

Response Reduction Factor for Lateral Load Resisting Frames with Vertical Discontinuity

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ABSTRACT: Earthquake resistant structures are always designed for reduced lateral forces, as it is subjected to actual acceleration. This reduction factor reduces the actual acceleration of the seismic on structure which depends on over strength, ductility, redundancy and damping coefficient of the structure. The 'R' factor is discussed in many well-developed seismic design codes for several structural configurations. Hence, defined 'R' factors considered for lateral frames with vertical discontinuity at the ground storey are unrealistic due to deficient in lateral stiffness. The present research work carried to assess the realistic 'R' factors for the actual structural forms chosen for the study by pushover analysis. The computation models of OMRF and SMRF with vertical discontinuity in load path, for different position at ground storey is modeled in SAP2000. The stiffness and ductility of the structure is studied for the same frames to understand the effect of discontinuity in lateral load resisting structure. In this paper, response reduction factor for a floating column building is defined to all zone condition, different soil condition and for default and user defined hinge lengths.

KEYWORDS: Floating Column, Response Reduction Factor, Default Hinges and User Defined Hinges, Pushover Analysis.

I. INTRODUCTION

In India many urban multistorey reinforced concrete buildings have open first and ground storey as an unavoidable aspect. Structures that have discontinuous walls and columns in any storey or with unusual tall storey tend to fail or damage, which is being in that storey. This is mainly adopted to provide accommodation, reception lobbies or parking in ground and first storey. The base shear experienced by a structure during an earthquake (EQ) is dependent on its natural time period and the seismic load distribution is dependent on the mass and stiffness along the height of the structure. The reaction of a structure during an earthquake depends on its size, overall shape, mass and geometry, other than the load path i.e. how the EQ forces are transferred to the foundation. The seismic forces developed at higher storey are necessary to bring down to the foundation by the shortest path, presence of any discontinuity or deviation in load transmitting path leads to the bad performance of the structure.

Floating column (FC)

A column is a vertical element or member starting from foundation level and used to transfer the load to the ground. The word floating column in a building is also a vertical member which (due to client's requirements, architectural plan and site condition) at its termination level rests on a transfer girder or beam which is a horizontal member. These beams transfer the load to other columns below.

Plastic hinge length

The default hinge length values are require to assign to the elements as M_3 hinges for beams and PM_2M_3 hinges for columns using SAP 2000. There are many user-defined hinge length values are given by different authors. Out of these formulas only two formulas are considered, which Park and Paulay et al. [10], and Priestley et al. [11], prescribed.

$$\begin{aligned} L_p &= 0.5H \\ L_p &= 0.08Z + 0.022f_{ye} d_b \geq 0.044 f_{ye} d_b \end{aligned} \quad (1)$$

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L_p = Length of plastic hinge.

H = Depth of the member.

f_{ye} = Yield strength,

d_b = Dia of longitudinal reinforcement

Z = Critical distance from the critical section of the plastic hinge to the point of contra flexure.

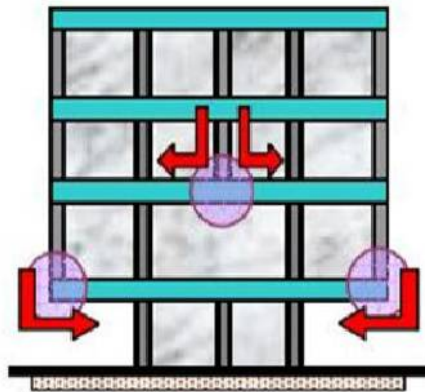


Fig. 1 Floating column resting on beam

II. LITERATURE REVIEW

Many multistorey reinforced buildings with an open storey accommodated for vehicle parking, reception lobbies were collapsed or severely damaged in Gujarat during 2001 Bhuj EQ. Structure failed due to the discontinuity in load path at lower and upper storey suggested by clients, architectures due to site requirement.

- Prerna Nautiyal et al. [1], Investigated the effect of a floating column under earthquake excitation for different soil conditions and the magnification factor. Linear dynamic analysis performed on two cases of special moment resisting frame (SMRF) models G+3 and G+5 by STAAD.Pro to study the variation in base shear and moments for different soils. Response spectrum analysis (RSA) is done corresponding to zone V, hard soil and medium soil and 5% damping as per IS 1893 (2002) for all building frames. Base shear value is more for the building with normal columns than the floating column building.
- Sabah Farheen et al. [2], Computed the effect of seismic forces in members supporting floating columns in a typical reinforced concrete multi-storey building. The ordinary moment resisting frame (OMRF) G+6 building situated in seismic zone V on type II soil, as said by IS 1893-2002 were modeled and analyzed in SAP 2000 by static equivalent method. Resistance force by infill wall and diaphragm action of slab to the lateral load by earthquake is considered, infill wall was modeled by Equivalent diagonal struts. The exterior and interior columns of the ground storey which support the cantilever span develop higher value of shear force and bending moment under gravity as well as seismic load combinations.
- Tejash Patel et al. [3], Studied the effect of response reduction factor of RC framed staging elevated water tank using static pushover analysis. Non-linear static pushover analysis performed on RC framed elevated water tanks having a single height and varying capacities in ETABS. The response reduction factor (R) is mainly affected by the seismic zone and fundamental time period of water tanks. The response reduction factor reduces as the seismic zone increases and increases as the fundamental time period increases.
- Mehmet Inel et al. [4], Compared the effects of plastic hinge properties in non-linear analysis of reinforced concrete building. Analysis was carried out in SAP 2000 for both 4-storey and 7-storey buildings: to identify the probable differences in the results due to the variation in hinge length property. SAP 2000 provides the option to assign default and user defined hinge properties. The hinge length has an effect on the displacement

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capacity of the structures and it shows the variation of about 30% in displacement capacities. Displacement capacity depends on the section properties and transverse reinforcement at the possible hinge regions.

- Kruti J. Tamboli et al. [5], Computed the response reduction factor (R) and ductility value (μ) for asymmetric RC frame structure using nonlinear static pushover analysis. This paper is provided 'R' value for asymmetric RC bare frame, asymmetric RC frame with X bracing at alternate bay, shear wall at alternate bay. Analysis was carried out in SAP 2000, on a typical 4-story RC frame. RC braced frame has more lateral strength and stiffness as compared to bare RC frame. Yield lateral force and ultimate lateral forces are more in case of RC frame with X bracing at alternate bays and in RC frame with shear wall than the bare RC frame. The value of response reduction factor of asymmetric RC frame is affected by the bracing system arrangement.

III. OBJECTIVES

Vertical discontinuity of load transferring path to ground in lateral load resisting frames in floating column affects the structural response of a system. There is no codal provision for analysis and design of floating columns. IS code provides response reduction factor only for OMRF and SMRF along with other structures. Response reduction factor for OMRF with floating column and SMRF building with floating column is not defined in any code.

- 1) To study the static non-linear seismic behaviour of multi-storey building with discontinuity in load path.
- 2) To study the response reduction factor for the OMRF and SMRF, for different soil conditions with vertical discontinuity at ground storey and at different positions.
- 3) To study the variation in response reduction factor 'R' obtained by assigning default and user defined hinges.
- 4) To study the variation in response reduction factor with respect to lateral stiffness of the building.
- 5) To study the response reduction factor for OMRF with vertical discontinuity at ground storey and at different positions with respect to different zones.

IV. CONCEPT OF RESPONSE REDUCTION FACTOR

Response reduction factor 'R' is mainly dependent on three factors like strength factor, ductility and structural redundancy as it mentioned in ATC-19. The most important purpose of this code is to give the information regarding the key components or factors that influence the mathematical values assigned to 'R'. The proposed formulation does not specifically describe the special effects of plan and vertical irregularity in framing systems. There is no codal provision to assign response reduction factor to the floating column building. However, ATC-19 provides the factors on which response reduction factor depends, which intern helps to find the response reduction factor for irregular structures. Following are some of the provisions discussed in Applied Technology Council (ATC) - 19 code book. Response reduction factor 'R' is mainly dependent on three factors.

$$R = R_u \times R_s \times R_R$$

1. R_s = Over strength factor
2. R_u = Ductility factor
3. R_R = Redundancy factor

Estimation of over strength factor as it is recommended in ATC-19

Over strength factor (R_s) accounts for the yielding of a structure at load higher than the design load, due to various partial safety factors like strain hardening, oversized members and confinement of concrete. Even non-structural elements also have an effect on over strength factor.

$$R_s = \frac{V_o}{V_d}$$

V_o = Maximum base shear from pushover curve

V_d = Design base shear calculated from IS 1893-2002

$$A_h = \frac{S_a}{g} \times \frac{l}{R} \times \frac{Z}{2}$$

A_h = Design horizontal seismic coefficient for the structure.

Z = Zone factor

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Sa/g= Average response acceleration coefficient

I=Importance factor

R=Response reduction factor

V_d=W×A_h

W=Total weight of the building

Estimation of ductility factor (R_μ)

$$R_{\mu} = \left(\frac{\mu - 1}{\phi} \right) + 1$$

$$\mu = \frac{\Delta m}{\Delta y}$$

Δm=Maximum drift capacity=0.004H

Δy=Yield drift from pushover curve

φ For different type of soil

$$\phi = 1 + \left(\frac{1}{10T - \mu T} \right) - \left(\frac{1}{2T} \right) e^{-1.5(\ln T - 0.6)^2} \quad \text{for Hard soil}$$

$$\phi = 1 + \left(\frac{1}{12T - \mu T} \right) - \left(\frac{2}{5T} \right) e^{-2(\ln T - 0.2)^2} \quad \text{for Medium or Alluvium soil}$$

$$\phi = 1 + \left(\frac{T_g}{3T} \right) - \left(\frac{3T_g}{4T} \right) e^{-3(\ln(\frac{T}{T_g}) - 0.25)^2} \quad \text{for soft soil}$$

T= fundamental time period of the model from software.

T_g= Predominant period of the ground motion.

Estimation of redundancy factor (R_R)

Redundancy factor depends on the number of vertical framing elements in seismic force resistance. Yielding at one point or place in the building does not imply, yielding of the structure as a whole. Therefore, the load distribution due to redundancy of the structure provides additional safety. Redundancy factor cannot be larger than one. Redundancy factor (R_R) from Table 2 of ATC-19, 1995 is given below.

Table I: Values of Redundancy factor

Lines of vertical seismic framing	Redundancy factor
2	0.71
3	0.86
4	1.0

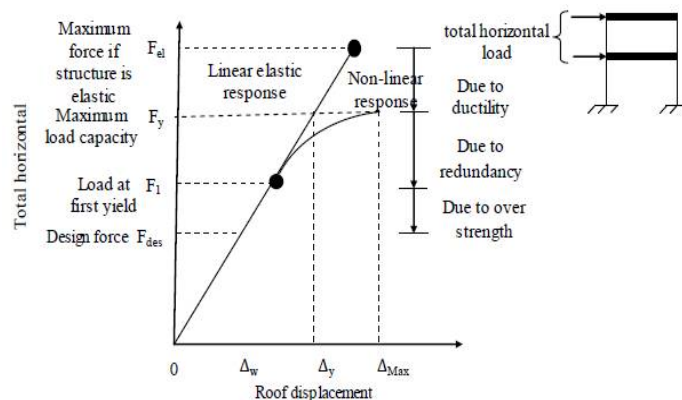


Fig. 2 Concept of response reduction factor

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V. METHODOLOGY AND STRUCTURAL MODELING

An 8-storey building with ordinary moment resisting frame and special moment resisting frame in two orthogonal directions was selected for the study. The building had one brick thick exterior infill wall along with periphery of the building above the ground storey. The resistance to the lateral force for infill brick wall was considered by modeling the wall as equivalent strut. The building was considered to be located in Zone V on Type I and Type II soil, as per IS 1893:2002. The dimensions of the members were selected based on the design for gravity loads and building was modeled in SAP 2000.

- An 8-storey building is modeled and designed only for gravity loadings. The designed cross section properties and percentage of reinforcement are used for seismic analysis.
- The static-non linear analysis is carried out with default hinges for I series models by assigning the different soil conditions for ordinary moment resisting frame and special moment resisting frame, to define the response reduction factors.
- The variations in response reduction factor with respect to variation in lateral stiffness are computed for the II series models by static non-linear analysis.
- The variation in response reduction factor with respect to zones is defined for I series models by assigning default hinges by pushover analysis.
- The variation in response reduction factor is defined for I series models by assigning user defined hinges by pushover analysis.

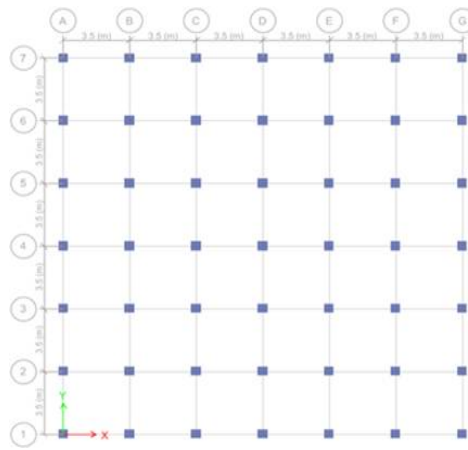
Table II: Building data and loading details used in modeling

Bays along X and Y 6 at each 3.5m		
Type of building	General	
Seismic zone	V	
Type of frame	Ordinary moment resisting frame (OMRF) Special moment resisting frame (SMRF)	
Soil	Hard, Medium	
Importance factor	1	
Plinth height from foundation	2 m	
Storey height	3.2m	
Slab	150 mm	
Beams	300×450 mm	
Transfer girder at ground storey	300×750 mm	
Columns	375x375mm, 400x400mm, 500x500mm, 600x600mm, 700x700mm.	
Main wall	300 mm	
Partition wall	150 mm	
Parapet height	750 mm	
Parapet thickness	300 mm	
Unit weight of brick infill	20 kN/m ³	
Unit weight of concrete	25 kN/m ³	
Storeys	Live load	4 kN/m ²
	Floor finish	0.75 kN/m ²
Roof	Live load	2 kN/m ²
	Floor finish	1.5 kN/m ²
f _{ck}	20 N/mm ²	
f _y	415 N/mm ²	

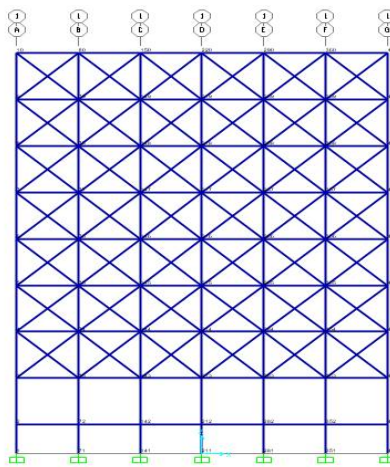
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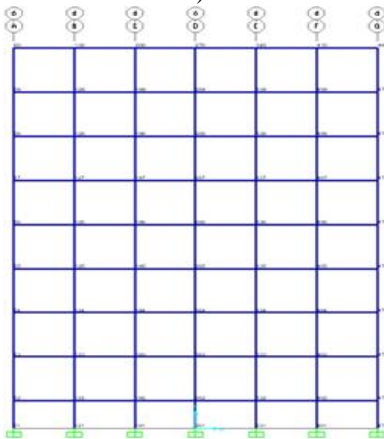
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a)



b)



c)

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Fig. 3(a, b, c) Plan and elevation of conventional model (C)

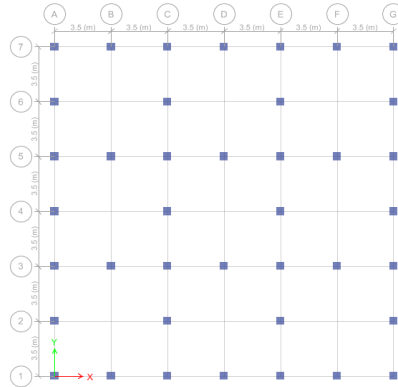


Fig. 4 Plan of floating column building A (FCA) frame

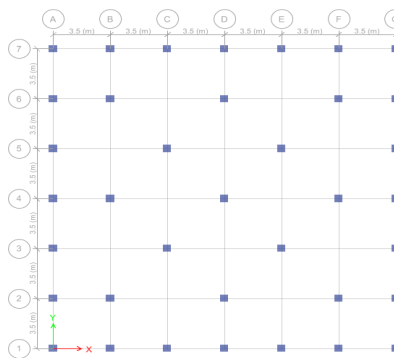


Fig. 5 Plan of floating column building B (FCB) frame

VI. RESULTS AND DESCUSSION



Fig. 6 Capacity curve as per FEMA-356 coefficient method for pushover analysis

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1) Variation in Base shear, Lateral displacement and Stiffness.

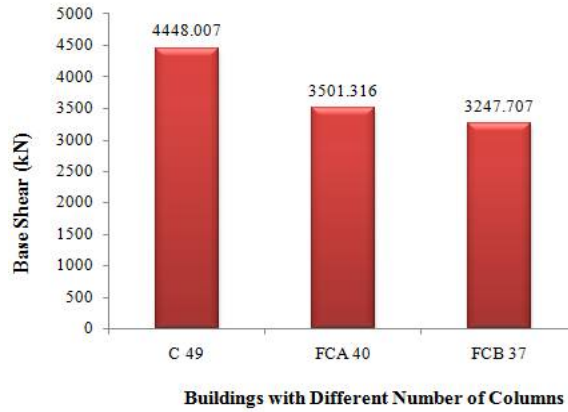


Fig. 7 Variation in base shear of OMRF

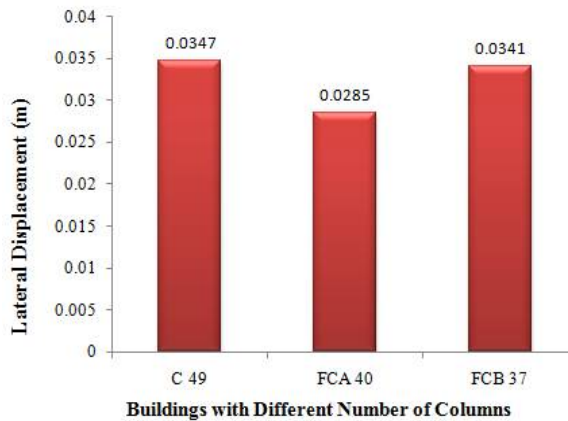


Fig. 8 Variation in lateral displacement of OMRF

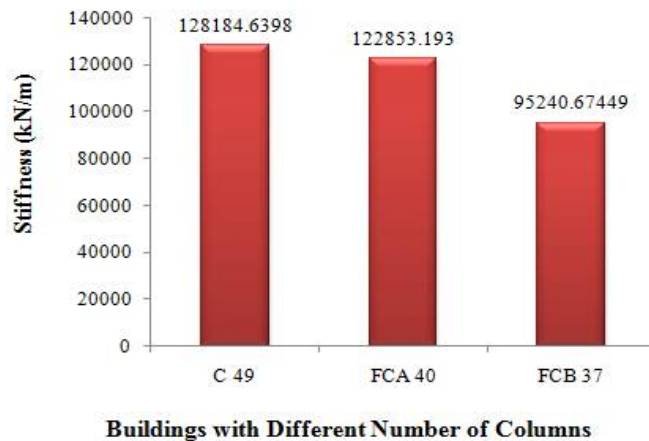


Fig. 9 Variation in stiffness of OMRF

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2) Response reduction factor with default hinge length.

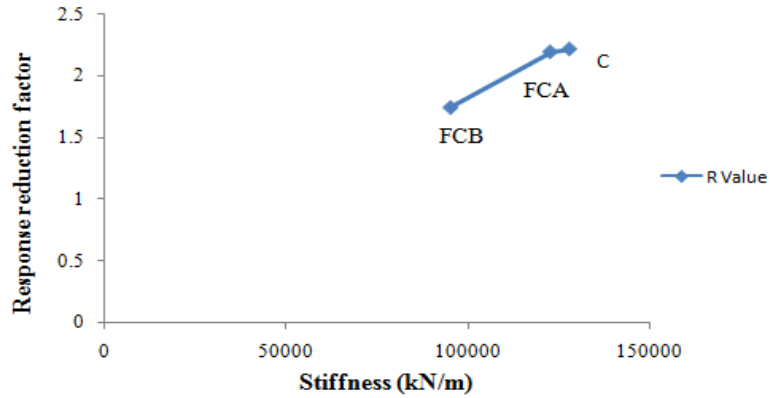


Fig. 10OMRF in hard soil

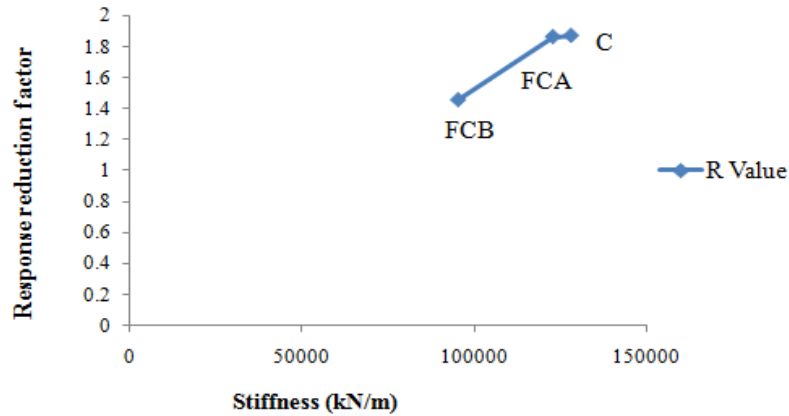


Fig. 11 OMRF in medium soil

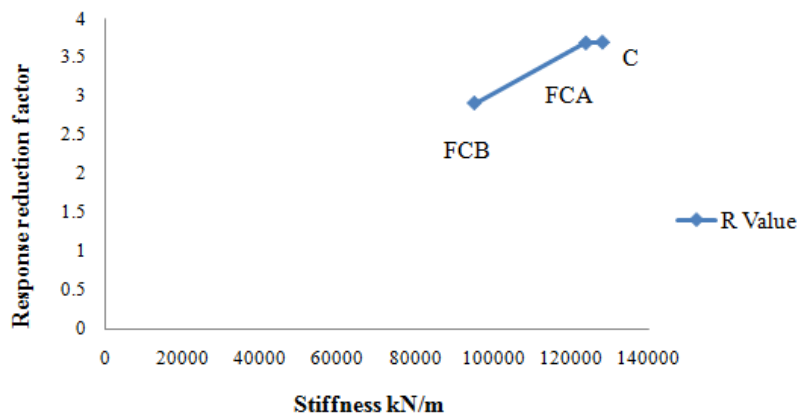


Fig. 12SMRF in hard soil

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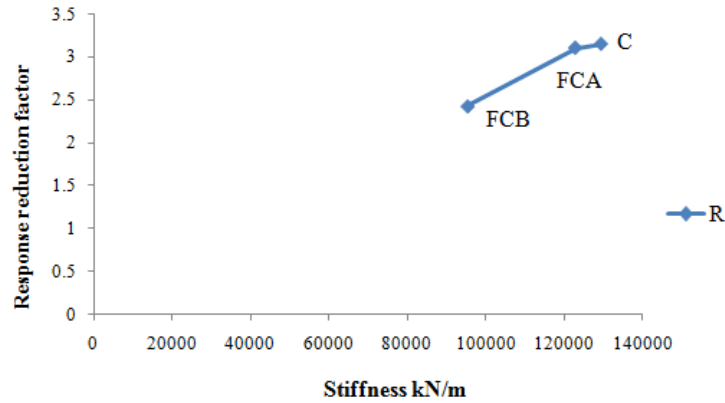


Fig. 13 SMRF in medium soil

3) Response reduction factor for user defined hinge length.

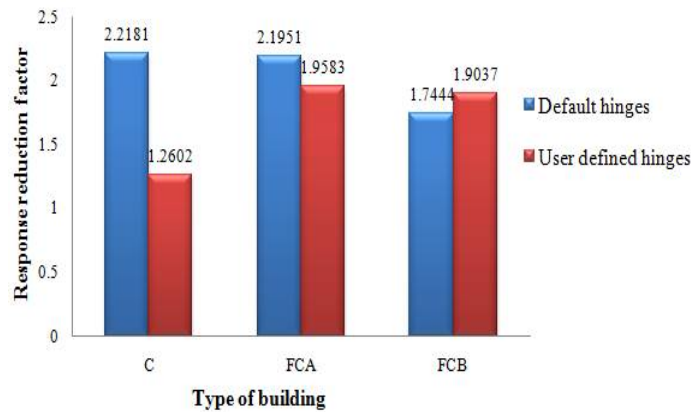


Fig. 14 'R' for OMRF in hard soil

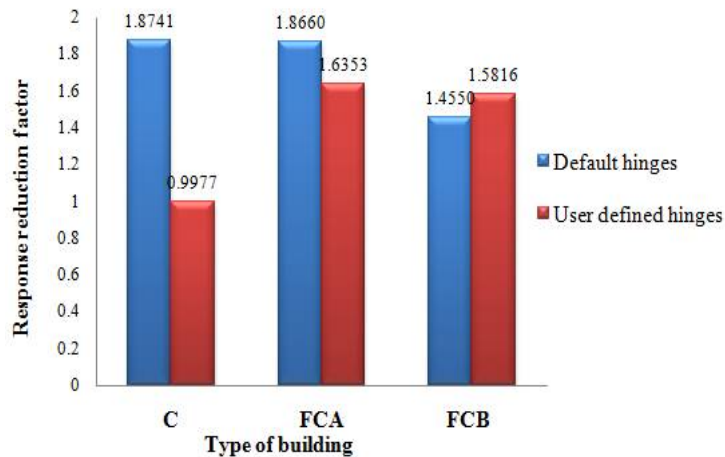


Fig. 15 'R' for OMRF in medium soil

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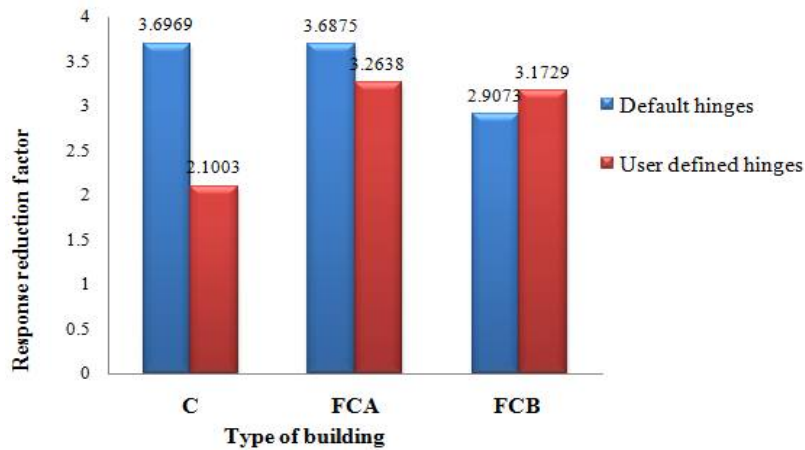


Fig. 16 'R' for SMRF in hard soil

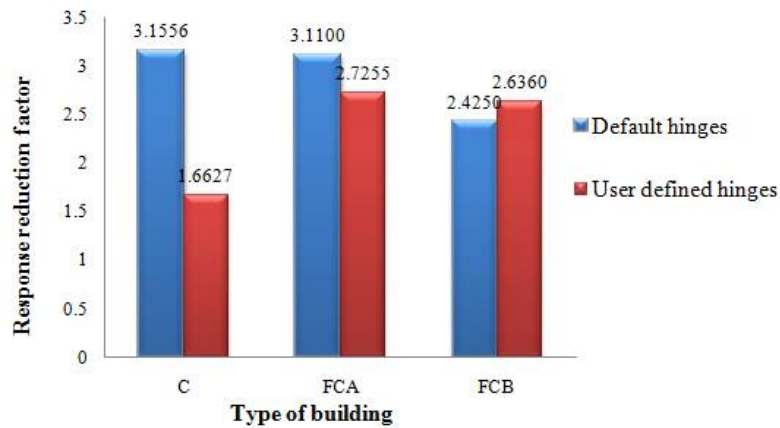


Fig. 17 'R' for SMRF in medium soil

4) 'R' for different sizes of columns in FCA frame

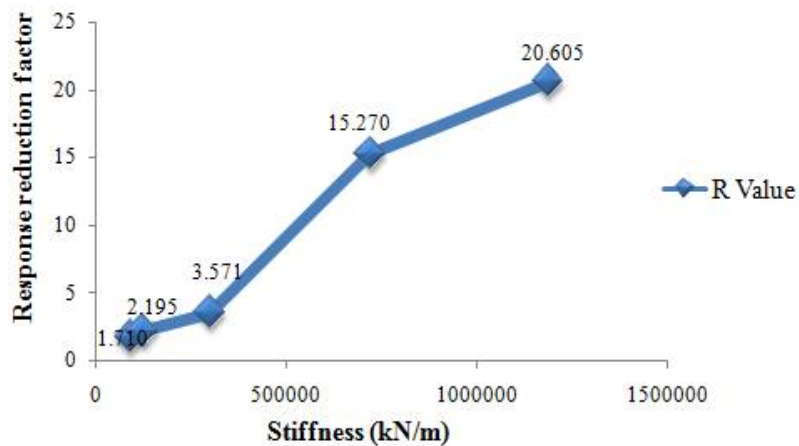


Fig. 18 Variation in 'R' for OMRF with respect to stiffness

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5) Response reduction factor for different zones

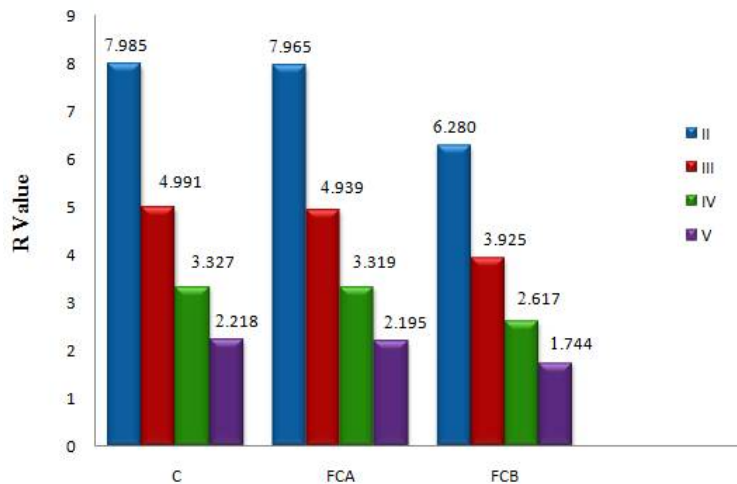


Fig. 19 Variation in ‘R’ for OMRF with respect to zones

Stiffness of FCA and FCB frame in its ground storey decreases around 18.5% and 24.5% respectively. Base shear in ‘C’ building is more compared to the FCA and FCB building. Lateral displacement of conventional building is more than those FCA and FCB buildings. The lateral displacement decreases around 17.87% from ‘C’ frame to ‘FCA’ frame and it reduces 1.73% from ‘C’ to ‘FCB’ building. In case of FCA building reduction in lateral displacement value is due to the presence of floating column in ground storey. Though the stiffness of FCB frame reduces around 24.5%, lateral displacement decreases only 1.73%. This indicates displacement values are more affected by the position of floating columns in ground storey. Stiffness of FCA and FCB frames is less, because these two buildings have less number of columns in its ground floor.

Conventional building has higher response reduction factor than the floating column building FCA and FCB. ‘R’ is mainly dependent on the type of soil and hard soil has higher value of ‘R’. Soil factor and over strength factor is more in case of hard soil. In C and FCA frame ‘R’ factor reduces 0.85 times from hard soil to medium soil and for FCB it reduces 0.834 times. The hard soil factor is 1.2 times higher than the medium soil factor in SMRF. ‘R’ value obtained from user defined hinge length value reduces 0.876 times in FCA frame than the default hinge length. In FCB frame user defined hinge length ‘R’ value is 1.087 times more than the default case.

Response reduction factor is dependent on the hinge length provided, which in turn depends on the section properties. Base shear obtained from this, in FCA and FCB frame is comparatively more than default hinge length. Therefore, the position of floating column and section properties of transfer girder has its own effect on user defined hinge length. It is also dependent on type of soil and ‘R’ is more in hard soil. Here, in C frame ‘R’ value reduces 0.79 times and 0.83 times in FCA and FCB frame from hard soil to medium soil.

The value of ‘R’ increases in case of higher column size. As the size of column increases, stiffness of the structure increases and it ends up with the higher value of response reduction factor. Response reduction factor reduces as the seismic zone increases in C model as well as in building with floating columns. In all types of frames ‘R’ value is more for zone II and less for zone V. ‘R’ value is very high for C frame than FCA and FCB frames in all zones. ‘R’ reduces from lower zone to higher zone. For conventional building ‘R’ value reduces from 7.98524 to 2.21812, from zone II to zone V. In FCA frame ‘R’ reduces from 7.96509 to 2.19507 from zone II to zone V. The ‘R’ for FCB frame in zone II is 6.27986 and it reduces to 1.74441 in zone V. It is found that R factor is inversely proportional to zone.

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VII. CONCLUSION

In this study the response reduction factor (R) for G+7 storey lateral load resisting frames with vertical discontinuity are evaluated by taking different parameters using non-linear static pushover analysis. The conclusions of the present study are summarized as follows.

1. The values of base shear, lateral displacement, and stiffness in C model are higher than the building with floating columns. Base shear decreases as the vertical discontinuity in building increases. The number and position of floating columns affect lateral displacement in a building. The variation in base shear and lateral displacement is found nearly 21% and 18%.
2. Buildings with floating columns have lesser value of 'R' factor. The value of 'R' is directly dependent on stiffness of the structure. As stiffness value increases, response reduction factor also increases. The values of 'R' for building with vertical discontinuity in load path are less than the conventional building. In OMRF, 'R' value with respect to default hinges decreases 0.9896 to 0.786 times in floating column buildings. Stiffness is directly proportional to the value of 'R'.
3. The type of soil and the seismic zone considerably affects the 'R' value. The value of 'R' is more for hard soil than the medium soil in case of FC building. The value of 'R' reduces as the seismic zone increases in building with floating columns. The 'R' value increases as the size of column increases in FC building.
4. It is observed that response reduction factor for FCA frame reduces 0.85 times from hard soil to medium soil in both OMRF and SMRF in seismic zone V. 'R' value for FCA frame in zone II is 7.96509 and in zone V is 2.19507.
5. In case of user defined hinge length model the 'R' value is more for building with vertical discontinuity in its load-transferring path. The 'R' value is mainly dependent on the hinge length provided. In both default and user defined hinge models hard soil has higher value of 'R' than medium soil. For C model, hinges formed by default itself provides higher value of response reduction factor. In all types of buildings base shear obtained by user-defined hinge is more than the default hinge length. Therefore, the use of user-defined hinge length is preferred in case of building with vertical nonlinearity.
6. Estimation of exact value of 'R' for building with floating columns with exact analysis leads to an efficient and effective design of building with vertical discontinuity. R-value depends on many factors like type of soil, seismic zone, stiffness, column size and hinge length.

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