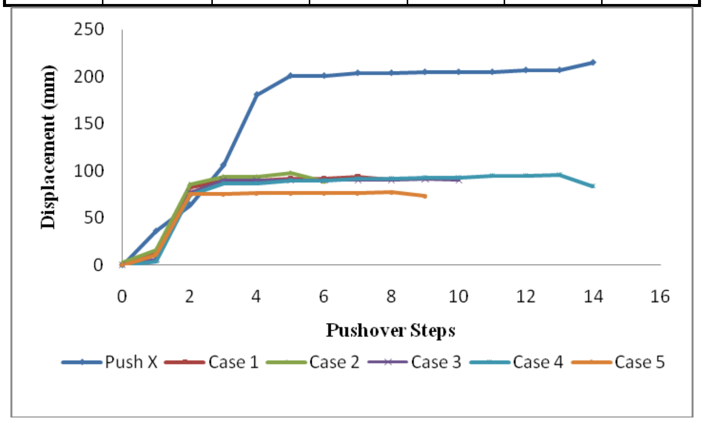
Steps	Push Y	Case 1	Case 2	Case 3
0	9	2	2	0
1	46	4	12	4
2	60	74	76	62
3	92	146	118	62
4	162	219	--	62
5	232	282	--	62
6	282	--	--	62
7	--	--	--	62
8	--	--	--	62
9	--	--	--	62



Displacement of Floor at Various Steps in Y Directions

Table 6.3: Data for pushover curve of building using different bracing system in X direction.

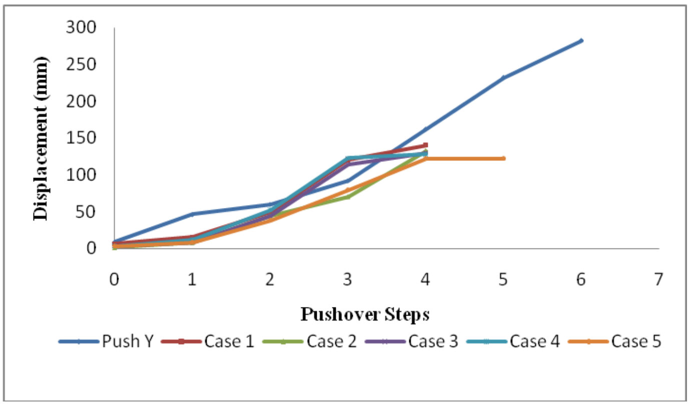
Steps	Push X	Case 1	Case 2	Case 3	Case 4	Case 5
0	0	0	3	0	0	0
1	36	13	16	6	4	11
2	64	83	86	77	75	75
3	106	90	94	90	87	75
4	181	90	94	90	87	76
5	201	92	98	90	90	76
6	201	92	89	90	90	76
7	204	94	--	90	92	76
8	204	91	--	90	92	77
9	205	--	--	91	93	73
10	205	--	--	90	93	--
11	205	--	--	--	95	--
12	207	--	--	--	95	--
13	207	--	--	--	96	--
14	215	--	--	--	84	--



Displacement of Floor at Various Steps in X Direction

Table 6.4: Data for pushover curve of building using different bracing system in X direction.

Steps	Push Y	Case 1	Case 2	Case 3	Case 4	Case 5
0	9	6	1	3	3	3
1	46	15	8	8	12	8
2	60	49	44	44	52	38
3	92	120	70	114	123	79
4	162	140	132	130	128	122
5	232	--	--	--	--	122
6	282	--	--	--	--	--



Displacement of Floor at Various Steps in Y Direction

7. DISCUSSION AND CONCLUSION

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. In that case, we can restrengthen the structure by providing shear walls which provides an excellent mechanism for energy dissipation.

In this paper, building having shear walls at different location and different types of bracing system have been analyzed by pushover analysis to study their behavior when subjected to lateral loads. 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. 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, and nearly same for inclined bracing and inverted V bracing. From above discussion it is concluded that in X bracing system deflection is minimum compared to shear walls at corner and base shear is also reduced, so from economic point of view and easy in installation we can provide X bracing system to the structure to resist the seismic forces without compromising with strength and stiffness of the structure.

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