Response Reduction Factor for Lateral Load Resisting Frames with Vertical Discontinuity of Asymmetrical Structure

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ABSTRACT In recent times, the RC building construction with vertical discontinuity that is floating column structures are unavoidable feature and increases trends day by day. To reduce lateral forces the earthquake resistance structures are designed so the response reduction factor (R) is used to determine these lateral forces by using base shear values. The R factor depends upon the overstrength factor, ductility factor, redundancy factor also the sizes of columns, types of soil, zones and load transferring path, etc. The IS code provides response reduction factor only for OMRF and SMRF along with other structures like Braced frame system, Structural wall system, Dual system, Flat slab structure wall system, etc. so there are no codal provisions for floating column structures. Thus it is essential to study the real behaviours of RC buildings with discontinuity in load transferring path through non-linear static analysis, so the present research work is done on trying to find R factor for vertical discontinuous asymmetrical structure for different soil conditions and different positions of floating column using moment resisting frames. And the structure is analyzed by response spectrum analysis and non-linear static analysis using SAP2000 software.

KEYWORDS Floating Column, Non-Linearity, Moment Resisting Frames, Response Reduction Factor, Pushover Analysis

1. INTRODUCTION

In recent time history, most structures are constructed with more open space at the ground storey or first storey due to the aesthetical point of view or the client's requirements. This is mainly required for parking space, reception halls, shopping malls, and accommodations, etc. So the structure with floating columns is an unavoidable feature. A floating column is a vertical member which rests on a beam called a transfer girder or beam but does not transfer the load directly to the foundation. The behaviour of a structure during an earthquake depends upon many factors like the type of soil, zones, sizes of structures, loading conditions, the geometry of the structure, and load transferring path. So it is very important to study the real behaviour of structure with vertical discontinuity. Also, there are large damages of these types of structures in highly seismic areas so to reduce chances of failure of structure it is necessary to use retrofitting methods like moment resisting frames, shear walls, dampers, etc. These types of structures with floating columns are analyses by using ETABS, STAAD Pro, and SAP2000.

Following are some aspects of such studies regarding the behaviour of floating columns under dynamic analysis. Also, many researchers studied about response reduction factor for vertical discontinuous structure, Non-linear static analysis, and positions of floating columns.

Figure 1: - Floating or Hanging Column

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Pratyush Malaviya et al. [1], Considered 2 storey regular building structures without floating columns and buildings with different positions of the floating column by using Staad Pro software. Analysis of the building was done under static loading and earthquake response spectrum for medium soil conditions. The results are presented in terms of the weight of concrete and steel provided for different type's models.

Vinod Kumar Meena et al. [2], Studied the effect of a floating column under earthquake excitation and determination of magnification factors for the safe and economical design of a building having floating columns. For this they prepared four models such as floating column due to discontinuity of centre column for G+3, floating column due to discontinuity of side column for G+3, floating column due to discontinuity of centre column for G+5, floating column due to discontinuity of side column for G+5. The results were obtained in terms of magnification factor for every model.

Sampada Mahadev Gangavali et al. [3], Conveyed to evaluate the reasonable 'R' factors for the real underlying structures picked for the investigation by pushover analysis. They figured models of OMRF and SMRF with vertical discontinuity in the load path, for an alternate position at the ground storey is modelled in SAP2000. The stiffness and ductility of the construction are read for the equivalent edges to comprehend the impact of brokenness in sidelong burden opposing structure. In this paper, they portrayed the reaction decrease factor for a floating column structure for all zone conditions, distinctive soil conditions, and for default and user-defined hinge length. They concluded that R-value depends on many factors like the type of soil, seismic zone, stiffness, column size, and hinge length.

Kruti J. Tamboli et al. [4], Figured the response reduction factor (R) and ductility value (Rμ) for asymmetric RC frame structure utilizing nonlinear static pushover analysis. This paper is given the 'R' value for asymmetric RC bare frame, asymmetric RC frame with X bracing at substitute bay, a shear wall at substitute bay. Investigation was completed in SAP 2000, on a normal 4-story frame. RC propped outline has more sidelong strength and stiffness when contrasted with exposed RC frame. Yield lateral force and ultimate lateral forces are more in the case of RC frame with X bracing at alternate bays and in RC frame with the shear wall than the bare RC frame. The worth of the response reduction factor of asymmetrical RC frame is influenced by the propping framework game plan.

T. Sahithi Gupta et al. [5] Carried the effects of floating columns of an RC frame structure for G+14 stories at different seismic zones (zone II and zone III) in India and additionally he contemplated the impact of position of floating column at various areas in the thought about arrangement. The results are performed in terms of storey drift and quantity of steel required. From the examination, they inferred that the design without floating column has more sidelong drift than the construction with drifting segments at all different seismic zones in India.

2. OBJECTIVES OF THE STUDY

The behaviour of the structure during an earthquake depends upon the load transferring path. As there is no codal provision for vertical discontinuous structure in IS code. So present research work is done on trying to find R factor for vertical discontinuous asymmetrical structure with lateral load resisting frames.

1. To study the behaviour of floating columns under the seismic loading by using non-linear static analysis.
2. To study the response reduction factor for structure with a vertical discontinuity at the ground storey and different locations.
3. To determine the response reduction factor for the ordinary moment-resisting frame (OMRF) and special moment-resisting frame (SMRF) for different soil conditions.

3. CONCEPT OF RESPONSE REDUCTION FACTOR

The response reduction factor is used to reduce the elastic response of the structure. As per IS1893:2016, the R factor mainly depends upon the overstrength factor, ductility factor, and redundancy factor.

\[ R = R_\mu \times R_s \times R_r \]

Where, \( R_s \) = Overstrength factor
\( R_\mu \) = Ductility factor
\( R_r \) = Redundancy factor

The overstrength factor is the additional strength required beyond the design strength. It depends upon many structural and non-structural elements like the oversized member, strain hardening, confinement...
of concrete, load factors and multiple load cases, etc. The overstrength factor is the ratio of maximum base shear from pushover curve to the design base shear from IS 1893:2016.

\[ \text{Rs} = \frac{V_o}{V_b} \]

Where,

- \( V_o \): Maximum base shear from pushover curve
- \( V_b \): Design base shear calculated from IS 1893-2016

\[ V_b = W \times A_h \]

Where,

- \( W \): Total weight of the building
- \( A_h \): Design horizontal seismic coefficient for the structure.
- \( Z \): Zone factor
- \( S_a/g \): Average response acceleration coefficient
- \( I \): Importance factor
- \( R \): Response reduction factor

The ductility factor is the capacity to undergo large inelastic deformations without significant loss of strength or stiffness. The displacement ductility factor (\( R_\mu \)) is the ratio of ultimate deformation to yield deformation. In the current examination condition proposed by Miranda and Bertero is utilized to assess the ductility factor (\( R_\mu \)).

\[ R_\mu = \left( \frac{\mu - 1}{\Phi} \right) + 1 \]

Where,

- \( \mu \): \( \frac{\Delta m}{\Delta y} \)
- \( \Delta m \): Maximum drift capacity = 0.004H
- \( \Delta y \): Yield drift from pushover curve

\( \Phi \) For a different type of soil

For rock site:

\[ \Phi = 1 + \left( \frac{1}{10T - \mu T} \right) - \left( 1 - 1.5(\ln T - 0.6) \right)^2/2T \]

For medium or alluvium site:

\[ \Phi = 1 + \left( \frac{1}{12T - \mu T} \right) - \left( 2 - 2(\ln T - 0.2)^2 \right)/5T \]

For soft soil site:

\[ \Phi = 1 + \left( \frac{T_g}{3T} \right) - \left( 3T_g - 3(\ln (T/T_g) - 0.25) \right)^2/4T \]

Where,

- \( T \): Fundamental time period of the model from software.
- \( T_g \): Predominant period of the ground motion.

The redundancy factor depends on the number of vertical framing participate in seismic resistance. Yielding at one area in the design doesn't suggest yielding of the construction as a whole. Hence the load dispersion, due to redundancy of the structure, gives an extra safety margin. The values of the redundancy factor as suggested by ATC-19 are shown in Table 1.

| Lines of vertical seismic framing | Redundancy factor |
|----------------------------------|-------------------|
| 2                                | 0.71              |
| 3                                | 0.86              |
| 4                                | 1.0               |
Figure 2: - Concept of Response Reduction Factor

4. STRUCTURAL MODELLING

A 6 storey asymmetrical building with an ordinary moment resisting frame and special moment resisting frame is selected for the study. The structure is modelled and analyzed with lateral loading. Provide floating columns at a different location for checking base share, lateral displacement, and lateral stiffness of the structure. Non-linear static analysis is used for analyzing the structure. The variation in response reduction factor to variation in position and soil condition are computed by static non-linear analysis. Trying to find R factor for OMRF and SMRF for different soil conditions and locations.

Table 2: - Building data and loading detail used in the modelling.

| Type of building | General |
|------------------|---------|
| zone             | III     |
| Type of frames   | Ordinary moment-resisting frame |
|                  | Special moment-resisting frame |
| Soil             | Medium, Hard |
| Importance factor| 1       |
| Story height     | 3 m     |
| Beam             | 230x450mm, 230x500mm |
| Slab             | 120mm   |
| Transfer girder  | 350x600mm |
| Column           | 230x450mm, 230x500mm, 400x550mm, 450x500mm, 500x500mm. |
| Live load        | 2 KN/m  |
| Dead load        | 13.8 KN/m |
| Fck              | 30 Mpa  |
| Fy               | 500 Mpa |
| Density of concrete | 25 KN/m³ |
| Density of steel | 7850 KN/m³ |
| Constraints      | All joints are rigid. |
|                  | Supports at the base are fixed. |

For analysis purpose, ten models considered namely:

MODEL 1: Structure without the floating column for OMRF.
MODEL 2: Structure with the floating column at the ground floor for OMRF.
MODEL 3: Structure with the floating column on the second floor for OMRF.
MODEL 4: Structure without the floating column for SMRF.
MODEL 5: Structure with the floating column on the ground floor at SMRF.
MODEL 6: Structure with the floating column on the second floor for SMRF.
MODEL 7: Structure with floating column at ground floor for medium soil condition for OMRF.
MODEL 8: Structure with floating column at ground floor for hard soil condition for OMRF.
MODEL 9: Structure with floating column at ground floor for medium soil condition for SMRF.
MODEL 10: Structure with floating column at ground floor for hard soil condition for SMRF.

Figure 3: - Plan view of structure without floating column.

Figure 4: - Plan view of structure with floating column.

Figure 5: - 3D view of the structure with the floating column.

Figure 6: - Structure with the floating column at the ground.

Figure 7: - Structure with the floating column on the second floor.
5. RESULTS AND DISCUSSION

![Figure 8](image)

Figure 8: - Capacity curve as per FEMA-356 coefficient method for pushover analysis.

5.1 VARIATION IN BASE SHEAR, DISPLACEMENT, AND STIFFNESS

The response spectrum analysis and pushover analysis are carried out by using SAP2000 software by following seismic code IS1893 (part I):2016.

5.1.1 BASE SHEAR - Base shear is the horizontal reaction at the base against horizontal earthquake load. This base shear is acting at the base or supports of the structure or wherever the structure is fixed.

![Figure 9](image)

Figure 9: Graphical representation of base shear.

5.1.2 DISPLACEMENT - Storey displacement is the lateral movement of the structure caused by lateral force. The deflected shape of a structure is the most important and most visible point of comparison for any structure. No other parameter of comparison can give a better idea of the behaviour of the structure than a comparison of displacement.
5.1.3 **STIFFNESS** - Stiffness of any structure is the ability of the structure to resist deformation under the applied force. Stiffness is measured in force per unit displacement.

**Figure 10**: Graphical representation of displacement.

**Figure 11**: Graphical representation of stiffness of the structure.

5.2 **LEVELS OF DISPLACEMENT DUCTILITY IN THE STUDY BUILDING**

This table includes maximum base shear from pushover curve, design base shear as per IS 1893:2016, maximum drift and yield drift from pushover curve, etc.

**Table 3**: Displacement ductility of the structure.

| Models | Vo     | Vb     | △U   | △Y   | µ     | ϕ     |
|--------|--------|--------|------|------|-------|-------|
| 1      | 10417.32 | 4843.59 | 0.03294 | 0.009 | 3.66  | 0.867  |
| 2      | 7720.021  | 4691.977 | 0.03373 | 0.0249 | 1.357 | 0.830  |
| 3      | 9482.669  | 4691.977 | 0.03675 | 0.02311 | 1.914 | 0.837  |
| 4      | 11032.24  | 2906.158 | 0.03108 | 0.012 | 2.597 | 0.848  |
| 5      | 7720.021  | 2815.186 | 0.03373 | 0.0238 | 1.36  | 0.830  |
| 6      | 9365.835  | 2815.186 | 0.03786 | 0.0310 | 1.25  | 0.829  |
| 7      | 11281.677 | 4747.604 | 0.03157 | 0.0249 | 1.267 | 0.833  |
| 8      | 5573.09   | 3505.923 | 0.02523 | 0.0129 | 1.955 | 1.000  |
| 9      | 10165.95  | 2848.502 | 0.03841 | 0.0248 | 1.548 | 0.833  |
5.3 *RESPONSE REDUCTION FACTOR*

This table includes the overstrength factor, ductility factor, and response reduction factor.

| Models | Overstrength factor (Rs) | Ductility factor (Rµ) | 2R  | Response reduction factor (R) |
|--------|--------------------------|-----------------------|-----|-----------------------------|
| 1      | 2.15                     | 3.13                  | 6.729 | 3.36                        |
| 2      | 1.64                     | 1.298                 | 2.128 | 1.064                       |
| 3      | 2.021                    | 1.733                 | 3.502 | 1.777                       |
| 4      | 3.796                    | 2.883                 | 10.943 | 5.47                        |
| 5      | 2.742                    | 1.301                 | 3.567 | 1.783                       |
| 6      | 3.326                    | 1.20                  | 3.9912 | 1.995                       |
| 7      | 1.589                    | 1.664                 | 2.644 | 1.322                       |
| 8      | 2.376                    | 1.224                 | 2.908 | 1.454                       |
| 9      | 3.568                    | 1.457                 | 5.198 | 2.599                       |
| 10     | 3.634                    | 1.708                 | 6.206 | 3.103                       |

5.3.1 *OVERSTRENGTH FACTOR*  
5.3.2 *DUCTILITY FACTOR*

*Figure 12*: Overstrength factor.  
*Figure 13*: Ductility factor.
The variations of response reduction factors due to different locations of floating column for OMRF.

The variations of response reduction factors due to different locations of floating column for SMRF.

The variations of response reduction factors due to different soil conditions of floating column for OMRF and SMRF.

6. CONCLUSIONS

Calculation of response reduction factor using non-linear static analysis is done for 10 types of RC buildings. The obtained Response Reduction Factors are additionally examined and compared with different structural parameters of the structures. The followings are the conclusions arrived from the analysis and interpretation of the results.

1. The base shear value of structures without floating columns is more than the structure with the floating column. The base shear of the building is raised when we shift the floating column towards the top storey also it depends upon the types of soil conditions it is a maximum of medium soil than hard soil conditions for a structure with the floating column at the ground storey.
2. The displacement of structure with the floating column is slightly more than that of structure without floating column. Its value decreases for hard soil conditions than the medium soil for both OMRF and SMRF.
3. The value of the response reduction factor (R) is lesser for a structure with a floating column than the structure without a floating column. R-value is lesser for the floating column at the ground storey and it increases towards the top storey. R-value for hard soil condition is more than the medium soil condition for both OMRF and SMRF.
4. R-value for the special moment-resisting frame (SMRF) is more than the ordinary moment-resisting frame (OMRF).
5. The sizes of columns increase the response reduction factor also increases and it depends upon the stiffness of the structure.
6. So the R-value depends upon many factors like the type of soil, locations of the floating column, numbers of the floating column, the geometry of the structure, sizes of a column, and the moment-resisting frames.

7. **LIMITATIONS OF STUDY**
1. Only ten models of asymmetrical (U shape) structures are considered.
2. Only response spectrum analysis and non-linear static analysis is considered.
3. The location of the floating column at the ground and second column is considered.
4. Only specific sizes of column and transfer girder are selected for analysis.
5. Only moment resisting frames are considered.

8. **SCOPE FOR FUTURE WORK**
1. More study is required for asymmetrical structures with different shapes.
2. Study for soil structure integration is required.
3. Study of variation in the dimensions of floating column and its effects on the response parameters.
4. Study the variations of floating columns for Time History analysis in SAP2000.

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