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Response Reduction Factor for Steel Frames

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Abstract— In last decades' steel structure has played an important role in construction Industry. It is necessary to design a structure to perform well under seismic loads. The seismic performance of a multi-story steel frame building is designed according to the provisions of the current Indian code (IS 800 -2007) and IS 1893: 2002. The objective of the present study in steel frames is that steel has ability to undergo seismic excitation. The R factors of these frames are evaluated from their nonlinear base shear versus roof displacement curves (pushover curves) The structure is analyzed in SAP2000 to check its adequacy compared to code recommended R value. In this study steel framing systems were investigated with regards to their lateral load carrying capacity and in this context seismic response modification factors of individual systems are analyzed. Numerous load resisting layouts, such as different bracing systems and un-braced moment resisting frames with various story configurations are designed and evaluated in a parametric fashion. Method of analysis, design and evaluation data are presented in detail. Previous studies in literature and the theory of response reduction factor is also presented.

Index Terms— response modification factors, steel frames, non-linear static analysis, seismic performance.

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1 Introduction

Structures which were designed and built according to the actual seismic codes were subjected to strong ground motions, exceeding the levels for which they were designed. Damage assessment during these events has enabled engineers to learn and improve the building code provisions and construction techniques for buildings located in regions of high seismic hazards

Hence a number of high and mid rise buildings were designed as steel moment resisting frames on primary lateral load resisting system. This type of construction was considered the safest one to be able to sustain large plastic deformation in bending and shear. In general, it can be stated that the behavior of steel buildings during such earthquakes was satisfactory. However, damage with local failures in the steel elements or in the beam-to-column joints was observed. This proves that steel structures are vulnerable to seismic excitation and the importance of improving design rules for buildings in seismic zones was evident. These rules should take into account the real structural behavior, the ductility demand under cyclic loading and damage due to the plastic deformation that should not exceed limits related to the local and global ductility of the structure. In general design criteria and structural systems are chosen on the basis of a specified level of reliability so that the structure will not be damaged beyond certain limits. Some recent seismic design codes are based on force-controlled design or capacity design. In order to develop simple design rules for steel structures in seismic zones it is important to characterize the behavior of steel members and beam-to-column joints under cyclic reversal loading, and to focus on the damage caused by plastic deformations and low cycle fatigue. Theoretically, when considered at a material level steel can develop a large ductility as obtainable by a tensile test but in practice, the global inelastic behavior of steel structures, local buckling and low-cycle fatigue influences both in the steel members and their connections.

2 Response reduction factor

During an earthquake when a building sways the distribution of damage over height depends on the distribution of lateral drift. Structural designers adopt the strong-column/weak-beam principle by requiring that the sum of column strengths exceed the sum of beam strengths at each beam-column connection.

The factor by which the actual base shear forces, generated when the structure remains elastic during its response to the Design Basis Earthquake (DBE) shaking, which shall be reduced to obtain the design lateral force is called the response reduction factor. This factor permits a designer to use a linear elastic force-based design while accounting for non-linear behavior and deformation limits:

$$R = Ve/Vd$$

The concept of response modification factor (R) was proposed based on the premise that well-detailed seismic framing systems could sustain large inelastic deformations without collapse and develop lateral strengths exceeding their design strength. The ground motion is unpredictable and irregular in direction, magnitude and duration. Therefore, past ground motion records serve as a starting point to form a basic understanding of characteristics of the excitation such as the displacements, velocities, and accelerations.

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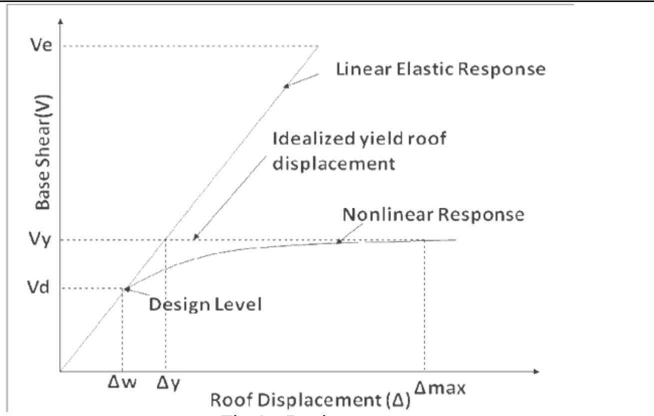

Fig 1 . Pushover curve

3 STRUCTURAL MODELLING AND ANALYSIS

The objective of the present study is to evaluate the response reduction factors for buildings designed and detailed as per IS code. The elastic forces are reduced by a response reduction factor to calculate the seismic design base shear. It is required to ensure that the designed building exhibit the adequate response reduction factors. The actual response reduction factors can be calculated using a pushover analysis, modelling the nonlinearity in the materials. This chapter discusses the nonlinear modelling, static push over analysis of the designed steel frames and the estimation of response reduction factors.

3.1 Building Configuration and Design details

Different types of steel framing systems are taken into consideration and subjected to analysis. Frame systems with their variations of 3, 6, 9 stories with 3 bays so as to keep the aspect ratio constant for all the models and in addition to these, 3 different bracing configuration are modeled. The variation of response reduction factors with variation in storeys and variations in bracing system is determined and compared with the codal provisions. The bracing systems used are - without brace and single bracing

The frames are assumed to be located in seismic zone II, the soil type chosen is medium and importance factor of 1.0 is assumed. The dead, live loads are calculated using IS 875 Part 1 (1987) and lateral loads are calculated as per IS 1893(2002).

In the present study, the grade of steel used is Fe 250. The live load is taken as 3.5kN/m^2 for floors and 1.5kN/m2 for roof. Here RC slab of M25 is provided and secondary beams of I section supporting them in order to serve the purpose of resisting the lateral earthquake load alone.

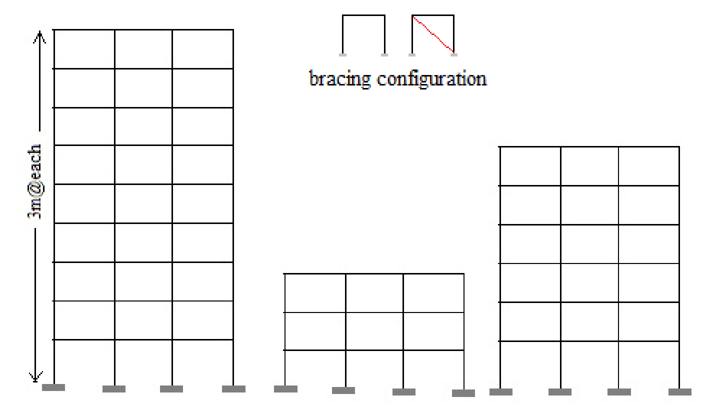

Fig 2. Building elevation details

TABLE 1
SECTION DETAILS

Section	Height h	Width b	Thickness t
Brace Tube 120	120mm	120mm	10mm
Brace Tube 140	140mm	140mm	10mm
Brace Tube 160	160mm	160mm	10mm
Beam IPE 330	330mm	160mm	7.5mm*11.5mm
Column HE 400A	390mm	300mm	11mm*19mm
Column 2 HE 450A	440mm	300mm	11.5mm*21mm

3.2 Pushover analysis

Pushover analysis is a static, nonlinear procedure done in order to analyses the seismic performance of a building where the computer model of the structure is laterally pushed until a specified displacement is attained or a collapse mechanism has occurred. The gravity load is kept as a constant during the analysis. The structure is pushed until sufficient hinges are formed such that a curve of base shear versus corresponding roof displacement can be developed and this curve known as pushover curve. The maximum base shear the structure can resist and its corresponding lateral drift can be found out from the Pushover curve. Pushover analysis performed is force controlled. In the force controlled pushover analysis type the force is given the approximate limit to run the program of pushover analysis it is kept constant or the increment of load is done up to that limit of force. This method is used only when the load to be applied is known i.e. (gravity load). It is essential to

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apply the dead and live loads (i.e. G+0,3Q) on the frame before we intend to push the frame using lateral load. We need, first, to set the GCSA (G+0,3Q) to Nonlinear so that the program can use this case as the starting point for the pushover.

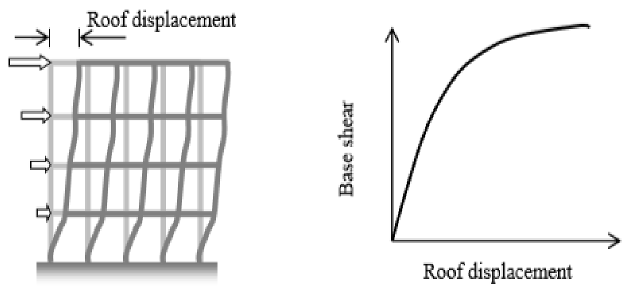


Fig 3 . Construction of Pushover curve

3.3 Equivalent Lateral Load Analysis

According to IS 1893: 2002, The total design lateral force or design seismic base shear (Vb) acting on the entire building along any principal direction shall be determined by the following expression: Vb = Ah * W ------------------ (1)

Ah = Design horizontal acceleration spectrum using the fundamental natural period T, and shall be determined by the following expression: Ah = (Z I Sa / 2 R g) ------------- (2)

Z= Zone factor, I = Importance factor, R = Response reduction factor, Sa/g = Average response acceleration coefficient T is the fundamental natural period for buildings. The total Seismic Weight of the structure, W, shall be calculated as the seismic weight of each floor which is its full dead load plus appropriate amount of imposed load. The seismic weight of the whole building is the sum of the seismic weights of all the floors.

The total design base shear Vb calculated shall be distributed along the height of building as per the following expression

$$Q_i = V_b . \{W_i.h_i^2 / \Sigma W_i.h_i^2\}$$

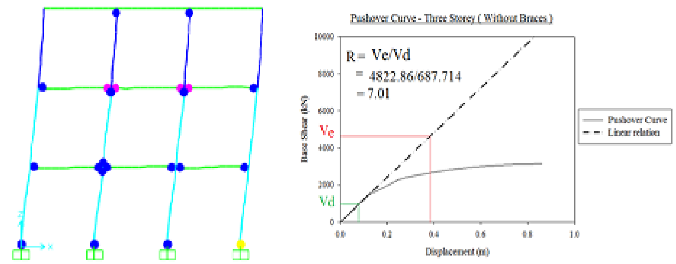
Qi = Design lateral force at i^{th} floor and h_i = height of ith floor from base.

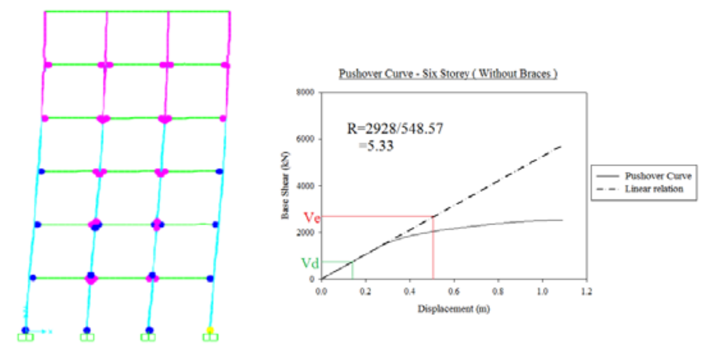
5 Results and Discussions

In this section, results of the analysis and evaluations of this study are tried to be summarized

5.1 Effect of number of stories on R value

In order to study the effect of number of storeys in the strength and displacement, capacity of frames considered.





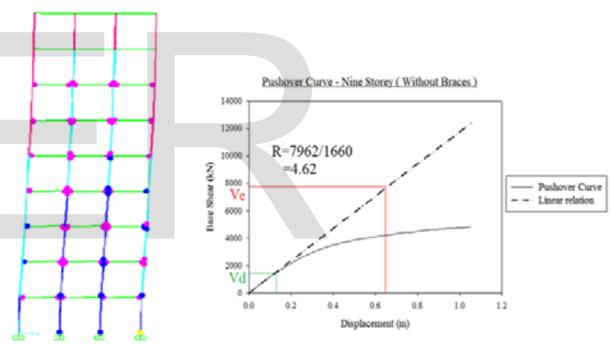
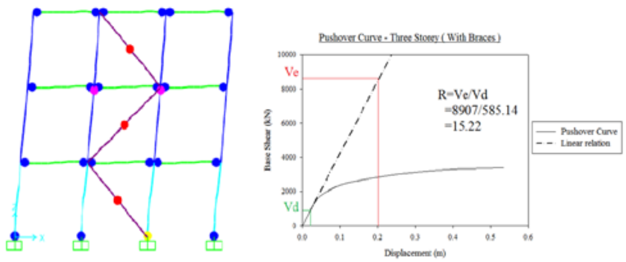


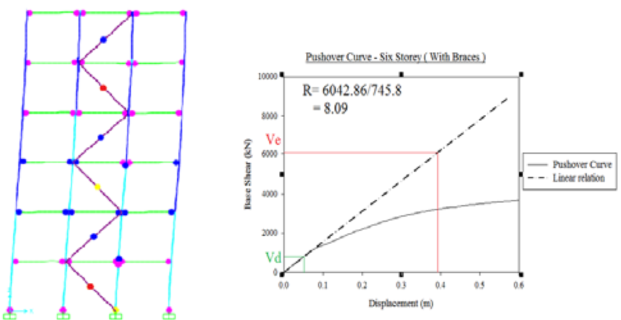
TABLE 2

Single brace	Disp u1	Ve KN	Vd KN	R=Ve/Vd
3storey	0.2228m	8907	585.143	15.2
6storey	0.3907m	6042.8	745.8	8.09
9storey	0.5803m	7932	1608	4.93

5.2 Effect of bracing on R value

In order to study the effect of changing bracing configuration





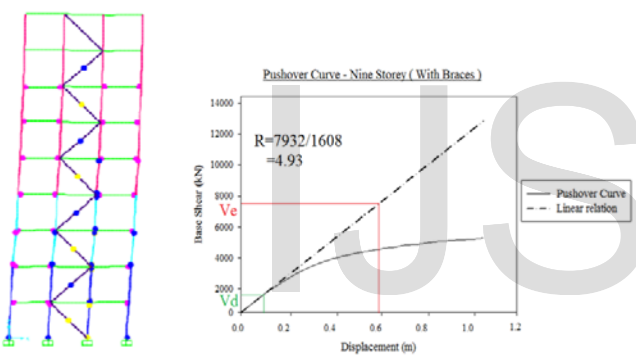


TABLE 3

No of storeys	Disp u1	Ve KN	Vd KN	R=Ve/Vd
3 story	0.3806m	4822.8	687.71	7.01
6 story	0.554m	2928	548.57	5.33
9 story	0.6511m	7962	1660	4.62

Based on this study, overall results of "R" factors obtained for most of the systems are considerably higher when compared to codal specified value of 4 for steel moment resisting frames

6 Summary of Results and Remarks

The objective of this study was to estimate the response reduction factors. For this a nonlinear Static Pushover Analysis was carried out for all the frames considered. The following are the conclusions of the study:

1. It is observed that as the number of storeys increases the R factor tends to decrease. The shorter frames exhibit higher R values compared to taller frames
2. With difference in bracing configuration, the structure is becoming further stiff and thus reduces lateral displacement.
3. Increasing the stiffness of the frame in general, whether due to changes in material or geometric properties, leads to an increase in the R factor value
4. Ductility of a moment-resisting steel frame is to some extent affected by its height. When bracing systems are included, the height dependency of ductility is greatly magnified.
5. The codal provision specify the R value as =4 for all type of steel frames which is not realistic. But in actual case, response reduction factor depends upon symmetry of plan, ductility of structure, over strength provided by materials and height of structure

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