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Response Reduction Factor for RC Buildings considering the Effects of Masonry Infill

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Abstract

The actual earthquake force is considerably higher than what the structures are designed for. The structure is allowed to be damaged in case of severe shaking. The structures are not designed for the actual value of earthquake intensity as the cost of construction will be too high for the events with lower probability of occurrence. Hence, structure is designed for seismic force much less than what is expected under strong shaking if the structure were to remain linearly elastic. This reduction is done by the help of factor called response reduction factor R which depends upon ductility factor, strength factor, structural redundancy and damping of the structure. This study is focused to find out ductility reduction factor, over strength factor and then to find response reduction factor R for various configurations of RC framed with infilled masonry structures by the non-linear static analysis. One of the major output of this study is the empirical formulation of the reduction factors based on different building parameters.

Keywords

Non-linear static analysis, Response reduction factor, Ductility Reduction Factor, Over-strength Factor

1. Introduction

The recent Gorkha earthquake of magnitude 7.8 in 25th April 2015 is one of the several great earthquakes by which Nepal faced extensive damage, loss of life and property. Severe shakings had come before and it certainly will continue in the future too. However, the structures are not designed for the actual value of earthquake intensity as the cost of construction will be too high. The well-detailed structure can sustain large inelastic deformations without collapse due to its ductile behaviour and develop lateral strength in excess of their design strength due to its reserved strength. This inelastic deformations may be utilized to absorb certain levels of energy leading to reduction in the forces for which structures are designed. The actual intensity of earthquake is reduced by a factor called response reduction factor R which is the important parameter that reflects the capability of structure to dissipate energy through inelastic behaviour. Response reduction factor is the parameter that is put forward to account for the structural redundancy, over-strength, ductility and damping but these all factors are not considered by many codes. Also from previous studies it can be seen that the response reduction factor for regular framed structures varies with the number of stories and bays. It depends upon various parameters such as column size, reinforcement, irregularity, loading, number of storey, etc. as it is sensitive to both geometric configuration and material strength. But the codes at present provide single value of response reduction factor depending upon type of structural system. Masonry infill also provides some added stiffness to the structures but still most of researches are based on RC structures with neglecting the impact of the infills on resisting the lateral forces. This study is focused on the evaluation of response reduction factor for regular RC- framed structures with masonry infill and also attempted to study its variation with the increase in the number of stories, number of bays and change in bay length with the use of static nonlinear pushover analysis.

2. Response Reduction Factor

The concept of response reduction factor is used by most of the seismic codes to account for the nonlinear response of the structure. R simply represents the ratio of the maximum lateral force which would

Response Reduction factor for RC buildings with considering the effects of Masonry Infill develop in a structure, responding entirely linear elastic under the specified ground motion, to the lateral force which has been designed to withstand. Over strength, redundancy and ductility together contribute to the fact that an earthquake resistant structure can be designed for much lower force than is implied by the strong shaking. Mathematically R is expressed as:

$$R = R_S \times R_\mu \times R_R \tag{1}$$

Where, R_s is the over strength factor, R_μ is the ductility factor and RR is the redundancy factor. The ductility reduction factor (R_μ) is a factor which reduces the elastic force demand to the level of idealized yield strength of the structure and, hence, it may be represented as the following equation:

$$R_\mu = \frac{V_e}{V_y} \tag{2}$$

V_e is the maximum base shear if the structure remains elastic and V_y is the maximum/ ultimate base shear considering an inelastic response. The overstrength factor (Rs) may be defined as the ratio of actual to the design lateral strength:

$$R_S = \frac{V_y}{V_d} \tag{3}$$

Where V_y is the base shear corresponding to the actual yielding of the structure and V_d is the code-prescribed unfactored design base shear. The value of redundancy factor RR may be taken as 0.86 for two-bay structures and 1 for three or higher bays than that as per ATC-19.

3. Methodology

Since the principle objective of our study is to calculate response reduction factor R of the masonry infilled RC-framed buildings, suitable models of different buildings are selected. The structural modeling of the buildings with various configurations is done with the help of the suitable finite element modeling software. After that, non-linear static pushover analysis of the model buildings are done to obtain the Pushover Curves. With the help of the Pushover Curve, ductility reduction factor, over strength factor are find out and then response reduction factor R is calculated. After that, the comparative study of R among different configuration of structures and the result interpretations are carried out reaching to some conclusions.

4. Structural Description and Material Properties

The regular reinforced concrete 3D framed structures with masonry infill are considered in this study. The buildings considered are the symmetric buildings having equal number of bays in both the horizontal directions. For the study of response reduction factor, the structural building is provided variations on the storey number, bay number and bay length. The study is limited to the 3 to 5 number of stories, 2 to 4 number of bays and the bay length is varied to 3.5m, 4m and 4.5m. Finite element analysis software SAP2000 v21 is used for the non-linear static analysis in this study.

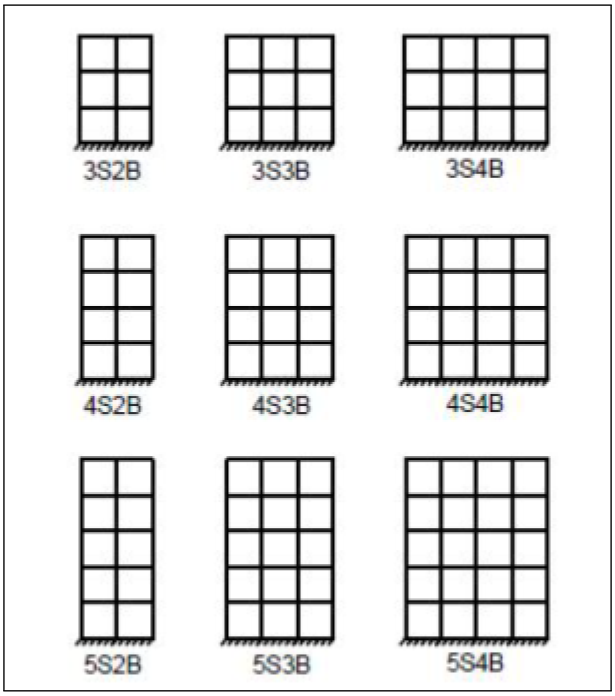

Figure 1: Typical Elevations of Building Models

The concrete grade of M25 is used with an elastic modulus of 25000 MPa according to IS456:2000. The concrete weight per unit volume is taken as 25 KN/m3 with Poisson's ratio of 0.2. Reinforcement bar HYSD500 TMT with elastic modulus of 200000 MPa is used for the structural design with Poisson's ratio as

0.3. Columns of square sections 400mm*400mm are taken and the beams of rectangular sections 300mm*350mm are taken for the design. Slab of thickness 125mm is taken. The masonry wall thickness is taken as 230mm with unit weight of 18.75 KN/m3, elastic modulus E of 4200 MPa and Poisson's ratio of 0.3.

5. Structural Modeling and Analysis

For the modelling of the structural buildings, Finite element analysis software SAP2000 v21 is used. Foundation is assumed to be rigid. Primary components beam, column and slab are modelled and in addition to this, infill walls are modeled as diagonal struts by using equivalent diagonal struts as per FEMA 356 Method. Effects of the staircase and openings are not considered. Secondary effects such as temperature, creep, shrinkage etc. are not considered to simplify the analysis process. The earthquake load is calculated for the building using seismic coefficient method as per IS 1893(Part I):2002. The load combination was chosen as per the recommendation of IS: 456-2000 and IS 1893(Part I):2000. Hinge is defined for column, beam and wall strut using default values for hinge properties. For column Auto P-M2-M3 hinges are defined which yields based on the interaction of axial force and bending moments at the hinge location, for beams Auto M3 hinge is defined and for wall strut Axial P hinge is defined.

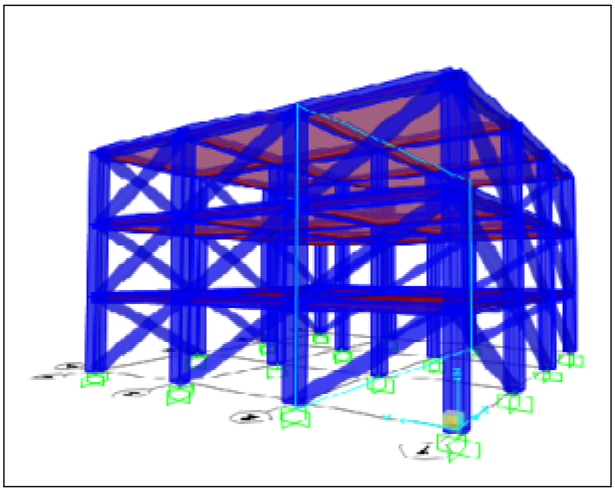

Figure 2: Finite Element Modeling of 3S3B building model

Analysis of building models are carried out by non-linear static pushover analysis using finite element analysis software SAP2000v21 in order to estimate the duc¬tility and over-strength factor of the required modelled buildings as they are the essential to compute the response reduction factor R for each model. The analysis based on the displacement controlled procedure is carried out to obtain the Pushover Curve.

6. Results and Discussion

For the calculation of the Response Reduction Factor of the structural building, pushover curve obtained from the SAP2000 is processed to get the values of yield base shear, yield displacement and maximum displacement by linear idealization. The variation of reduction factors with the variations on number of stories, number of bays and length of bays are studied to generate the results.

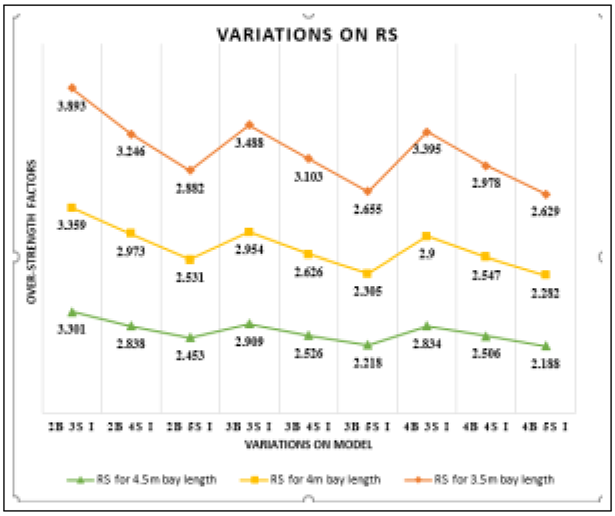

Figure 3: Variations on Over-strength Factor with different building configurations

The variation on over-strength factor can be seen with the variations on the number of stories, number of bays and the length of bays. As we go on increasing the number of stories, the over strength factor of the building goes decreasing. It may be due to the increase of the design base shear as the seismic weight of the building increases. As we go on increasing the number of bays, the over-strength factor of the buildings is again found to be decreasing. And as we go on increasing the length of the bays, it is again found to be on a decrease. This shows that the over-strength factor have the inverse relation with the number of stories, number of bays and the length of bays.

Similarly, the variation on ductility reduction factor also can be seen with the variations on the number of stories, number of bays and the length of bays. With the increase in the number of stories,the ductility reduction factor also goes on increasing. The increase in time-period with the building height may be responsible for it. With the increase in the number of bays, the ductility reduction factor is found to be decreasing which may be due to the increase in the stiffness of the building with the increase in bays. Also it is found that, as we go on increasing the length of the bays, the ductility reduction factor also goes on increasing.

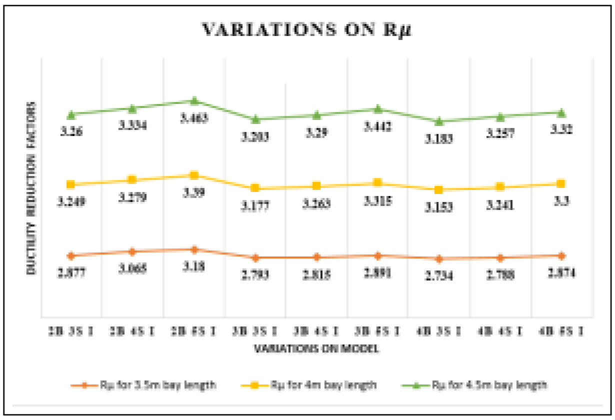

Figure 4: Variations on Ductility Reduction Factor with different building configurations

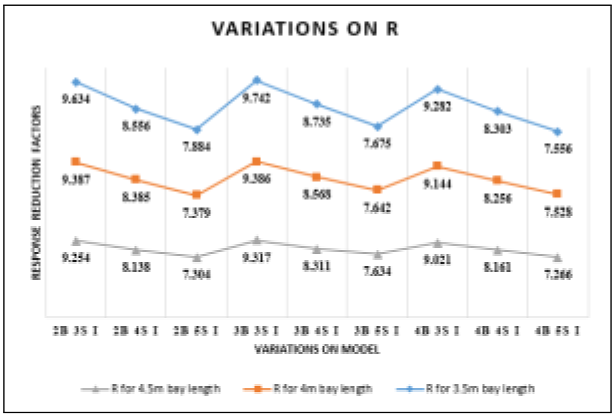

Figure 5: Variations on Response Reduction Factor with different building configurations

With the variation found on the over-strength factor and ductility reduction factor due to different building configurations, it is certain that there is also variation on the response reduction factor. From this study, it is found that the response reduction factor goes on decreasing with the increase on stories of the buildings.For the constant redundancy factor, response reduction factor may seem to be on decrease with the increase in bays, but redundancy factor increases with the increase in the bays. So, response reduction factor may be on the rise due to the effect of redundancy factor on the number of bays. And, with the increase in the length of bays,the value of response reduction factor is found to be decreasing. On varying the building configurations, we can find that there is the variation in the value of ductility reduction factor, over-strength factor and in the overall value of the response reduction factor. So, the development of a generalized empirical equation is attempted here to calculate the over-strength factor and the ductility reduction factor with the help of which the value of the response reduction factor for the building can be estimated. The ductility reduction factor is given as:

$$R_{\mu} = 1.258 - 0.069NB + 0.086 \times NS + 0.4148 \times LB \tag{4}$$

The over-strength factor is given as:

$$R_S = 6.797 - 0.177 \times NB - 0.429 \times NS - 0.419 \times LB \tag{5}$$

Here, NS denotes number of stories, NB denotes number of bays and LB denotes the length of bays in meter. To check for the validity of these equations, a random was analysed in the SAP2000 and the values obtained from the analysis and the values obtained from the proposed equations are compared which showed that the equations can closely predict the values of the reduction factors.

7. Conclusions

The study is done to evaluate the response reduction factor for the regular masonry infilled RC- framed buildings. The models are studied by allowing the variations on the configuration. Among many parameters, number of bays, length of bays and number of stories are chosen for the study. The study proposes the equations for over-strength and ductility reduction factor, which if not accurately, closely predicts the value for response reduction factor highlighting the fact that the single value of reduction factor can not justify the building for a given framing type.

The study shows that over strength factor of the buildings decreases with the increase in the number of stories, number of bays and the length of the bays in the building. Also, ductility reduction factor of the building increases with the increase in both number of stories and the length of bays but decreases with the increase in the number of bays. The variation in these values, with addition on the variation on the value of redundancy factor, varies the value of the response reduction factor with the different building configurations.

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