Comparison of Building Performance with Partial Retrofitting and Full Retrofitting

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Comparison of Building Performance with Partial Retrofitting and Full Retrofitting

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Abstract

Buildings damaged in past earthquakes have exemplified the poor performance of reinforced concrete moment resisting frame (RC MRF) buildings due to inadequate design and wrong construction practices. The only way to avoid damage to existing buildings is to retrofit them. There is a large stock of RC MRF buildings constructed as per old Indian standards. With the latest revisions in codal provisions, these buildings are considered to be inadequately designed. Therefore, a large stock of existing buildings needs to be retrofitted. However, retrofitting of houses is not a common practice among the general public in India. To encourage retrofitting among the general public, the efficacy of retrofitting needs to be proven with the well-laid process.

In this paper, a case study is done to understand the performance of G+5 storey RC MRF precode building after partial and full column retrofitting. Pushover Analysis (POA) is performed to obtain the capacity of the precode building. The capacity is compared with the seismic demand of that area to decide whether retrofitting is required or not. Initially, ground storey columns are retrofitted and POA is performed to study the damage distribution and obtain the updated capacity curve. It is observed that damage shifted to the first storey. Further, the first storey columns are retrofitted and POA is performed again. From the hinge mechanism, it is observed that the damage propagated to the second storey. Further, the second storey columns are retrofitted and POA is performed again to obtain updated capacity and damage propagation. This process is done until the updated capacity of the building exceeds the seismic demand of the building. It is concluded that retrofitting of first few stories doesn't yield the desired results. Hence, performance needs to be checked after each retrofitting scheme.

Keywords : *Partial retrofitting; column retrofitting; damage distribution*

Introduction

There has been extensive damage observed in RC MRF buildings in the past few earthquakes in India. This has exemplified the poor performance of RC buildings due to inadequate design and reinforcement and wrong construction practices. One way of reducing these damages to a substantial amount is the retrofitting of existing buildings. According to the census 2011, there are 70,983,679 number of existing RC MRF buildings in India. Since the latest Indian standards (IS-1893) for earthquake resistant design were revised in 2016, the number of RCC MRF buildings built as per the previous code might have expanded further in the next 5 years. Therefore, there is a dire need for retrofitting/strengthening of those buildings as per the latest IS codes. However, retrofitting is not a common practice among the general public in India. No insurance policies, no government regulations and no trust in the retrofitting process are some of the reasons for it. To encourage the general public to retrofit their houses, there is a need to develop trust in the retrofitting process. This can be accomplished by establishing a process of retrofitting to resist earthquakes with minimum damage and by proving its efficacy in increasing the capacity of the building as per the seismic hazard of the region. How much to retrofit is the question which needs to be answered to ease out the decision-making process involved in retrofitting. A case study is done to compare partial and full retrofitting of a regular RC MRF building of G+5 storey to observe the performance of upper stories after retrofitting.

2. Case Study

A G+5 storey building with 3 bay is taken up for the study of comparison of building performance due to partial and full retrofitting. The building is assumed to be a precode building i.e., constructed in the year 2010 and hence designed as per the previous Indian codal provisions as per IS 1893 (Part 1): 2002 [1] and ductile detailing is provided as per IS 13920: 1993 [2]. Cross-sections of members of the precode building are mentioned in Table 1. The slab thickness assumed is 150 mm. Grade of concrete and steel assumed are M30 and Fe415 respectively. The building is assumed to lie in a city of seismic zone V in India with medium soil type

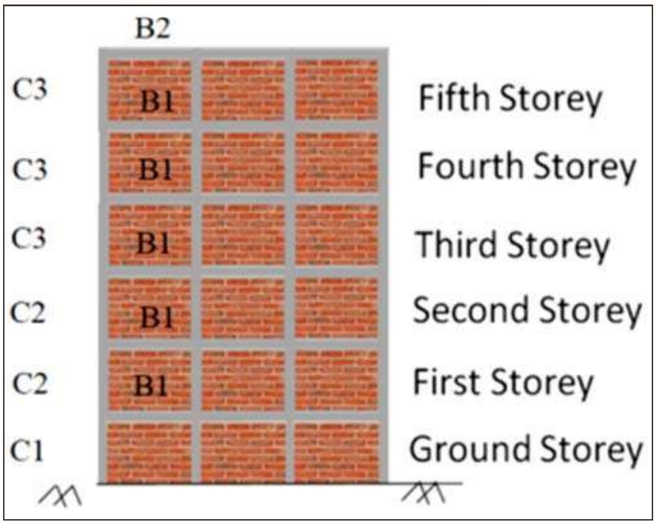


Fig. 1 : Elevation of Precode building

and is assumed to be a lifeline building.

Unreinforced brick masonry infill wall thickness is assumed as 150 mm. Material properties of the brick masonry are taken from Kaushik *et al.* [3]. Various expressions for strut width calculation have been proposed by Holmes [4], Mainstone [5], Decanini and Fantin [6], Paulay and Priestley [7], Liaw and Kwan [8], Durrani and Luo [9], Chrysostomou and Asteris [10]. For retrofitted buildings following Mainstone (1971)[5] expression which has also been adopted in IS 1893 (Part 1): 2016 for strut width calculation. Though single strut models give abrupt failure of infill wall, for this case study it is acceptable since the objective is to observe global capacity [11]. Live load of 2.5 kN/m^2 in rooms and 1.25 kN/m^2 on roof slab and floor finishes of 1 kN/m^2 as per IS 456 : 2000 [12] are considered. Load combinations for building design are considered as per IS 456 : 2000 [12].

Concrete jacketing is adopted for retrofitting of columns and this local retrofitting is done as per code IS 15988: 2013 [13], where the amount of area of concrete and steel is increased as per the clause 8.5.1.1 and 8.5.1.2. Also, stirrup spacing and diameter are provided as per the clause 8.5.1.2. The modified moment of inertia is taken from clause 7.2.3. Sizes of retrofitted crosssection are mentioned in Table 1.

Table 1 : Crossections of precode and retrofitted building

Section Name	Precode Size (LXB) (in mm)	Retrofitted size (LXB) (in mm)
C1	300×300	500×500
C2	250×250	450×450
C3	250×250	450×450
B1	230×250	430×450
B2	230×250	430×450

3. Methodology

Numerical modelling of the building in 2D is done in SAP2000. Sections are modelled as frame elements with ductile flexural and brittle shear hinges. Infill is modelled as a single strut element with brittle axial hinges. Shear and axial hinges are user defined whereas flexural hinges are defined as auto (program defined) hinge. Pushover Analysis (POA) is done with monotonically increasing lateral load to achieve target deformation at the roof. For hinge unloading during POA, secant stiffness method is used.

POA is performed to understand damage propagation from the hinge mechanism of the building and to know the maximum capacity of the structure. The hinge mechanism of the precode building as presented in Fig. 2(a) obtained from POA highlights the damage in columns and beams of ground storey. Therefore, the ground storey is retrofitted with a column jacketing scheme and again POA is performed for the building. After retrofitting ground storey, it is observed that damage has propagated to the first storey columns as highlighted by the hinge mechanism shown in Fig. 2(b). Therefore, the first storey is retrofitted and POA is performed again. From the hinge mechanism as shown in Fig. 2(c), it is observed that damage has propagated to the second storey columns. Then the second storey is retrofitted and again same procedure is adopted, POA is performed and damage propagation is checked. It is observed that damage propagated further to the third storey. Retrofitting of the third storey shifted damage to the fourth storey. In this way of retrofitting, the damage is observed to have been shifted to the upper stories. The retrofitted column (RC) schemes adopted are named as RCG, RC1, RC2, RC3, RC4 and RC5 for retrofitting upto ground storey, first storey, second storey, third storey, fourth storey and fifth storey, respectively. RC5 is full retrofitting of the building where columns of all the floors have been retrofitted.

Table 2 : Number of hinges in each damage state

Model	Opera-tional	Imme-diate Occup-ancy	Life Safety	Colla-pse Preve-ntion	Colla-pse	Total
Regular	111	36	11	3	25	186
RCG	115	31	13	5	22	186
RCG to 1	112	33	14	3	24	186
RCG to 2	117	28	16	1	24	186
RCG to 3	116	28	19	3	23	189
RCG to 4	121	24	19	2	23	189
RCG to Top	111	24	19	6	29	189

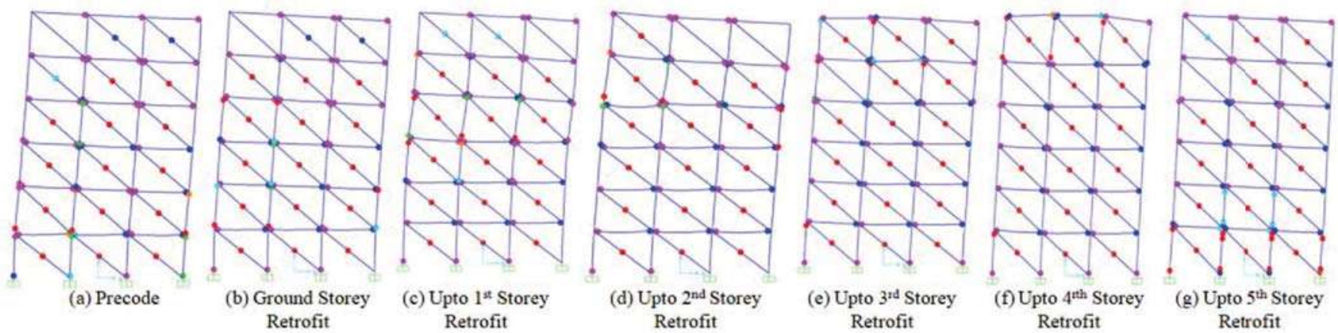
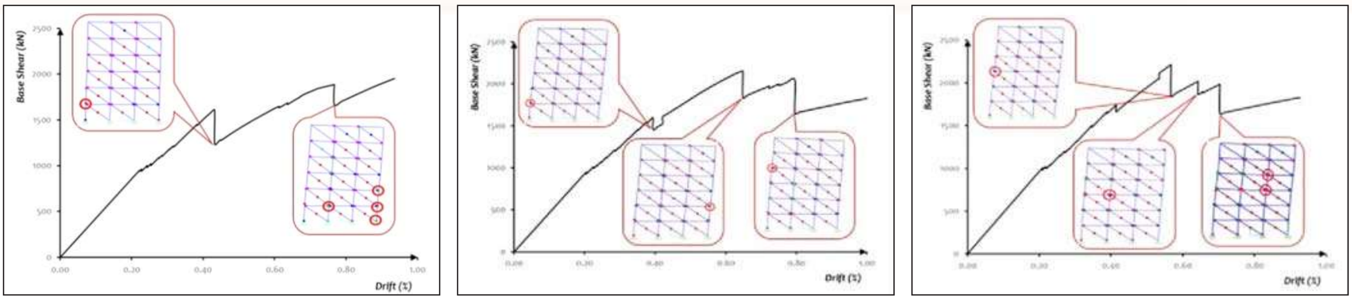


Fig. 2 : Hinge mechanism of the precode building with retrofitted columns scheme



(a) (b) (c)

Fig. 3 : Capacity curve of precode building, RCG, RC1, respectively alongwith hinge mechanism at drop locations

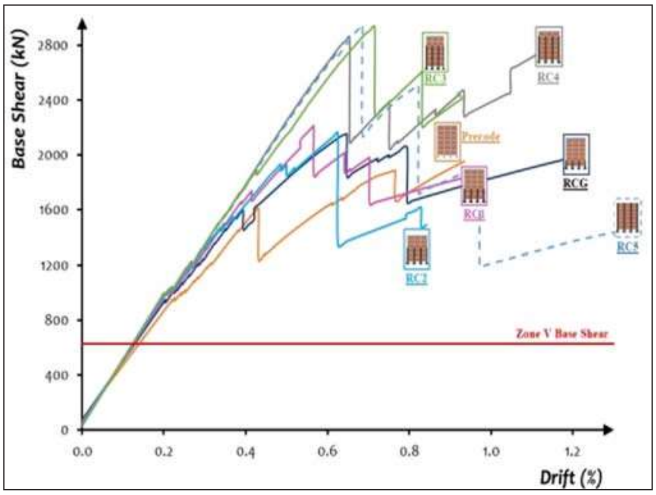


Fig. 4 : Capacity curve comparison of Retrofitted column scheme (RC)

The decision of retrofitting till a certain storey is taken up by plotting the capacity curve of the building after each storey retrofitting. After each storey retrofitting, the capacity curve shall be compared with the seismic demand as per the seismic hazard of that area. Seismic demand is the base shear attracted by the building during an earthquake ground motion and is calculated as per IS 1893-2016 clause 7.6 [14]. The seismic weight of the 2D building is 4646 kN and the seismic coefficient for the current study is 0.135. Therefore, the base shear calculated is 627 kN. If the capacity curve is less than the seismic demand, then next storey retrofitting shall be done. This procedure is followed until the retrofitted building capacity curve exceeds the seismic demand of the area.

4. Observation

Capacity curves obtained from POA of the precode building retrofitted as per various schemes RCG, RC1, RC2, RC3, RC4, RC5 are plotted for comparison as shown in Fig. 4. The capacity curve of the precode building retrofitted upto each storey as per RC scheme is assigned a colour coding as highlighted in Fig. 4. The pushover curve of the precode building is plotted in Fig. 3(a).

The first drop in the capacity curve of precode is due to a sudden failure of the first storey column as highlighted in Fig. 3(a).

After the failure of one member, forces are redistributed and pushover curve further picks up the slope to attain ultimate strength. The second drop in the capacity curve is due to sudden failure of two column of the ground storey and one column failure of the first storey as highlighted in Fig. 3(a).

Again forces are redistributed and pushover curve increases to attain ultimate strength of the building.

On retrofitting of ground storey of precode building i.e., RCG, it is observed that the first drop in the elastic curve is due to failure of one column of the first storey. Second drop after the first peak strength is due to the failure of another exterior column in the first storey. The third drop in curve indicates the failure of one exterior column in the third storey, each as highlighted in Fig. 3(b).

From the capacity curve of building retrofitted upto first storey i.e., RC1, it is observed that the first drop in the curve is due to failure of two exterior columns of the second storey and third storey. The second drop is due to failure of interior columns of the second storey and third storey. The third drop is due to failure of interior third storey column at top and bottom as highlighted in Fig. 3(c).

Similarly, for capacity curves of RC2, RC3, RC4 and RC5, drops can be observed due to formation of hinges of different damage states in structural members.

On comparison of these capacity curves, it is observed that though the initial strength of RCG is higher than that of precode building but with two drops in strength it is lesser than the precode strength. Therefore, it can be concluded that only ground storey retrofitting cannot increase the strength to significant extent and the same is evident from the Fig. 4, where only partial increament in strength of RCG is observed. Similarly, in RC1 and RC2, the same trend of higher initial strength and later on decrease in strength is observed. In RC3, strength increment is observed when compared with the precode building. In RC4 and RC5, again no further strength increment is observed, it is almost same as RC3 scheme.

It can be concluded that with partial retrofitting i.e., when one or a few storey columns are retrofitted, strength increment is not observed substantially. For efficient retrofitting, the capacity of each retrofitting scheme shall be computed and compared. The storey upto which retrofitting shall be done on site is decided from the comparison of each RC scheme capacity curve. Also, the capacity shall exceed the seismic demand. For this case study, base shear expected is also plotted in Fig. 4 as the horizontal threshold line to decide whether the building needs retrofitting or not. Though the current capacity of the precode building is sufficient and it doesn't need retrofitting but still retrofitting is done at upper stories to observe the performance of retrofitted upper stories and to lay the process to carry out the retrofitting action.

Table 2 presents the number of hinges formed in various damage states for all retrofitting scheme. Though the total number of hinges in collapse state remains same even after retrofitting of the structure, however from hinge mechanism it is evident that more number of hinges is formed in beams of the retrofitted frame.

5. Conclusion

The case study presented a comparison of capacity curves for all retrofitting schemes. Comparison is done to understand the difference in outcomes of partial and full retrofitting of columns. Damage is shifted to the upper stories after retrofitting of each storey as observed from the hinge mechanism as shown in Fig. 2. Capacity curves are plotted for all RC schemes and precode building to compare the performance with the desired capacity as shown in Fig. 4. Observations from the study are mentioned below.

1) No capacity increment is observed in the building with partial retrofitting i.e., with retrofitting of one or two storey columns. Though initial strength increased with ground storey retrofitting, however, due to redistribution of forces after the drop in the capacity curve, strength reduced.
2) Significant capacity increment is observed after retrofitting of the third storey i.e., RC3. On further retrofitting to fourth and fifth storey, capacity remained the same. Therefore, the decision of retrofitting shall include a comparison of capacity curves for all RC schemes to decide the storey up to which retrofitting shall be carried.
3) Better results may be observed if beam strengthening is also done along with column strengthening.

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