Research Article Impact Factor: 4.226 ISSN: 2319-507X
Abhijit P. Ghadi, IJPRET, 2015; Volume 3 (9): 98-108 IJPRET

INTERNATIONAL JOURNAL OF PURE AND APPLIED RESEARCH IN ENGINEERING AND TECHNOLOGY

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EVALUATION OF RESPONSE REDUCTION FACTOR FOR REINFORCED CONCRETE FRAME

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Accepted Date: 05/03/2015; Published Date: 01/05/2015

Abstract: Damage levels of building structures under a design earthquake are closely related to the assigned values of response reduction factors. In present study, response reduction factor, which permit estimation of inelastic strength of structure from elastic strength of structure, is evaluated. Values of this response reduction factor, proposed in many of the existing standards, are empirical in nature and are typically based on a general consensus of engineering judgments and the observed structural performance in past earthquakes. Various researchers stressed upon the need to establish a proper response reduction factor through an analytical approach, based on different parameters governing the structural performance level. In the investigation, nonlinear static analysis of analytical model of four story special moment resisting frame structure is conducted for local seismic conditions. From the analysis, response reduction factor and its different components are estimated.

Keywords: Response reduction factor; Structural performance level; Nonlinear static analysis; Special moment resisting frame.

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How to Cite This Article:

Abhijit P. Ghadi, IJPRET, 2015; Volume 3 (9): 98-108

PAPER-QR CODE

INTRODUCTION

In preliminary design process for earthquake resistant structure, the methods used are mainly forced based. The internal forces developed in structural members are evaluated by equivalent linear static methods. To incorporate nonlinearity, the use of response reduction factor is done which reduce the value of design base shear. The design base shear is evaluated by dividing the elastic base shear by response reduction factor. Many design codes used response reduction factor to get design base shear.

$$V_d = \frac{V_e}{R} = \frac{S_{a,5} \, x \, W}{R}$$

Where W is total weight of building and S_a is spectral acceleration corresponding to 5 percent damping. R is termed as "response reduction factor" in Indian standards, behavior factor in Eurocode EC8 [1] and "response modification factor" in ASCE7 [2]. The present study focused on component wise evaluation of response reduction factor. IS 1893:2002 [3] gives value of R factor as 5 for special moment resisting frame and 3 for ordinary moment resisting frame. These values are presented on past experiences and results through response reduction factor mainly depend upon over-strength, ductility, damping provided to structure etc. the present study provide a rational approach to evaluate response reduction factor for special moment resisting frame. Most of the research work has been carried out to determine the ductility level and component of response reduction factor of structure considering different local seismicity conditions. Some of the researchers have studied on various components of response reduction factor in detail.

DIFFERENT COMPONENTS OF RESPONSE REDUCTION FACTOR

Commonly the response reduction factor is expressed in terms of over-strength, ductility, redundancy and damping of structure. Mathematically it can be written as:

R= R = R_s*R_μ*R_ξ*R_R

Where R_s is strength factor, $R_\mu$is ductility factor, $R_\xi$is damping factor and R_R is redundancy factor.

The maximum lateral strength of building (V_u) will generally exceed the design lateral strength (V_d) of building because the members or elements are designed with capacities substantially greater than design actions and material strength also exceed specified nominal strengths. Thus the strength factor or over-strength factor is defined as ratio of ultimate base shear to design base shear.

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

The ductility factor (R_μ) is a measure of global nonlinear (whole structure) response of framing system and not the component of that system. It is measured as ratio of ultimate or maximum base shear to base shear corresponding to yield (Ve). Many studies have been carried out to calculate ductility factor of structure. Among these, work done by Newmark and Hall [4], Krawlinker and Nassar [5], T. Paulay [6] and M. J. N. Priestley [7] are significant. In present study, the relationship between R_μ and ductility level (μ) developed by T. Paulay and M. J. N. Priestley is used. As per T. Paulay and M. J. N. Priestley, the relationship is given by,

$R_\mu = 1 + (\mu - 1)\, T/0.70$

The redundancy factor, (R_R) is measure of redundancy in a lateral load resisting system. In RC structures, the moment resisting frames, shear walls or their combinations are the most preferred lateral load resisting systems. Sometimes, the central frames are only designed for gravity loads and the perimeter frames are designed as the lateral load resisting systems. Thus the redundancy in lateral load resisting systems depends on the structural system adopted. As per ASCE7 [1], the redundancy factor is taken as 1 when the structure consist of parallel frame system. Following this suggestion of ASCE7, for present study the value of redundancy factor is taken as 1. The damping factor (R_ξ) depends upon external damping provided to structure. For structure which is not provided with any external damping, it is taken as 1. In this study, there is no provision of external damping system is made. Thus, R_ξ is taken as 1. Different codes suggest different values for response reduction factor depending upon type of structural system, ductility class, damping etc. values of R specified in IS1893:2002, ASCE7, EC8 are given table 1-3 respectively.

Table 1.Values of R as per IS1893

Structural system	R
Ordinary moment resisting frame	3.0
Special moment resisting frame	5.0

Table 2.Values of R as per ASCE7

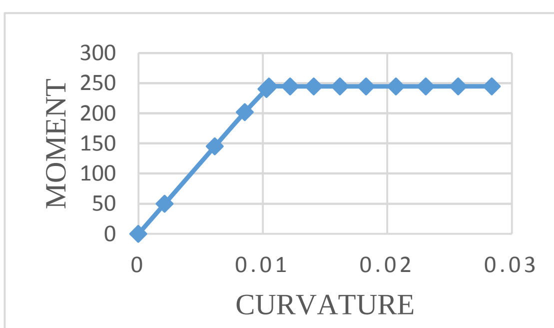
Structural system	R
Ordinary moment frame	3.0
Intermediate moment frame	5.0
Special moment frame	8.0

Table 3.Values of R as per EC8

Structural system	R
Medium ductility class(DCM)	$3.0V_u/V_y$=3.90
High ductility class(DCH)	$4.5V_u/V_y$=5.85

DESCRIPTION OF STRUCTURAL SYSTEM CONSIDERED

The structural system considered for present study is typical four story reinforced concrete structure intended for a regular office building in seismic zone III as per IS1893:2002. The seismic demands of structure is calculated as per IS1893:2002 and the design is done as per IS 456 [8] and IS 13920 [9]. The study building is assumed to be located in zone III. The floor to floor height of building is taken as 3.5m and depth of foundation is taken as 2m. Plan dimensions are taken as 25m x 25m with 5 m width of each bay. The typical elevation of building is given in figure 1.



The design base shear for building is calculated as per IS 1893 as follows:

$$V_d = \frac{Z \times I \times S_a}{2 \times R \times g} \times W$$

Where z is zone factor (0.16 for zone III), I is importance factor (1 for this building), R is response reduction factor (5 for SMRF) and W is seismic weight of building. Other parameters assumed for this study are given below.

Data assumed for four story building frame:

Type of structure: Special moment resisting frame.

Number of stories: 4.

Floor to floor height: 3.5m.

Infill wall: 230mm thick.

Imposed load: 4 KN/m^2.

Floor finish: 1.5 KN/m^2.

Materials: Concrete (M25) and Reinforcement (Fe415).

Type of soil: Medium.

Specific weight of concrete: 25 KN/m^3.

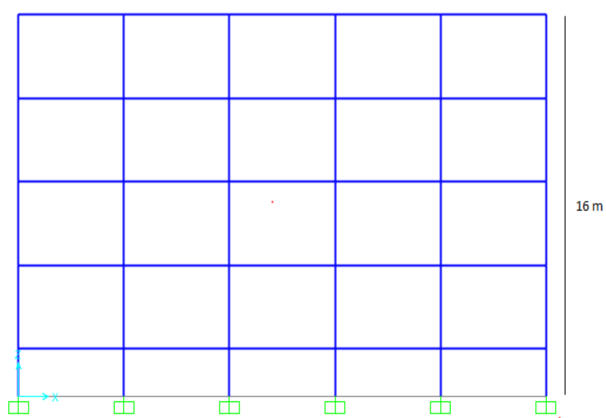
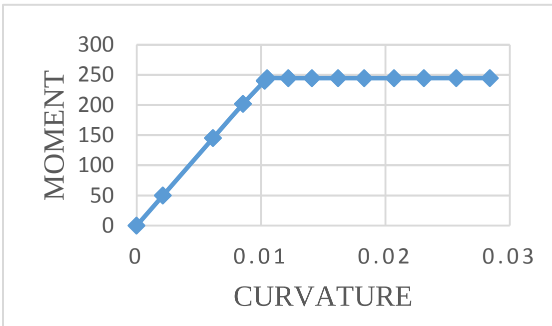


Figure 1. Typical Elevation of Building

MODELLING OF RC MEMBER

Estimation of R values of this frame depends significantly on how well the nonlinear behavior of these frames are represented in analysis. The nonlinear of frame depends primarily on moment rotation behavior of its member, which in turn depends upon moment curvature characteristics of plastic hinge section and length of plastic hinge. In addition two aspects, other important aspect.

1) Figure 2. Moment-curvature relationship for beam section

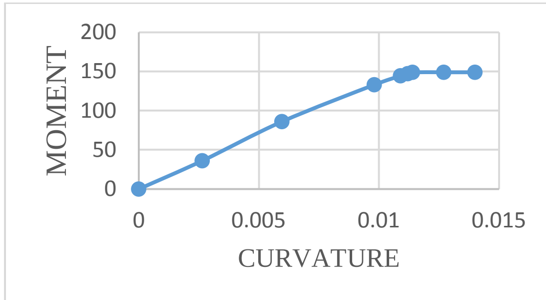


i.e. discuss in this section is the initial stiffness of member.

Moment-curvature relationship basically depends upon stress-strain characteristic of section. Stress-strain model for sections are developed using widely used modified Kent-Park [10] model with the help of MATLAB, which consider confinement effect of (closed) transverse reinforcements. Various other mathematical model for this that are frequently referred in literature are those proposed by Mander et al.[11], Baker and Amarakone [12], Roy and Sozen [13], Soliman and Yu [14], Sargin et al [15], Sheikh and Uzumari [16] and Sattcioglu and Razvi [17]. Moment curvature relationship for different section is then plotted using SAP 2000. Hinges are defined on basis of moment-curvatre relation and hinge length. Hinge lengths are evaluated using relation given by Priestley [6]:

$L_p = 0.08L+0.022\, f_y\, d_{bl}$

Where L_p is effective hinge length, L is the distance from the critical section to the point of contraflexure, f_y is yield strength of longitudinal bar having diameter d_{bl}. For moment resisting frame in which lateral forces, earthquake loads, are predominant, the point of contraflexure typically occurs close to mid span of a member. The moment-curvature characteristics for beam section andcolumn section is given in figure 2 and figure 3 respectively.



2) Figure 3. Moment-curvature relationship for column section Computed hinge lengths for sections are given in following table 4.

Table 4. Hinge length for frame members

Member	Section	Clear span(mm)	Hinge length(mm)
Beam	250 ×500	4500	408
Column	500 x 500	3000	310

NONLINEAR STATIC ANALYSIS

Analysis of frame has been done by using SAP 2000, which is a structural analysis program for static and dynamic analysis of structure. In present study, SAP nonlinear version 17 is used to perform pushover analysis. First, equivalent static analysis is performed to calculate design base shear. Pushover curve or capacity curve, plot between base shear vs displacement, is obtained from nonlinear analysis performed on frame under consideration. For nonlinear static analysis, displacement control strategy is used. Inter-story drift ratio is checked for different steps to get performance limits of frame. As per ATC-40 [18], the performance level for given frame is found to be immediate occupancy.

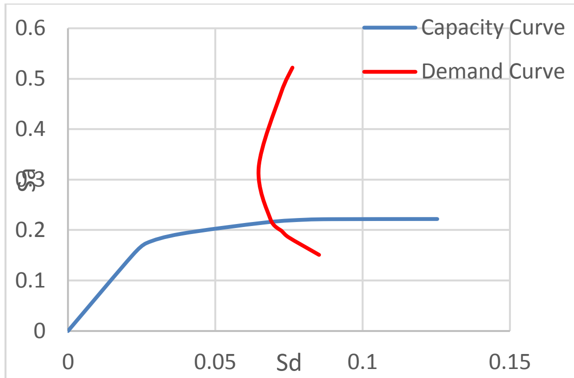


Figure 4. Plot of performance point

ESTIMATION OF RESPONSE REDUCTION FACTOR AND ITS COMPONENTS

As discussed earlier, response reduction factor mainly depends upon over-strength factor and ductility factor of structure. To estimate all these factors, we need ultimate base shear, elastic base shear, ductility level of structure and base shear corresponding to yielding. All these parameters can be evaluated from capacity curve which is given

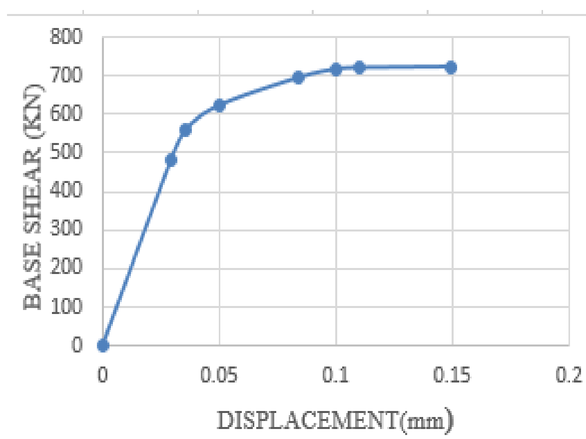


Figure 5. Capacity Curve

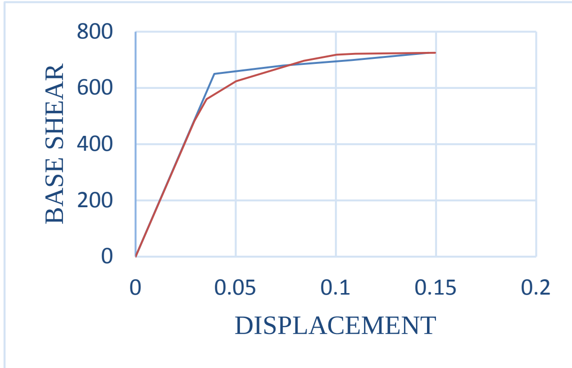


Figure 6. Bi-linearization of capacity curve

Figure 5 for the structural system under consideration. The bi-linearization of capacity curve can be done as per the procedure specified in ATC-40 [18] to obtain yield base shear and displacement. (Fig.6)

The output parameters from capacity curve are given in Table 5.

Table 5. Pushover parameters for present structure

Vd (KN)	Vu (KN)	Δy (m)	Δu (m)	μ
490	727	0.0394	0.1496	3.79

Evaluation of response reduction factor and its component and also comparison with value given in IS 1893:2002 is given in Table 6.

Table 6. Different components of R factor

R_s	R_μ	R_R	R	IS code (R)
1.48	3.71	1	5.49	5

CONCLUSION

Based on results and observations of present study, the following conclusion can be drawn.

1) The response reduction factor for present structural system considered is on higher side as compared to IS code value.

2) Based on performance limit of given structure (ATC-40, inter-story drift ratio), IS 1893:2002 over-estimate the value of design base shear for given structure.
3) The actual value of response reduction factor in real life is expected to be even less than what is computed here, because of various reasons, such as irregularity in dimensions leading to minor moderate torsional effects, lack of quality control, not following the ductile detailing requirements exactly as per the guidelines etc.

The conclusions of the present study are limited due to symmetry of plan configuration and also only one (zone III) seismic zone is considered

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