Evaluation of ductility factor for structures subjected to long period of vibration

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Abstract-
The response modification factor (R) in IS1893 [5] is a significant parameter in the analysis of seismic design of structure by means of non-linear response of a structure. This paper enumerates on determining the actual values of R factor for RC special moment resisting frame by performing detailed non-linear static pushover analysis for various 2D framed structures of special moment resisting frames. A parametric study has been carried out by varying the time period up to 4 of the structure and zone factor and the corresponding R values are obtained, which primarily depends on three other factors. From the detailed analysis, a relationship between response reduction factor, Time period, Zone (Rµ-T-Z) has been proposed. The results show that the values of R, given in the codes are pessimistic and hence, an optimistic value shall be adopted based on the analytical results. As an application, the values arrived from the proposed relationship is then compared with the values obtained from the structures analyzed.

Keywords- Reduction factor, time period, pushover analysis.

1. INTRODUCTION:

The philosophy of seismic design for buildings are outlined in various codes such as IS 1893 [5], Euro Code 8 [7], ASCE 7 [6]. For earthquake design the non-linear response are taken for only selected components and elements. Still these codes do not exactly include the non-linear response of structure in the design methodology. These designs are performed on the basis of forced base analysis process instead of displacement-based analysis process. Since the previous days of seismic design, the equivalent static lateral force method is carried out for analysis by the structural engineers. Because this method is simple and easy to follow. Computational time required for analysis are also less.

During earthquake, large lateral and overturning force will occur in building. The earthquake force which is considered for building design are lesser than actual earthquake force. The building cannot be designed for actual earthquake force because the construction cost will be too high. The engineer’s main goal is to design a building that should be durable, safe and economical. To attain this goal, the engineer has to decrease the intensity of load acting on the structure. In the case of seismic design, the intensity is reduced by including the response reduction factor (R). In ASCE 7 this R is termed as response modification coefficient and in Euro Code 8 as behavior factor. These response reduction factors are indirectly report to the non-linear response of the structure.
For finding the lateral force acting on the structure, these codes include the response reduction factor. The objective of this paper is to estimate the seismic response reduction factor for the framed structure. By including the R factor in the design which shows that non-linear characteristics are included in it.

Andrew whittaker et al [1] deals with response reduction factor ‘R’ by splitting into three factors namely strength factor, ductility factor and redundancy factor and states that R obtained by the experiments are lower than R mentioned in NBC. Apurba Mondal et al [3] deals with response factor R of ductile RC frames and specifies that the factor prescribed in code (IS 1893) is potentially dangerous and leads to underestimation of design base shear of the structure.

2. DESCRIPTION OF SEISMIC RESPONSE REDUCTION FACTOR(R):

The force modification factor or response reduction factor $R$ shows the structure capacity to energy-dissipate through inelastic behavior. The expression of Response factor depends upon ductility, strength, damping and redundancy [1],

$$R = R_\mu R_s R_h R_\zeta$$

Where $R_\mu$ is ductility factor, $R_s$ is over-strength factor, $R_h$ is redundancy factor, $R_\zeta$ is damping factor.

$R_\mu$ was calculated by the ratio of base shear upon elastic response to ultimate base shear. In this study the Miranda et al [8] proposed an equation for $R_\mu-\mu-T$ relationship is used to define the ductility factor.

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

Where, $\mu = \frac{\Delta u}{\Delta y}$ and $\phi = 1 + \left(\frac{1}{12T - \mu T}\right) - \left(\frac{2}{5T} e^{\left[-2(\ln T - 0.2)\right]}\right)$

$$2 \leq \mu \leq 6$$

The ductility factor $\mu$ was calculated by the ratio of ultimate displacement ($\Delta u$) to yield displacement ($\Delta y$)

$R_s$ was calculated by the ratio of ultimate base shear to the design base shear, the equation is expressed as

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

From the idealized-bilinear pushover curve, the values of ultimate displacement ($\Delta u$), yield displacement($\Delta y$), ultimate base shear($V_u$) and design base shear($V_d$) are achieved. The American code (ASCE7) [6] suggests that the redundancy factor is to be taken as 1.0. Damping factor are considered as 1.0 [1], if there is no damping device are provided. The damping factor is an important one if any damping device is provided.
The Response reduction factor value changes corresponding to the factors mentioned above. But IS-1893 code suggests that the response reduction factor are not dependent on the height of the structure and different zones.

The roof displacement versus base shear force for the framed building is shown in fig 1. This relation is enhanced by push over analysis, represents the frames global response which is subjected to increasing lateral load. By using this relation for design, the main advantage is that the structure is to be idealized as single degree of freedom of system and provided a relation between displacement, deformation, force and energy dissipation for a framed building. One of the disadvantages is that there is no data given for the distribution of displacement over the frame height.

![Diagram of roof displacement vs base shear relationship](image)

Figure 1. Roof displacement vs Base shear relationship

Table 1- R values in different codes for Reinforced Concrete Structures.

| Code Description                                  | R Value |
|--------------------------------------------------|---------|
| American Standards (ASCE7)                       |         |
| Ordinary Moment Frame                            | 3.0     |
| Special Moment Frame                             | 8.0     |
| Eurocode (EC8)                                   |         |
| Medium Ductility Class                           | 3.90    |
| High Ductility Class                             | 5.85    |
| Indian Standards (IS 1893:2000)                  |         |
| Ordinary Moment Resisting Frame                  | 3.00    |
| Special Moment Resisting Frame                   | 5.00    |

3. **FINITE ELEMENT ANALYSIS**

The scope is to study the response of the structure for dynamic loads in addition to that of gravity loads. Dynamic loads are always unpredictable and large in magnitude that the structure loses its elasticity under dynamic loading. This loading deals with the analysis that is beyond the elastic capacity of the building and where the structure enters the state of plasticity. To get the response of the building under
dynamic loading, it is necessary to do pushover analysis. This gives the nonlinear response of the structure where the analysis is carried out for displacement-controlled load pattern. The displacement of the structure increases with loading once the structure crosses the elastic limit the plastic hinges starts appearing from the bottom floor and starts propagating to upwards to the roof. These plastic hinges restrict the moment rotation of the joints. Federal Emergency management Agency (FEMA) explains the characteristics of plastic hinges. For carrying out pushover analysis SAP 2000 software is used and the hinge characteristics, preloaded in the software are utilized. The different levels of effect of plastic hinges like immediate occupancy, life safety and collapse prevention were compared with of FEMA 356.

The study is carried out on four different regular symmetric structural systems namely G+18, G+24, G+30, G+36 which are planned as ordinary frames. The system has 3 bays which are of 15m in length in both the directions with each bay spanning 5m. The live load of 4kN/m2 [10] is assigned. The response spectrum analysis is carried out according to the provisions of IS 456-2000 [4] and IS 1893 [5]. For modelling and analysis, SAP 2000 software is used. The design base shear is calculated by using the relation

\[ V_d = \frac{ZIS}{2Rg} \times W \]

Where

\[ V_d = \text{design base shear} \]
\[ Z = \text{Zone factor as given in IS 1893 – clause 6.4.2. For the study, zone factors II, III, IV and V are considered for all four structural systems} \]
\[ R = \text{Response reduction factor (5)} \]
\[ I = \text{Importance factor. Special moment resisting frame SMRF (I=5.0) is adopted for the analysis} \]
\[ S_d/g = \text{average response acceleration effect} \]

The grade of concrete and steel adopted is M25 and Fe415 respectively.

The design base shear \( (V_d) \) is obtained by the relation. The dynamic base shear \( (V_b) \) is obtained by analysis and the factor \( V_b/V_d \) is multiplied with that of response factors.

IS 13920 [9] is used to achieve ductility of the frame since SMRF is adopted. The system is also designed in accordance with that of strong column-weak beam condition. The significance of this condition is safety of the structure. The dimensions of the structure is given to satisfy the strong column-weak beam condition and also economy is also not compromised.

**Table 2** Sectional dimensions after employing SCWB Theory

| Frame | Members | Dimension (m) |
|-------|---------|---------------|
| G+18  | B (G-6) | 0.5x0.55      |
|       | B (6-12)| 0.4x0.5       |
|       | B (12-18)| 0.35x0.4     |
|       | C (G-6) | 0.8x0.8       |
4. RESULTS AND DISCUSSIONS:

In each of the various two-dimensional structures modeled comprising of different storeys, the interior RC frame of these models are alone considered and a static push over analysis is carried out in these selected frame models. From the static push over curve obtained for various models the formulae prescribed by Miranda and et [8] all were used for the prediction of response reduction factor and the effect of time period and zone factor in response reduction factor is studied and an empirical relation is proposed between these parameters.

4.1 EFFECT OF ZONE FACTOR:

The base shear generated at each storey and the characteristics of ground motion differs for each zone factor, since the Zone factor sues with the severity of the seismic force generated at that particular

| Zone | Storey | Width | Height |
|------|--------|-------|--------|
| G+24 | C (6-12) | 0.75x0.75 |
|      | C (12-18) | 0.7x0.7 |
|      | B (G-6) | 0.45x0.5 |
|      | B (6-12) | 0.4x0.45 |
|      | B (12-18) | 0.35x0.4 |
|      | B (18-24) | 0.3x0.35 |
|      | C (G-6) | 0.9x0.9 |
|      | C (6-12) | 0.8x0.8 |
|      | C (18-12) | 0.65x0.65 |
|      | C (18-24) | 0.6x0.6 |
| G+30 | B (G-6) | 0.5x0.55 |
|      | B (6-12) | 0.45x0.5 |
|      | B (12-18) | 0.4x0.45 |
|      | B (18-24) | 0.35x0.4 |
|      | B (24-30) | 0.3x0.35 |
|      | C (G-6) | 1.2x1.2 |
|      | C (6-12) | 1.15x1.15 |
|      | C (12-18) | 1.1x1.1 |
|      | C (18-24) | 1.05x1.05 |
|      | C (24-30) | 1.0x1.0 |
| G+36 | B (G-6) | 0.55x0.6 |
|      | B (6-12) | 0.5x0.55 |
|      | B (12-18) | 0.45x0.5 |
|      | B (18-24) | 0.4x0.45 |
|      | B (24-30) | 0.35x0.4 |
|      | B (30-36) | 0.3x0.35 |
|      | C (G-6) | 1.4x1.4 |
|      | C (6-12) | 1.35x1.35 |
|      | C (12-18) | 1.3x1.3 |
|      | C (18-24) | 1.25x1.25 |
|      | C (24-30) | 1.2x1.2 |
|      | C (30-36) | 1.1x1.1 |
location. When the zone factor increases, the base shear or the force generated will be more and in turn the reduction factor decreases. On the other way, the behavior of the zone factor also varies with the time period of the structure, since the time period increases with the height or number of storeys of the structure. Since this paper deals with structures having long period of vibration, with time period ranging from 2.1 to 5.1, the values of $R_{\mu}$ decreases with increase in time period as well as the zone factor. Thus, the values of $R_{\mu}$ shows a declining fashion with zone factor and time period and hence a relation is proposed.

4.2 EFFECT OF TIME PERIOD:

The Indian code [4] on earthquake resistant design delivers an empirical equation to determine the fundamental time period of the structure based on its length and width. As it was discussed earlier, the time period of the structure increases with increase in height of the structure. From the analysis it was observed that the time period of the structure remains constant with change in zone factor and and the relation between ductility factor $R_{\mu}$ and time period is obtained. Since this paper deals with long period structures, it is observed that the ductility factor increases with time period and hence it is obvious that the time period and zone factor are directly proportional to each other.

Table 3 Estimated ductility factors for varying zone factor and time period

| Zone | Storey | Time Period (T in sec) | Ultimate displacement ($\Delta u$ in m) | Yield displacement ($\Delta y$ in m) | $\mu=\Delta u/\Delta y$ | $V_U$ | $V_D$ | $R_{\mu}$ | Rs |
|------|--------|-----------------------|--------------------------------------|-----------------------------------|------------------------|-------|-------|-----------|-----|
| II   | G+18   | 2.11                  | 0.359                                | 0.0587                            | 6.11                   | 596.61| 76.83 | 6.22      | 7.76|
|      | G+24   | 3.29                  | 0.557                                | 0.138                             | 4.03                   | 732.2 | 68.22 | 4.00      | 10.73|
|      | G+30   | 3.91                  | 0.669                                | 0.1518                            | 4.4                    | 1004.77| 97.91 | 4.32      | 10.26|
|      | G+36   | 5.13                  | 0.879                                | 0.2579                            | 3.69                   | 1045.37| 93.95 | 3.64      | 11.08|
| III  | G+18   | 2.11                  | 0.356                                | 0.0587                            | 6.06                   | 596.61| 122.90| 6.19      | 4.85|
|      | G+24   | 3.29                  | 0.562                                | 0.1380                            | 4.07                   | 732.32| 109.15| 4.00      | 6.7 |
|      | G+30   | 3.91                  | 0.669                                | 0.1518                            | 4.4                    | 1004.7 | 156.61| 4.32      | 6.41|
|      | G+36   | 5.13                  | 0.879                                | 0.2379                            | 3.69                   | 1037.28| 150.33| 3.64      | 6.89|
| IV   | G+18   | 2.11                  | 0.359                                | 0.0587                            | 6.11                   | 596.61| 183.1 | 6.24      | 3.25|
|      | G+24   | 3.29                  | 0.526                                | 0.138                            | 4.07                   | 729.66| 163.72| 4.04      | 4.45|
|      | G+30   | 3.91                  | 0.669                                | 0.1518                            | 4.4                    | 1000.67| 235.01| 4.32      | 4.25|
|      | G+36   | 5.13                  | 0.879                                | 0.2379                            | 3.69                   | 14041.32| 225.58| 3.64      | 4.61|
| V    | G+18   | 2.2                   | 0.359                                | 0.0587                            | 6.11                   | 596.61| 276.61| 6.18      | 2.15|
|      | G+24   | 3.29                  | 0.562                                | 0.138                            | 4.07                   | 732.2 | 245.6 | 4.41      | 2.98|
|      | G+30   | 3.91                  | 0.669                                | 0.151                            | 4.43                   | 1004.7 | 352.21| 4.54      | 2.85|
|      | G+36   | 5.13                  | 0.879                                | 0.2379                            | 3.69                   | 10045.7| 338.28| 3.67      | 3.08|
5. CONCLUSION:

To conclude, the objective of determining the relation between ductility factor and zone factor and time period is studied and the significance in their characteristics are obtained satisfactorily. The key results observed are:

(i) The zone factor and time period plays a vital role in the evaluation of the ductility factor of the structure.

(ii) As the zone factor increases the ductility factor decreases and shows a inversely proportional fashion.

(iii) With respect to time period, the $R_\mu$ value increases with it and a directly proportional relation was observed.

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