Evaluation of Response Reduction Factors for Different Retrofitting Techniques Applied to open Groung Storey Building

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Evaluation of Response Reduction Factors for Different Retrofitting Techniques Applied to Open Ground Story Building

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Abstract

Most of buildings are constructed with open ground story. With increase in height of building need for parking space for people living in the building increases. In order to provide adequate amount of parking space the buildings now-a-days are constructed with open ground story. During Bhuj earthquake occurred in 2001 the buildings with open ground storey were observed with lots of damage on the column of the ground floor of open ground story. In this present study a 12 story building is considered to evaluate seismic performance of the building with open ground story, later retrofitted using bracing systems. Comparison of building with different infill patterns are made in order to study the effect of addition of infill to the open ground story. The low performance of open ground story building was retrofitted using bracings which enhance the behavior of the building by increasing the capacity of the building. Response reduction factor was later calculated in order to make a comparative study of the different infill patterns and retrofitted frames. Various other factors were calculated for the calculation of response reduction factor such as Ductility over strength factor and ductility reduction factor. Based on the comparative study of behavior of building, it was found that the open ground story has least performance. When building is properly retrofitted using bracing systems, it can increase the performance of the building.

1. Introduction

In today's era of construction practices, research action of infill is neglected for ease in analysis. But infill has its own stiffness. With addition of infill the ductility of the building decreases which clearly shows that the addition of infill restricts the additional movement of the building. This is because of diagonal action of the infill. When a building is constructed with open ground story, complete removal of infill from the 1^{st} story of the building leads to formation of soft story. The building with open ground story acts as an inverted pendulum. The upper part of the building act as a single unit, they move together as a lumped mass. These kinds of structure stand strong against gravity loads but are weak against lateral forces.

A proper retrofitting technique is necessary so that the performance of the building can be increased for resisting lateral forces. Addition of partial infill on the bottom story of the building can increase the capacity of the building. In present case the building is retrofitted using bracing system. Later a comparative study was made based on response reduction factor and ductility of the building.

2. R factor (Response reduction factor)

As per IS 1893(2016) response reduction factor is a factor by which base shear is induced in a structure. If it is to remain elastic, R factor is to be reduced for obtaining the design base shear. It depends upon various factors such as the perceived performance of the structure, characterized by ductile or brittle formation, redundancy in the structure or over strength inherent in the design process. Ductility is the ratio of displacement at maximum base shear to displacement at yield. Over strength factor measure the reserved strength of structure after formation of first hinge. Ductility reduction factor is responsible for dissipating hysteric energy of earthquake which results in reducing the maximum elastic seismic force in structures.

2.1 Calculation for Response reduction factor

Ductility reduction factor(R)

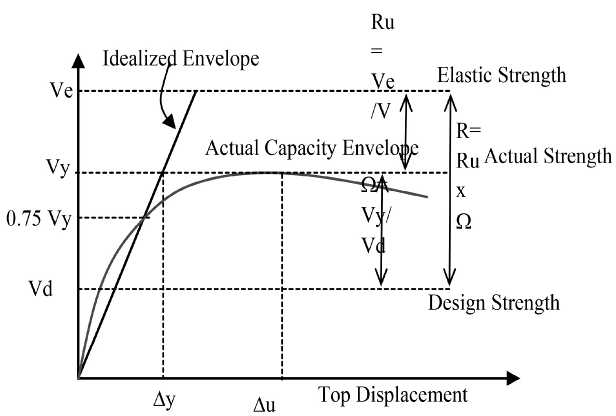

Fig. 1 Calculation for ductility reduction factor

2.1.1 Ductility $(\mu) = \frac{\Delta max}{\Delta y}$

Different formulae have been designed by the researcher to calculate ductility reduction factor. For the current study ductility force reduction factor is calculated using Newmark and halls formula[8]. Which is developed on inter relation between time period and ductility to calculate ductility reduction factor.

$R_\mu=1$ for T<0.2sec

$R_\mu=\sqrt{2\mu-1}$ for 0.2<T<0.5 sec

$R_\mu=\mu$ for T>0.5sec

2.1.2 Over strength factor (Ω)

$\Omega=\frac{vy}{vd}$

Where v_y is ideal yield base shear and v_d is design base shear

Calculation for yield displacement- The displacement is calculated at $0.75v_y$. The displacement at yield point can be calculated by using similarity of triangles.

2.1.3 Response reduction factor (R) = ductility reduction factor(R) x over strength factor (Ω)

3. Retrofitting of structure using bracing

Bracings can be provided in various patterns such as cross bracing Z bracing K bracing and many others format. In order to make a comparative study of bracing with infill cross bracing were used in this analysis. The alternate compression and tension format were used to analyze the structure for diagonal action.

4. Non-Linear static analysis

This analysis is also commonly known as pushover analysis.

4.1 Methods of pushover analysis

Displacement Coefficient Method (FEMA 356). This method estimates the elastic displacement of an equivalent SDOF system assuming initial linear properties and damping for the ground motion excitation under consideration. Then it estimates the total maximum inelastic displacement response for the building at roof by multiplying with a set of displacement coefficients.

Capacity Spectrum Method (ATC 40) Uses the estimates of ductility to calculate effective period and damping. This procedure uses the pushover curve in an acceleration displacement response spectrum (ADRS) format. This can be obtained through simple conversion using the dynamic properties of the system. The pushover curve in an ADRS format is termed a 'capacity spectrum' for the structure

Considered data for analysis-

DATA	VALUE
Grade of steel	Fe 415
Grade of concrete	M30
Live load	3KN
Floor finishing load	1.5 KN
Response reduction factor	5
No of story's	12
No of bays along x direction	6
Span along x direction	4
No of bays along x direction	6
Span along x direction	4
Floor to floor height	3m
Column size	400*600mm
Beam size	300*400mm
Depth of slab	150mm
Assumed bracing section	ISMB 400
Infill depth	230mm
Soil type	Medium

The type of analysis method used for pushover analysis was displacement based pushover analysis in which displacement is given at the top most node of center of gravity. Structure is displaced to 4% of height of the structure. [5]

5. Analytical modeling

5.1 Modeling of infill [1,7,9]- depth of infill is considered in between L/3 to L/5 where L is diagonal length of the infill. Width is equal to that if the width of infill wall. Diagonal struts can be modeled in many different ways such as single strut, double strut and 3-strut. Considered modeling for current study is single diagonal strut.

5.2 Provision of plastic hinges

Hinges were provided using Pristley and Pauly formula for hinge distances. P-M2-M3 hinges for column M3 hinges for beams (considering moment resistant frame) axial hinges for bracings and infill. Based on the plastic hinges the formation of mechanism can be studied. With help of deformation curve the pattern and failure mechanism of the members can be studied.

5.3 Procedure followed for analysis

Frames were first analyzed using nonlinear static analysis i.e. pushover analysis then the curves were bilinearized in order to evaluate various factors such as ductility over strength factor Response reduction factor using the formulae given above.

5.4 Frames taken into consideration

1) Bare frame

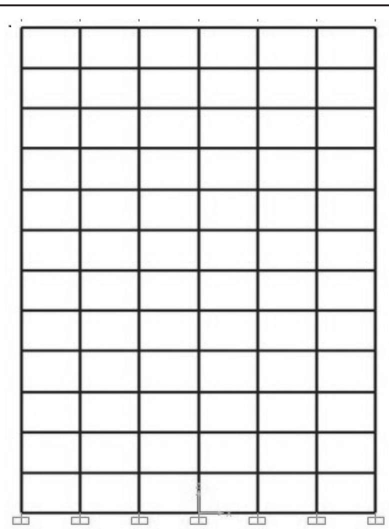

Fig 1 Bare frame

This frame consists of column beams and slabs. Wall loads are considered over beams. No additional modeling for wall is considered in this frame i.e. no additional stiffness of wall is considered in entire frame.

2) Fully infill frame

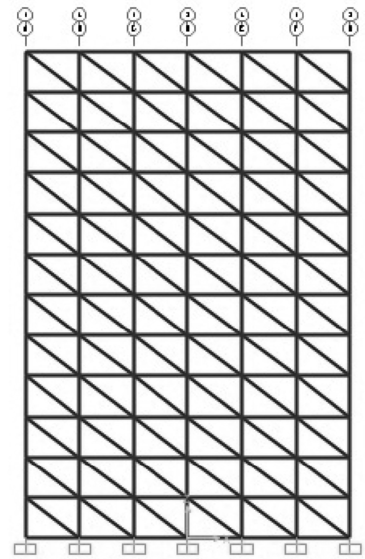

Fig 2 Fully infill

In this frame the building is modeled with infill throughout the building this case is considered for analytical study of difference between bare and building with open ground story. This frame consists of infill masonry wall throughout the frame in order to study the impact of it on the capacity of the building.

3) Open ground story

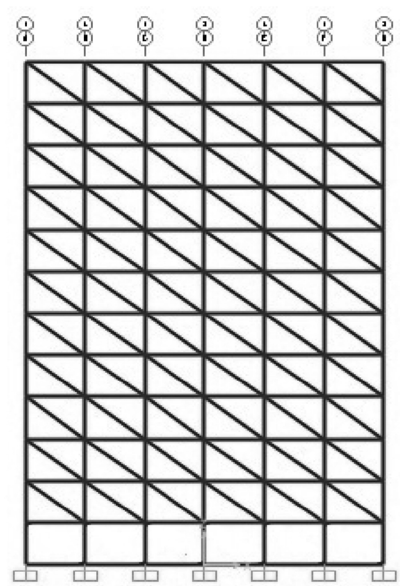

Fig 3 Open ground story

This building consists of infill wall on all floors except for ground floor. The paper mainly studies the impact of removal of infill from ground floor. This is a practical case made to study impact of removal of infill from the ground story of the building.

4) Center adjacent infill patterns

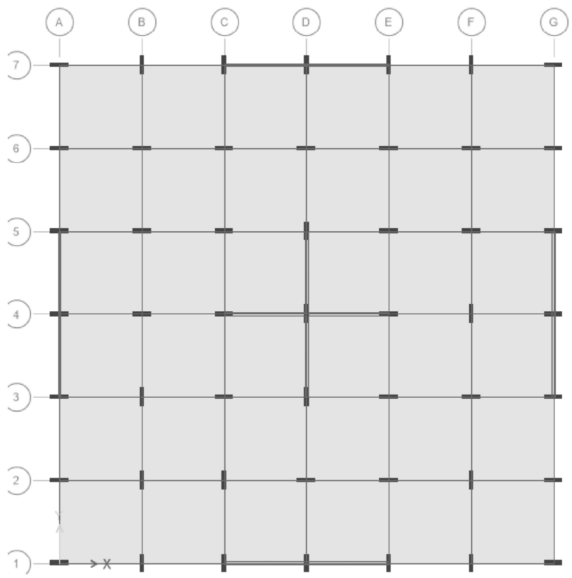

Fig 4 Center adjacent infill patterns

In this type of building infill are provided in center and middle part of the outer building as shown above, this type of pattern is taken into consideration as few buildings are constructed with partial infill walls on the ground floor. This pattern mainly considers infill in particular location to study the impact of infill on the open ground story.

5) Center corner infill pattern

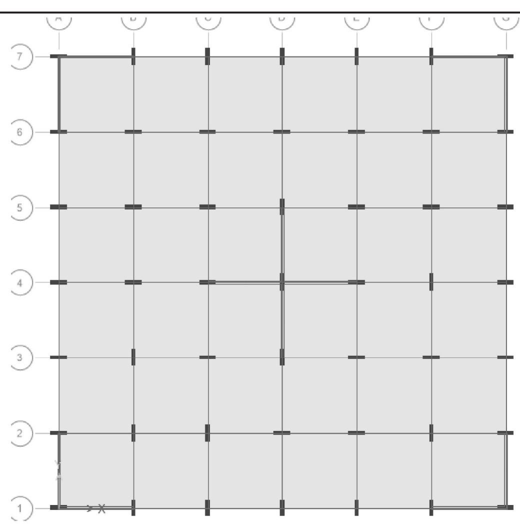

Fig 5 Center corner infill pattern

In this type of building infill are provided in center and corner part of the building as shown above.

6) Fully infill + bracing

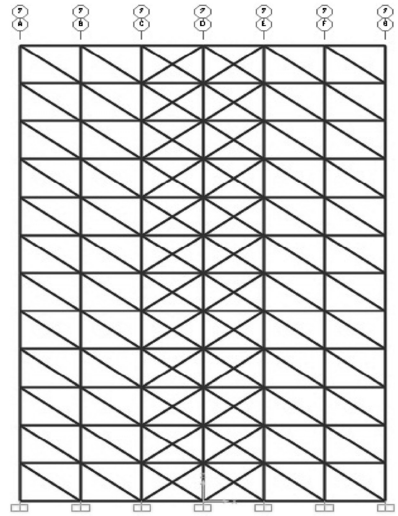

Fig 6 Fully infill + bracing

This frame consists of fully infill frame retrofitted with bracing. This frame is only considered to study the effect of addition of bracing to the frame.

7) Open ground story + bracing

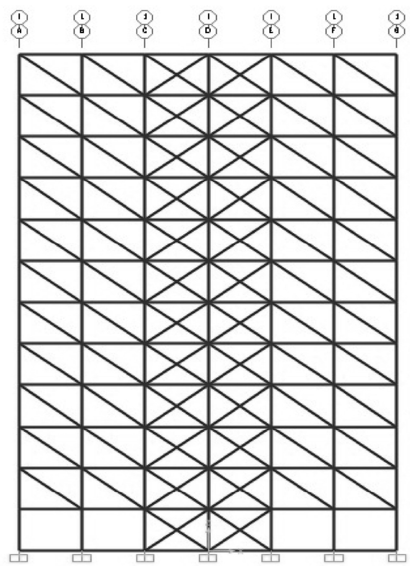

Fig 7 Open ground story + bracing

This frame is actual case which studies the effect of retrofitting open ground frame with bracing system. The bracing systems are provided over middle part of outer frame.

6. Results and discussions

6.1 Results from 3D pushover analysis

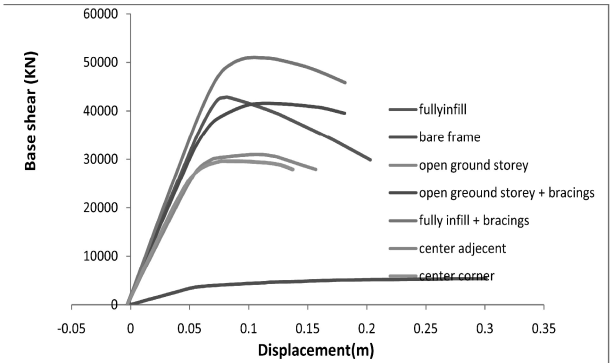

Fig 8 Base shear vs. displacement for different 3D cases

- Based on the study, building with no infill modeled showed the least stiffness. With infill effect consideration the stiffness of building increased. And with addition of bracing systems to the frame the capacity and ductility of the frame has increased significanly. This result clearly shows that the infill do add a significant amount of stiffness to the building by it daigonal strut action.
- The building does not consider the additional strength of the infill. Hence the stiffness of the building is lowest as compare to other frames. Due to less stiffness the ductility of the building is high as compare to other frame. Ignoring the strength of the infill walls the capacity of the building is too low as compare to other building
- With addition of infill to the building the stiffness of the building increases. As stiffness of infill is considered in this frame the capacity increases. The initial failure takes place in the infill of the middle stories. With failure of the infill the capacity of the frame decreases unless the hinges are formed in the column of the bottom stories.
- With removal of infill from the open ground story reduced the stiffness of building significantly considering the effect of the infill on the fully infill frame. The capacity of building reduces significantly with failure of column at ground floor. The building acts as inverted pendulum as complete mass source of building lies above the ground story of the building
- In frame the addition of infill adds stiffness increasing the base shear at performance point of the building. But the capacity is not increased significantly hence partial addition of infill cannot be considered as a good retrofitting technique.
- With addition of bracing system to the frame the capacity of the building with open ground story increases significantly. The capacity of building is nearly equivalent to that of building with full infill. With addition of bracing system to the frame, the addition strength of the infill was properly utilized increasing the capacity of the building. The transfer mechanism was properly studied

- With addition of bracing system to the fully infill system the capacity of building was increased. The additional effect of infill and the bracing increased the capacity and ductility of the building. However addition of infill will be enough for the building.

6.2 Discussion

Based on the above results it can be clearly seen that with removal of infill the performance of building decreases. Capacity decreases with removal of infill. When infill is removed from the ground story of the building the capacity of the building decreases. When the same building is retrofitted with bracing, the capacity of the building increases. When center corner and center adjacent infill were added the performance of building was not as enhanced as after addition of bracing. Hence the two added pattern at ground story were not effective retrofitting technique. Open ground storey building could not use the complete strength as the stiffness of the building was reduced leading to early failure of columns

6.3 Calculation for R factor

Case	ductility	Ductility reduction factor	Over strength factor	R factor
Bare frame	3.25	2.34	1.16	2.72
Open ground story	1.67	1.53	3.28	5.01
Open ground story + bracings	1.76	1.59	4.37	6.93
Fully infill	1.17	1.16	4.35	5.04
Fully infill + bracings	1.46	1.39	5.14	7.12

6.4 inter storey drift for different buildings

Story no	Fully infill + bracing	Open ground storey+ bracing	Fully infill	Bare frame	Open ground story
12	0.000294	0.000291	0.000326	0.001205	0.00032
11	0.000386	0.000382	0.000429	0.001812	0.00042
10	0.000464	0.000458	0.000519	0.002432	0.00051
9	0.000521	0.000515	0.000587	0.002961	0.00058
8	0.000561	0.000554	0.000638	0.003385	0.00063
7	0.000586	0.000579	0.000671	0.003709	0.00066
6	0.000597	0.00059	0.000689	0.00394	0.00068
5	0.000594	0.000588	0.000691	0.004086	0.00068
4	0.000575	0.000569	0.000673	0.004137	0.00067
3	0.000515	0.000506	0.000606	0.004032	0.00059
2	0.000414	0.000458	0.000489	0.00354	0.00059
1	0.000374	0.000697	0.000454	0.001858	0.00119

at ground story. With addition of bracings additional stiffness was provided to the structure leading to strengthening of the ground floor of the building. This addition of bracing system enhances the performance of structure.

From the above results it can be clearly seen that bare frame is the most ductile structure. R factor increases with addition of bracing to the structure by increasing its ductility. Ductility and the R factor of the building increases with the addition of bracing.

Conclusion

Complete removal of infill walls reduces the stiffness of the particular floor making it a soft storey. Addition of infill increases the capacity of the building. The building with open ground storey stands strong against gravity load but weak against lateral forces so addition of proper retrofitting agent was necessary. Based on the results after addition of bracing, the capacity of the building is increased. If a building is to be constructed with open ground story the proper measures must be taken to increase the stiffness of the building at the ground story. With addition of infill the ductility of the structure is decreased. Bare frame is the most ductile structure while fully infill is the least ductile structure. R factor ductility and other factors also increased with increase in performance after addition of bracing. R factor increased from 5.01 to 6.93 in case of open ground storey. Response reduction factor is maximum for fully infill with bracing frame. Partial addition of infill is not an effective method for retrofitting of building with open ground storey as the stiffness capacity was not achievedof the building is not increased leading to formation of initial hinges in columns of ground storey of the building. Whereas after addition of bracing the ground storey gets adequate stiffness. Addition of bracing enhances the performance of building with open ground storey almost to the same level of building with full infill. Enough stiffness has been achieved by addition of bracing to the frame,which fulfills the demand of the building. Partial addition of the infill to the building was in effective as enough.

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