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Study the behaviors of buildings designed for various MCR values

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Abstract

A lot of research attention was devoted to earthquake safety of buildings in India after the massive January 26, 2001 Bhuj Earthquake. The earthquake ranks as one of the most destructive events recorded so far in India in terms of death of people, destroy or damage of infrastructure and devastation in the last fifty years. shows a damaged building in Buhj, Gujrat, India. Many of the failures of RC framed buildings in Bhuj Earthquake are attributed to the weak column strong beam joints. Weak beam-column joint is measured to be one of the possibly weaker components related to a structure when that structure is subjected to dynamic loading. A number of examples are there throughout the world that buildings are failing globally through weak beam-to-column joints. Such weak beam column joints failure pattern need to be given individual attention.

Keywords: *Earthquake, RC framed, Beam*

1. Introduction

Capacity design philosophy suggested by Paulay and Priestley (1992) is the basis of behind the strong column weak beam concept for the improvement of earthquake resistant design of structure [1]. In this philosophy, structural design is formulated on the stress resultants achieved from linear structural analysis subjected to inter- national code specified design lateral forces as well as equilibrium compatible stress resultants achieved from predetermined collapse mechanism. Damages at some in some predetermined structural members may allowed in the earthquake-resistant design philosophy in order to have a good global behaviour of the building. The flexural strengths of structural-members are determined on the basis of global response of the structure to earthquake forces. For this purpose, within a structural system the ductile components can be permitted to yield whereas the brittle components are not permitted to yield and should have sufficiently higher strength. The capacity design philosophy sets strength hierarchy first at the structural component level and then at the global structure level. In order to satisfy the strong column beam weak philosophy, the strength of column shall be more than strength of beam and it can be written as, Mc _ Mb (1.1)

Where, Mc and Mb are moment carrying capacities of column and beam meeting at a particular joint respectively. This strong-column / weak-beam design philosophy ensures good ductility and a desirable collapse mechanism in the building. For ensuring good global energy-dissipation with less degradation of capacity at that connections the failure mode where in the beams form hinges is usually considered to be the most favourable mode.

2. Research Gap and Motivation

In order to ensure a favorable failure mode, design codes recommend minimum value of Moment Capacity Ratio (MCR) which is defined as the ratio of summation of column moment capacity to summation of beam moment capacity at a particular beam-column joint. Mathematically the expression can be written as, Failure of several international code compliant building structure during previous earthquake by development of storey mechanism increases concern on the applicability of the code requirements. It shows the values of MCR by various codes and published literature, where is over strength factor for beams. Discrepancies among the major inter-national codes with regard to MCR can be seen from the table. Indian standard codes for design of RC framed buildings are silent on this aspect. Draft 13920 (2014) code suggests a value of MCR similar to other international codes without proper theoretical basis [3]. Hence a rational study is required on the values of MCR. This is the fundamental motivation of this present research. The MCR is defined as the ratio of cumulative column moment capacity to cumulative beam moment capacity framing to a particular joint. Although this appears to be a simple, procedure for calculation of column moment capacity is a matter of concern for the design office as it depends on the axial force level the column is subjected to. During cyclic earthquake loading column experience arange of axial force due to various combinations of load, and unlike beam, column does not have a unique moment capacity. That makes the calculation of MCR cumbersome.

3 Review of Literature

This chapter deals with the current state of the art in the capacity based design approach suggested by major international design codes along with published literature. It starts with a review of published literature followed by a review of appropriate international design codes of practice on capacity based design of RC framed structure. The present study uses pushover analysis and seismic performance assessment using SAC-FEMA method. The methodology of pushover analysis as well as seismic performance assessment using SAC-FEMA method are explained in this Chapter.

3.1 Capacity Based Design of RC Framed Structure

In recent earthquakes all over the world the behaviour of reinforced concrete moment resisting frame structures has highlighted the consequences of poor performance of beam column joints. A huge number of research has carried out to understand the complex mechanisms and safe behaviour of beam column joints. Sugano et al., (1988) showed analytical and experimental investigation on thirty-storey Reinforced Concrete framed building in Japan and developed design thought to ensure a better collapse mechanism as well as to observe the ductility of plastic hinges [4]. It was assured by analytical and experimental investigation that the designed structure would have sufficient margin of seismic capacity as well as seismic performance. Nakashima (2000) examined for steel building for ensuring column-elastic behavior by keeping the column over strength factor [5]. For ensuring column-elastic response, with increase in ground motion amplitude column over strength factor increases.

3.2 Review of Major International Codes

Some international codes suggest the expressions to prevent storey mechanism of collapse due to possible hinge formations in columns. This actually aims at attaining stronger columns with moment capacities more than those of beams framing into a particular joint considering safety margin.

American Standard: ACI 318M-2014 suggests that summation of moment capacities of column framing into a joint evaluated at the joint faces the minimum column moment considering factored axial loads along the direction of lateral forces resulting in, should be greater than or at least equal to 1.2 times the moment capacities of the beam framing into it [11].

$$\sum M_c \geq 1.2 \sum M_b$$

European Standard: EN1998-1:2003 recommends the relation between moment capacities of columns and moment capacity of beams for all joint can be written as,

$$\sum M_c \geq 1.3 \times \sum M_b$$

In this equation Mc is summation of the minimum moment capacities of the columns considering all design axial forces and Mb is summation of the moment capacities of the beams framing into the joint [12].

4. Objectives of Present Study

Based on the above discussions presented in the previous section, the primary objectives of the present study are as follows:

1. To study the behaviour of buildings designed for various MCR values
2. To develop a computationally simple procedure for calculating the nominal design strength of column to be used in determining MCR at a beam-column joint.
3. To reach at an appropriate and acceptable MCR for capacity design of RC framed building using reliability based approach.

5. Methodology

The methodology functioned out to attain the above-declared objectives are as follows:

a. To carry out detailed literature review on MCR at beam-column joint.
b. To select building geometries with different heights and base widths, analysis and design to conduct equivalent static analysis.
c. To study the behavior of buildings designed with various MCR
d. To find out the possible range of axial loading in the columns (with respect to its maximum axial load carrying capacity) and to develop a computationally

6. Development of Simplified Procedure for Estimating MCR

The present chapter presents a procedure for calculation MCR by using SP16. In order to have more accurate calculation of MCR values, strength of material approach is used and a MATLAB program is developed to calculate the exact MCR value at the particular axial load in the column. This program uses the constitutive relation of concrete and steel as per Indian Standard IS 456:2000. The range of axial force in the most practical situations are found out to find out the minimum governing moment capacity of a column. Two methods are discussed in this chapter, one using SP-16 and another using analytical method. The minimum moment capacitity required for the conservative estimation of MCR of a column is expressed in terms of the moment capacity of column at zero axial force.

Range of Normalized Axial Force in Buildings Four code designed building models (4-storey, 6-storey, 8-storey, and 10-storey) are analysed with equivalent static approach to find out the axial force range for all the load combinations as per IS 1893 (2002) of various columns of the buildings [29]. All the design parameters are taken as same as that of the frames considered. Table 1-3 and fig 1-4 shows the variation of axial force in each storeys in exterior and interior columns of four, six, eight and ten storeyed buildings respectively. P= maximum axial force carrying capacity of the column; Pmax and Pmin= maximum and minimum column axial force demand of the earthquake.

The maximum and minimum axial loads in the columns are normalized with respect to the maximum axial load capacity of the column. The range of normalized axial load ratio of selected exterior and interior columns are also shown in the tables.

The variation of normalized axial forces in the selected exterior and interior columns in each storey are plotted graphically in Figs. 1-4 for four, six, eight and ten storeyed frames respectively. The Tables 1 to 2 and Figs. 1 to 4 show that range of normalized axial forces that generally the building columns experience is in the range of 0.1 to 0.4.(for interior column)

Table 1: Column axial force for four-storey building

Storey Level	Exterior Column		Interior Column	
	$\eta_1 = P_{max}/P$	$\eta_2 = P_{min}/P$	$\eta_1 = P_{max}/P$	$\eta_2 = P_{min}/P$
G	0.124	0.052	0.245	0.109
1	0.089	0.036	0.176	0.077
2	0.064	0.025	0.127	0.053
3	0.023	0.006	0.046	0.015
Mean	0.06	0.025	0.151	0.065
St. Dev.	0.025	0.008	0.084	0.04

Table 2: Column axial force for six-storey building Minimum Moment Capacity Column - SP16 v/s Analytical Method

Storey Level	Exterior Column		Interior Column	
	$\eta_1 = P_{max}/P$	$\eta_2 = P_{min}/P$	$\eta_1 = P_{max}/P$	$\eta_2 = P_{min}/P$
G	0.18	0.073	0.343	0.157
1	0.148	0.06	0.281	0.128
2	0.135	0.054	0.255	0.114
3	0.097	0.039	0.183	0.081
4	0.064	0.024	0.12	0.05
5	0.024	0.006	0.044	0.014
Mean	0.116	0.046	0.219	0.097
St. Dev	0.058	0.024	0.11	0.053

Two blocks of an existing building hospital building (as shown in Fig. 1) in Jamshedpur, India are considered. It show the three dimensional and plan view of Block D and Figs. 2 show the three dimensional and plan view of Block A respectively. An equivalent static analysis is conducted to obtain the axial force ranges in arbitrarily selected column sections. The moment capacities for minimum and maximum axial forces are calculated to find out the Governing minimum moment capacities in all the columns. Table 3 show the calculated values of minimum moment ratio Mmin / Mp=0 for all the columns in block-D and block-A respectively using both for SP-16 method and Analytical method.

The factor, Mmin / Mp=0 obtained using SP-16 and analytical method are found to be in the range of 0.84 to 1.08. Therefore an Equation can be proposed to calculate the column Moment capacity, Mc in terms of moment capacity at zero axial force Mc,P=0 can be proposed as.

$$\sum M_c = 0.8 \times \sum M_{c,P=0}$$

Table 3: Result of existing building Block-D

Col Id	Size (BD) (mmmm)	Reinforcement	P_{max} (kN)	P_{min} (kN)	$\frac{M_{min}}{M_{p=0}}$ (Matlab Program)	$\frac{M_{min}}{M_{p=0}}$ (by SP16)	Variation in %
C-1	230x400	8 NOS 16φ	393.4	40.5	0.91	1.01	9.9
C-2	230x400	8 NOS 16φ	647.7	16.9	0.92	1.00	8.0
C-3	230x400	8 NOS 16φ	573.6	11.3	0.93	1.00	7.0
C-4	230x400	8 NOS 16φ	353.9	35.0	0.91	1.01	9.9

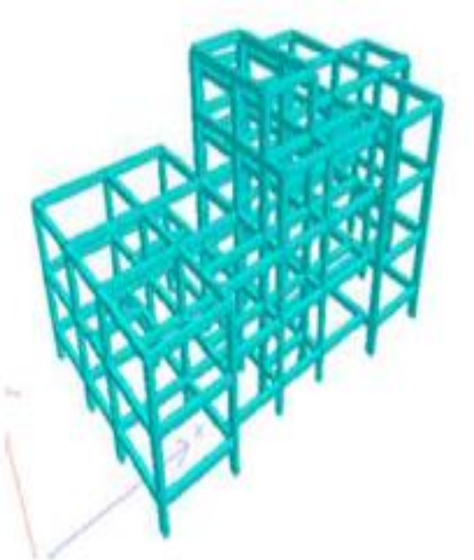

Figure 1: 3D view of Block-D, staff quarter Jamshedpur (G+2)

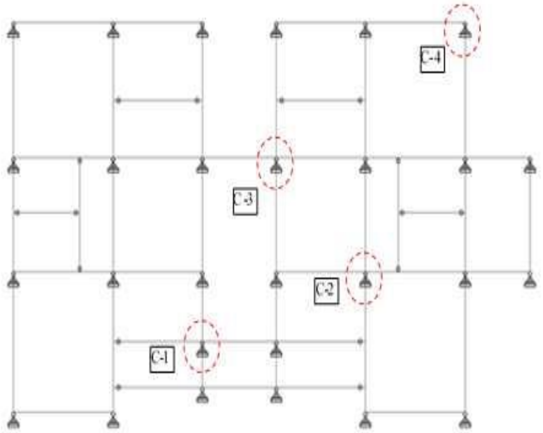

Figure 2: Plan view of Block-D, staff quarter Jamshedpur (G+2)

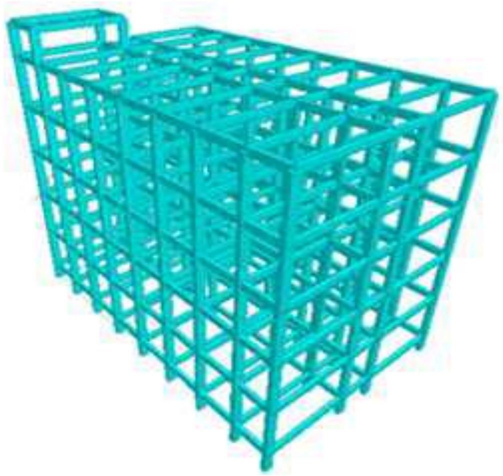

Figure 3: 3D view of Block-A, Jamshedpur Hospital Building (G+4)

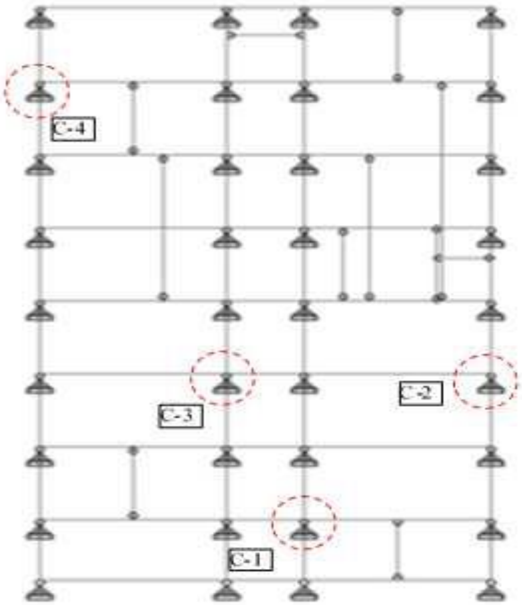

Figure 4: Plan view of Block-A, Jamshedpur Hospital Building (G+4)

7. Conclusions

1. Fragility analysis show that as the MCR value increases the probability of exceedance decreases proportionately. Reliability index of a building depends on MCR values.
2. As the MCR increases the reliability also increases. In order to obtain as estimate of minimum value of MCR required in a building, the achieved values of reliability is compared with the target values of reliability indices.
3. As the seismic zone increases the MCR value also shall be increased to achieve a target reliability. The minimum values of MCRs required for the four storeyed building to achieve the target reliability at CP level are 1.0, 1.2, 1.6 and 2.4 for seismic zones of II, III, IV and V. The minimum values of MCRs required to achieve the target reliability at SD level are 1.0, 1.0, 1.4 and 3.2 for seismic zones of II, III, IV and V. However, the building is failed to achieve the target reliability for IO level at seismic zone V.
4. The range of axial force in the typical building frames ranging from four to ten storey are found out. The range of axial force is found to be 0.1 0.4 for exterior column and 0.06-0.23 for interior column.
5. The values of minimum moment capacity for an existing building is calculated by both methods. The minimum moment carrying capacity can be conservatively determined to be about 0.8 times the moment capacity at zero axial force in a column.
6. Fragility analysis show that as the MCR value increases the probability of exceedance decreases proportionately. Reliability index of a building depends on MCR values. As the MCR increases the reliability also increases.

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