# PERFORMANCE ASSESSMENT OF UPPER STORIES IN AN OPEN GROUND STOREY BUILDING WITH RETROFITTED GROUND STOREY

by

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# PERFORMANCE ASSESSMENT OF UPPER STORIES IN AN OPEN GROUND STOREY BUILDING WITH RETROFITTED GROUND STOREY

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## *Abstract*

Open ground storey buildings are quite popular in India due to availability of parking space and high commercial value of the land. However, these open ground storey buildings become first victims during earthquake ground shaking. The same is evident from the collapse and huge damage in ground story columns during past earthquake events. This led to a huge loss of life and property. Hence, there is an urgent need to take up retrofit activities of open ground storey buildings. There were some instances where retrofit activities were taken up on open ground story buildings. However, the performance of the building was not tested after ground storey retrofit. To build confidence among the general public, there is a need to demonstrate that the retrofitted buildings not only save lives but also resist earthquake with minimum damage. This paper is an attempt to demonstrate the same.

In this paper, a case study of G+5 open ground storey building has been taken and nonlinear static pushover analysis (POA) is performed to obtain capacity curve. Later, the building is retrofitted in its ground/first storey and again capacity curve is obtained using the POA. It is found that the performance of the building significantly improved. However, from the hinge formation pattern, it is observed that the damage has propagated to the second storey. To improve the performance further, the second storey is also retrofitted and POA is performed again. Further, as per the damage propagation to upper stories, retrofitting is done to respective stories. It is found from the hinge pattern and capacity curves that in retrofitted buildings, capacity increased up to a certain storey and after that no increment in capacity was observed. It is concluded from the study that retrofitting of open ground storey building does not mean retrofitting of only ground storey but all such columns/stories where damage is getting distributed after the retrofit of open ground storey.

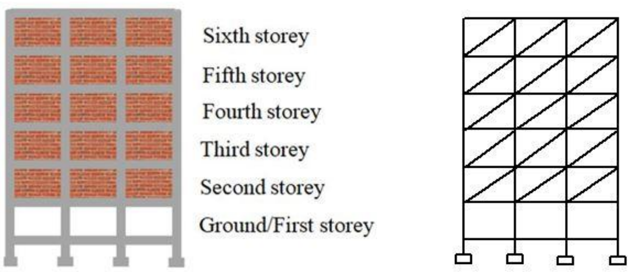
*Keywords: retrofitting; open ground storey; damage distribution*

## 1. Introduction

Seismic retrofitting of reinforced concrete (RC) buildings is the present issue with great social significance. Particularly, in open ground storey (OGS) RC buildings, since they have caused great casualties in past earthquakes. It has been observed OGS buildings have been the first victim of earthquake ground shaking leading to huge life and property loss. In the 2001 Bhuj earthquake, hundreds of OGS buildings collapsed. In 2015 Nepal twin earthquake, again the same story was repeated and a lot of OGS failures were observed. Due to land shortage and high cost of land in urban cities, they have become quite common in the last few years to accommodate large commercial spaces and parking. This popularity led to the construction of thousands of OGS in urban cities including seismically active regions as well. Therefore, retrofitting of these existing OGS buildings in the seismically active region is the need of the hour. In Ahmadabad, after 2001 Bhuj earthquake, some buildings have been retrofitted by their owners by increasing size of ground storey columns from floor level to soffit of the storey or by adding infill walls in the OGS [1]. However, the performance of those retrofitted buildings was not tested for an earthquake expected in that region. Since retrofitting is not a common and popular choice among the general public, it is necessary to demonstrate the improved performance of retrofitted buildings and encourage them to retrofit their houses. Proving that retrofitted buildings won't collapse and will survive with the least damage under an expected earthquake in their region would build trust in the retrofitting procedure. Also, the procedure to decide how much retrofitting and at what location shall be laid to assist retrofitting techniques. In this paper, a case study is performed by considering OGS buildings of two major urban cities, i.e., Guwahati and Darbhanga which lie in zone V with flat terrain.

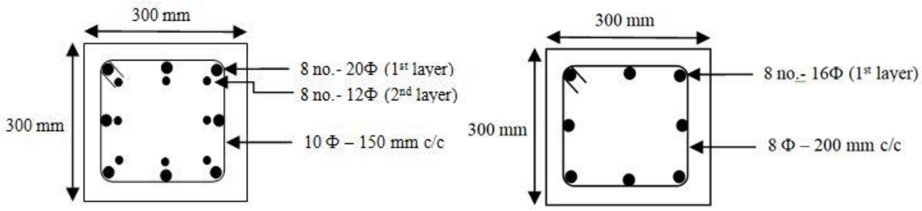
## 2. Case Study

Three bay G+5 open ground storey building with foundation at 1.5m below ground level is taken up for this study. The building is assumed to lie in zone V city say Guwahati or Darbhanga in India. The building is assumed to be a lifeline building. It is designed as a special moment-resisting frame per IS 1893 (Part 1) : 2016 [2] and ductile detailing is provided as per IS 13920 : 2016 [3]. Elevation of the assumed building is presented in Fig. 1 a). Grade of concrete and steel used are M30 and Fe415 respectively. Beam and Column cross-sections of OGS building are shown in Fig. 2 and slab thickness is 150mm.




a) b)

Fig. 1 a) Open Ground Storey b) Equivalent SAP model in 2D




a) b)



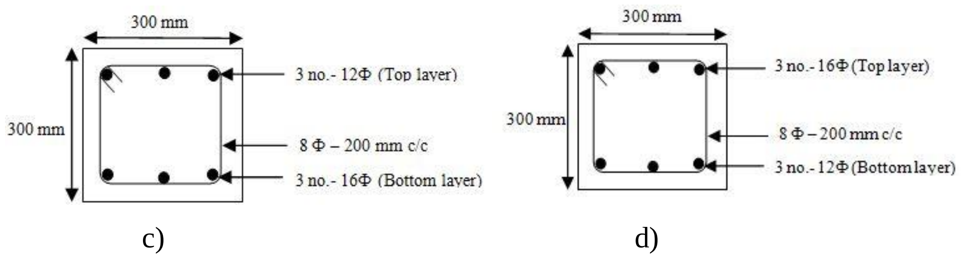



Fig. 2 Cross-sections of Open ground storey a) Ground storey column b) First storey column c) Beam mid-span cross-section d) Beam support cross-section

## 3. Numerical Modelling

Numerical model of the building includes all components contributing to mass, stiffness and strength of the building. Beam and columns are modelled as frame elements with ductile flexural hinges and brittle shear hinges. Infill wall is modelled as a single strut element with brittle axial hinges.

Mass of all structural and non-structural components are included as the dead load on the building. Live load of 2.5 kN/m2 in rooms and 1.25 kN/m2 on roof slab and floor finishes of 1 kN/m2 as per IS 456 : 2000 [4] are considered. Load combinations for building design are also considered as per IS 456 : 2000 [4]. The building is modelled in 2D for pushover analysis in SAP2000 for performance assessment after retrofitting as shown in Fig. 1 b).

Infill wall thickness is assumed as 120 mm. Material properties of the brick masonry are taken from Kaushik *et al*. [5]. Brick masonry infill wall is modelled as a single strut. Various expressions for strut width calculation have been proposed by Holmes [6], Mainstone [7], Decanini and Fantin [8], Paulay and Priestley [9], Liaw and Kwan [10], Durrani and Luo [11], Chrysostomou and Asteris [12]. Following Mainstone (1971) expression which has 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 this limitation is acceptable as our prime concern is to observe global capacity and performance in terms of lateral deformation. Ignoring the effects of wall openings, the width of an equivalent diagonal strut is mentioned in Eq. (1) where $\alpha_h$ is mentioned in Eq. (2). $E_m$ and $E_f$ are moduli of elasticity of the material of unreinforced brick masonry infill and RC MRF, $I_c$ is the moment of inertia of adjoining column, $t$ is the thickness of infill wall and $\theta$ is the angle of the diagonal strut with horizontal.

$$w_{ds} = 0.175\alpha_h^{-0.4} L_{ds} \tag{1}$$

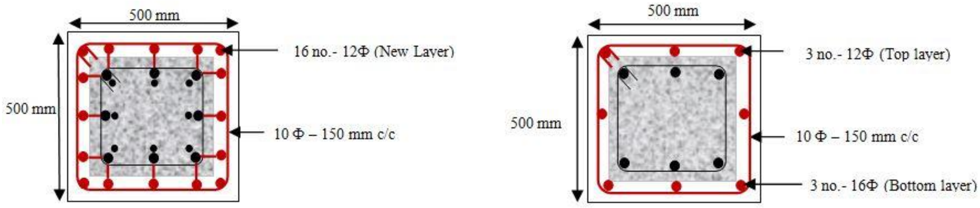
$$\text{where } \alpha_h = h\left(\sqrt[4]{\frac{E_m t \sin 2\theta}{4E_f I_c h}}\right) \tag{2}$$

## 4. Retrofitting Technique

Local retrofitting techniques of column jacketing and infill wall addition as suggested in the technical document by Vijayanarayanan *et al.* [1] are adopted. As per Goud *et al.* [13] building retrofitted with both column jacketing and infill wall addition gives better performance after retrofitting. Therefore, adopting column jacketing and infill addition both for OGS retrofitting. Concrete jacketing is done as per code IS 15988 : 2013 [14]. Column and beam sizes are increased from 300 to 500 mm. Cross-sections of retrofitted column and beam are shown in Fig. 3.






a) Column b) Beam

Fig. 3 Cross-sections of retrofitted column and beam

## 5. Numerical Analysis

Nonlinear static pushover analysis (POA) is done with monotonically increasing lateral load to achieve deformation at roof equal to 4% of the building height. POA is done for the 2D building model to obtain the capacity curve for an OGS building. As per the damage in OGS building, it is retrofitted at damage locations and again POA is performed for the retrofitted building to obtain the new capacity curve.

Fig. 4 (a) and (b) show the hinge mechanisms of OGS and OGS retrofitted with retrofitting scheme RC1. Comparison of hinge states of OGS and RC1 highlights the shift of collapse state hinges in the first storey of OGS to the second storey after its retrofitting. This indicates a shift of damage from first storey columns to second storey columns on retrofitting of columns of OGS. Infill wall damage persists in both cases. If building capacity required in any earthquake-prone area isn't met with RC1 retrofitting scheme, further retrofitting is required which can be planned as per the damage propagation observed from hinge mechanisms. One way is retrofitting of only columns of a storey presented in Fig. 4 by RC series. Another way is the retrofitting of columns and beams of a storey presented in Fig. 4 by RCB series.

POA is again performed for each retrofitting scheme and the capacity curves are obtained and plotted in Fig. 5 Comparison of hinge formation pattern is done. Fig. 4 (c) presents the hinge mechanism of RC2 which is retrofitting of only columns of the second storey. It is observed that hinges are now forming earlier in the third storey column than first and second storey columns. Therefore, second storey column damage has been shifted to third storey columns after retrofitting of the second storey. Similarly, damage propagates to fourth and fifth storey columns as observed in Fig. 4 (d) and (e) on retrofitting of third and fourth storey columns respectively. A similar trend of damage shift of beam and column to upper storey beam and column is seen in Fig. 4 (f), (g), (h) and (i) which present retrofitting schemes RCB involving both column and beam at each storey. Therefore, retrofitting of an OGS building doesn't mean retrofitting of just open ground storey, retrofitting of all damage potential elements shall be done to achieve minimum damage and maximum capacity.

Damage to a building is dependent on the expected earthquake in that region. Therefore, the capacity of the retrofitted building obtained from the POA is compared with the base shear expected in Zone V in India. As per the equivalent static method analysis, base shear attracted by the building during an earthquake ground motion is calculated as per IS 1893-2016 clause 7.6 [2]. Seismic weight of the 2D building is 2964 kN and the seismic coefficient for the current study is 0.135. Therefore, the base shear calculated is 400 kN. Same is plotted in Fig. 5 for the comparison.

## 6. Results and Discussion

Capacity curves obtained from POA of building retrofitted as per various schemes are used for comparison as shown in Fig. 5. The capacity curve for each storey retrofit is assigned a different colour. Black colour is assigned to ground storey retrofitting, pink, blue and green colours are assigned to first, second and third storey retrofitting respectively. The capacity curve with solid line represents retrofitting schemes where only columns are retrofitted and are named as RC series. The dotted line represents retrofitting schemes involving both beams and columns and is named as RCB series.



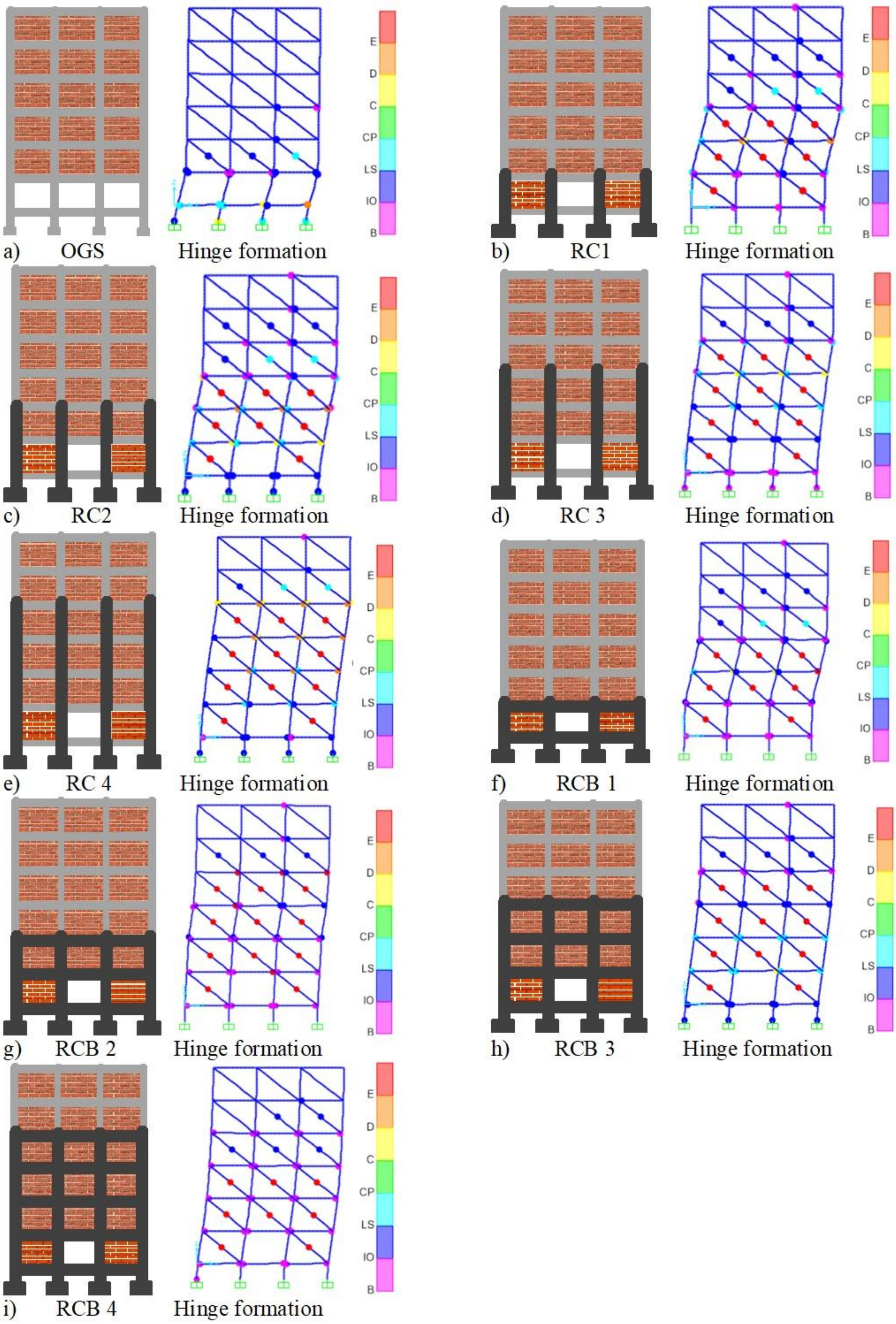



Fig. 4 Retrofitting schemes along with their hinge mechanisms



Capacity curves of retrofitting schemes RCB2 is compared with RC2, RC3 and RC4 as shown in Fig. 5. It is observed that the capacity of the scheme involving retrofitting up to the second storey beam and column, i.e., RCB2 is at par with the scheme involving only column retrofit up to the fourth storey, i.e., RC4 along with lesser deformation in the former case. Therefore, it is better to retrofit beam and column of up to the first storey rather than retrofitting upper storey columns first. However, the RC series, i.e., column retrofitting case is easier to carry out practically than the RCB series, i.e., beam column retrofitting case.

In only column retrofitting case, ground storey and first storey column retrofit increase capacity of the building with an appreciable amount, however, after that capacity increment is less. Similarly, in the beam column retrofitting case, ground, first and second storey beam retrofit case increased capacity of the building to an appreciable amount, however, after that no increment in the building capacity is observed. Therefore, it is concluded that the retrofitting of each storey doesn't contribute equally to the building capacity. After a certain storey, saturation in building capacity on retrofitting is observed and this storey may vary from type of retrofitting scheme. In this case study, the storey at which capacity saturation is observed is the second storey for only column retrofitting cases and third storey for both beam column retrofitting cases. Saturated capacity is the maximum capacity achieved for the building from that retrofitting scheme. Out of all the cases, in beam column retrofitting case maximum capacity is achieved along with the maximum ductility and stiffness.

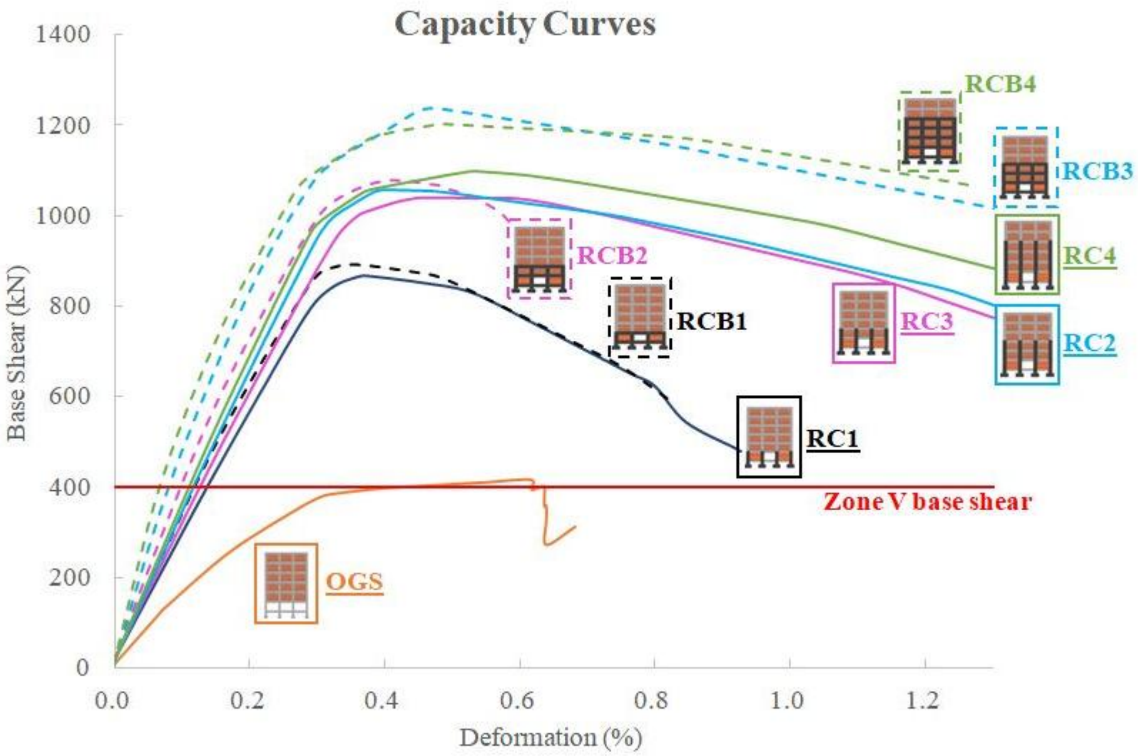



Fig. 5 Capacity curves for retrofitted buildings

Also, it is observed that all dotted lines have lesser deformation than their corresponding solid lines. This indicates that the building deformation is less where both beams and columns of a storey are retrofitted than the case where only columns of a storey are retrofitted.

For this case study, as per the expected base shear, ground storey column retrofitting is sufficient to avoid collapse and to get minimum damage in the building. There is no need for further retrofitting. Therefore, in the same way, location and amount of retrofitting required in a building shall be selected as per the expected base shear in that region after comparison from capacity curves as shown in Fig. 5.



## 7. Conclusion

Retrofitting of the open ground storey is not limited to just retrofitting of ground storey columns. After retrofitting of ground storey columns, damage propagates to upper stories as observed from hinge mechanisms obtained from pushover analysis of retrofitted buildings. Therefore, retrofitting of the upper stories are also required if higher capacity of the building is desired. The performance of OGS buildings retrofitted till upper stories with two types of schemes RC and RCB as shown in Fig. 4 has been assessed in the paper. Capacity curves are plotted for each retrofitting scheme to compare the performance as shown in Fig. 5. Observations from the study are mentioned below.

1. After ground/first storey retrofitting if further retrofitting is required, it is better to retrofit both beam and column till the second storey, i.e., RCB2 case rather than retrofitting only columns till fourth storey, i.e., RC4 case. As capacity is almost the same and deformation is lesser in the former case. Though practically column retrofitting is easier than beam column retrofitting of a storey.
2. Building capacity increment after each storey retrofit is appreciably increasing as we go on retrofitting upper stories. However, this trend continues only till few stories and after that saturation in building capacity is observed. In case of only column retrofitting, building capacity increases till second storey retrofitting and in case of both beam and column retrofitting, capacity increases till third storey retrofitting. Therefore, these threshold stories where capacity saturation is achieved are different for different types of retrofitting schemes. Also, this saturated capacity is the maximum attainable capacity and in this case study, it is achieved by retrofitting beam columns till the third storey.
3. Performance of a retrofitted building in terms of deformation is better when both beams and columns of a storey are retrofitted if compared with retrofitting scheme involving only column retrofit of that storey.
4. Also, the decision of the location of retrofitting should be taken according to the base shear expected at a place. The procedure adopted in this study can be used to take such decisions based on the damage propagation to upper stories observed from hinge mechanism of retrofitted buildings.

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