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# Effect of Moment Capacity Ratio at Beam-Column Joint on Ductility and Lateral Strength of RC Framed Building

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**ABSTRACT**
The design philosophy of "strong-column-weak-beam" demands good ductility and more desirable collapse mechanism in the structure. When only the flexural strength of longitudinal beams controls the overall response of a structure, RC beam-column connections shows ductile behavior. The failure mode where in the beams form hinges is usually considered to be the most favorable mode for ensuring good global energy-dissipation without much humiliation of capacity at the connections. Though many international codes recommend the moment capacity ratio at beam column joint to be more than one, but still there are lots of inconsistencies among these codes. So in the present work non-linear static analysis is being done using SAP 2000 for increasing moment capacity ratio at beam column joints and its effect on the global ductility and lateral strength of the structure is studied. As per ductility point of view evaluate MCR value for that structure. From the pushover curve it is observed that ductility and strength of the structure increases with increase of MCR at certain limit.
**Keywords -** Non-linear static analysis, moment capacity ratio, ductility, lateral strength, SAP 2000 etc.

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## I. INTRODUCTION

We know, earthquake is a global phenomenon. We cannot control and pre-predict earthquake forces. Past is witness to many devastation and destruction of structure due to beam-column joint failure due to earthquake. Practically we can't construct the structure earthquake proof, so there is the solution come in only one term and that is ductility. Make the structure enough ductile and forget about the forces come on it.

Capacity design procedure requires the total strength of column to be more than that of beam at a joint. Reason behind this is failure of a column leads to a global collapse mechanism. This design philosophy ensures better ductility and more desirable failure mechanism in the building [1]. Mathematically it can be expressed as, Mc>Mb. Where Mc and Mb are the moment capacities at the end of column and beam meeting at a joint respectively.

### 1.1 Moment Capacity Ratio

Moment capacity ratio (MCR) defined as the ratio of the summation of column moment capacities to the summation of beam moment capacities at a given beam- column joint in the considered direction of loading [2].

Moment capacity ratio (MCR) $= \frac{\sum Mnc}{\sum Mnb}$

Where Mnc= Flexural strength of columns framing into joint and Mnb = Moment capacities of beam framing it.

Column–beam flexural strength ratio is evidently an important variable for consideration in overall frame performance [3]. Many international design codes recommend that design flexural capacity of columns framing into the joint is greater than design flexural capacity of beam framing into it. According to some of these codes this ratio varies from 1 to 2.

**Table 1. Minimum MCR recommended by design codes and literature**

| Documents | MCR |
|---|---|
| Uma and Jain, 2006 [4] | 1.1 |
| ACI 318M-14 [5] | 1.2 |
| EN 1998-1:2004 [6] | 1.3 |
| NZS3101:1995 [7] | 1.4xΩ |
| IS 13920:2016 [8] | 1.4 |

### 1.2 Non-Linear Static Analysis

The pushover analysis of a structure is a non-linear static analysis under permanent vertical loads and gradually increasing lateral loads.

The equivalent static lateral loads approximately represent earthquake induced forces. A plot of the total base shear versus top displacement in a structure is obtained by this analysis that would indicate any untimely failure or weakness. The analysis is carried out up to failure, thus it enables determination of collapse load and ductility capacity [9]. In the present work the force deformation criteria for hinges developed by ATC 40 and FEMA have been used in pushover analysis.

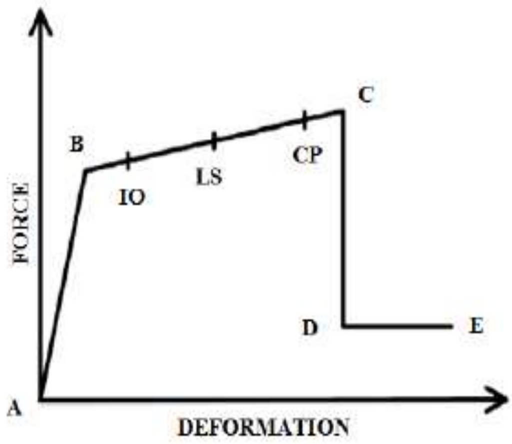


**Fig.1. Typical force-deformation curve showing performance levels. [10]**

The performance of the any building frame is combination of the performance of all its structural and non-structural components. The performance levels are discrete damage states identified from a continuous spectrum of possible damage states. The performance level based on the roof drifts are as Immediate Occupancy (IO), Life Safety (LS), Collapse Prevention (CP) [10].

## II. METHODOLOGY

- A RC framed building is designed using commercial software with V and IV seismic zones.
- Ultimate flexural capacity of beam (Mrb) is determined from the obtained data.
- Column reinforcement in the buildings is progressively increased to attain different moment capacity ratio (MCR) at beam column joint.
- Considering the beam and column reinforcement, the same building is modelled using SAP2000.
- Nonlinear static analysis is carried out by using SAP2000.
- Check the effect of various MCR on ductility and strength of RC framed structure.

## III. BUILDING DESIGN & MODELLING

The input data required for the design of these buildings are presented in Table 2 to 4.

**Table 2. General building and location details**

| | |
|---|---|
| Type of structure | Regular RC frame |
| Zone | V, VI |
| Soil type | Medium |
| Time period | Program calculated |
| Damping | 5% |
| Bay width | 4m |
| Storey height | 3m |
| Design philosophy | Limit State method as per IS 456:2000 |

**Table 3. Details of materials and section property**

| | |
|---|---|
| Beam for G+5 building | 230mm x 370mm |
| Beam for G+7 building | 230mm x 450mm |
| Column for G+5 building | 300mm x 450mm |
| Column for G+7 building | 300mm x 550mm |
| Concrete | fck = 25MPa<br>Poisons ratio=0.2<br>Density=25kN/mm$^2$<br>Modulus of elasticity= $5000\sqrt{fck}$ = 25000MPa |
| Steel | fy = 415MPa<br>Modulus of elasticity= $2x10^5$MPa |

**Table 4. Loading details for the design**

| | |
|---|---|
| Wall load | 13.8 kN/m |
| Live load | 2 kN/m |
| Floor finish | 1 kN/m |
| Equivalent lateral loads | As per IS 1893(part 1):2016 |

### 3.2 Modelling approach in SAP2000

From the design of building using commercial software ETABS, ultimate moment capacity of beam obtained from design results. By keeping the beam reinforcement fixed the column reinforcements are increased progressively and buildings are modelled using SAP2000 [11] and the hinge properties are defined and assigned as per FEMA 400 and ATC 40 guidelines [12].

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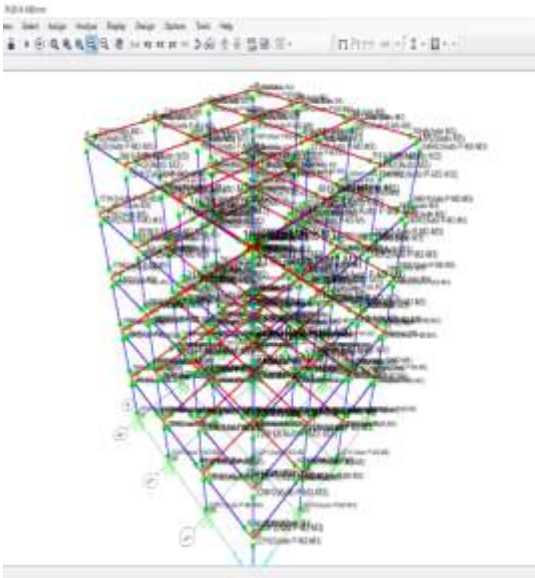

**Fig.2. Assigning hinges in SAP2000**

First gravity pushover is applied incrementally under force control for the combination of DL+0.25LL. Then lateral pushover is applied that starts after the end conditions of gravity push over under displacement control to achieve the target ultimate displacement or final collapse.

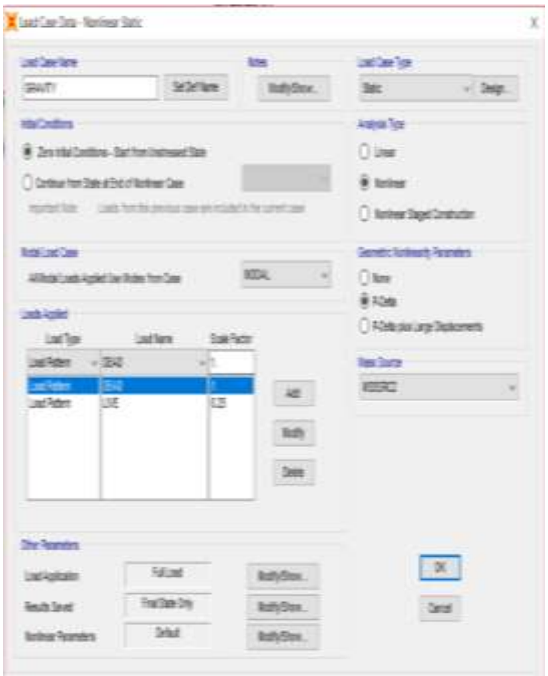

**Fig.3. Gravity pushover details**

In the model, beams and columns were modelled using frame elements, into which the hinges were inserted. Diaphragm action was assigned to the floor slabs to ensure integral lateral action of beams in each floor.

**Fig. 4. Lateral pushover details**

## IV. RESULT AND DISCUSSION

The main output of pushover analysis is pushover curve i.e. base shear versus roof displacement curve. This capacity curve is generally constructed to represent first mode response of the structure assuming that fundamental mode of vibration is predominant. The pushover curves for 5-storey and 7-storey framed buildings are shown in figs. From 5 to 8.

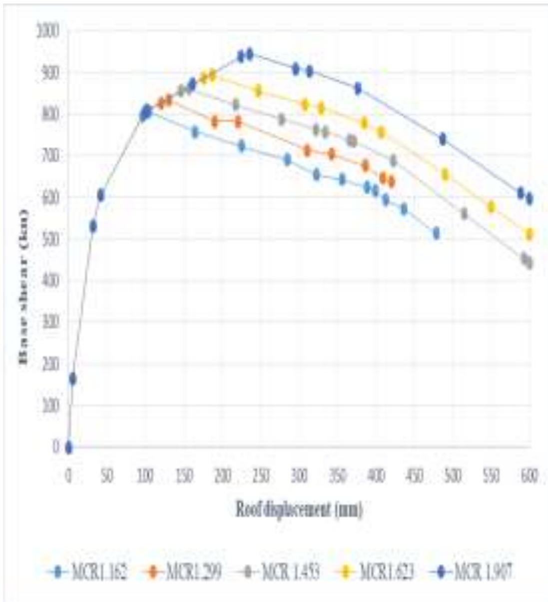


**Fig.5. Pushover curve for 5 storey building frame (zone V)**

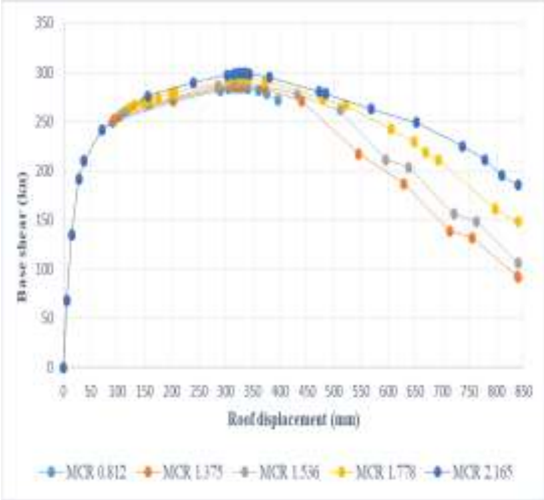


**Fig.6. Pushover curve for 7 storey building frame (zone V)**

These pushover curves show the base shear vs. roof displacement for a 5 storey and 7 storey building in seismic zone V and IV with different MCR values. The MCR values shown in the Fig.5 are taken from design axial load. Plastic hinge formation occurs in the inelastic range indicated by the nonlinear portion of the pushover curve. For MCR1.162 to MCR 1.299 the ultimate strength increases but ultimate displacement decreases may be because concrete is active in resisting moment or may be reinforcement detailing in the column. Then further increase of MCR from 1.453 to MCR 1.907 the ultimate strength increases with ultimate displacement upto target displacement.

Fig.6 shows the pushover curve for 7 storey building frame in seismic zone V. The curves are initially linear but start deviating as the beams and columns get into the inelastic range. For MCR 0.812 to MCR 2.165 the maximum strength increases but ultimate displacement is constant from MCR 1.375 as it achieve target displacement.

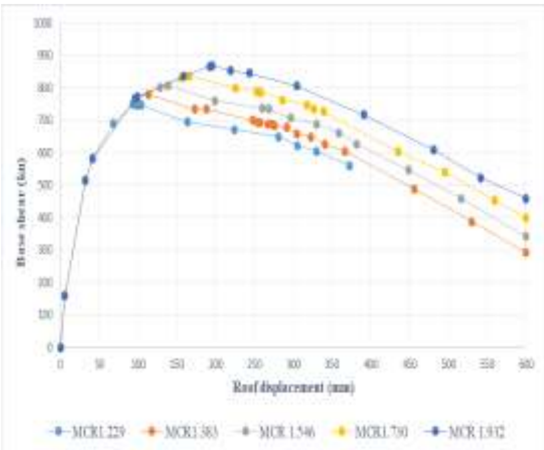

**Fig.7 Pushover curve for 5 storey building frame (zone IV)**

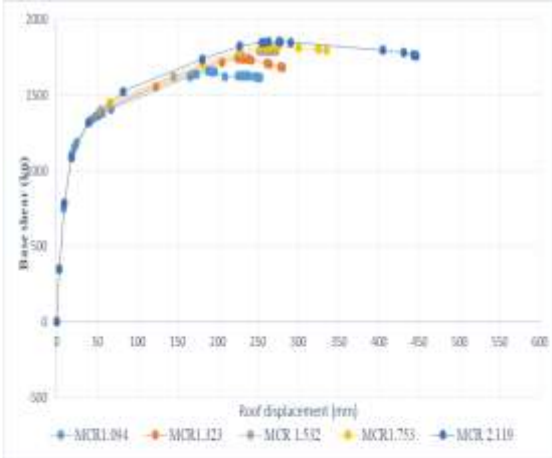

**Fig.8 Pushover curve for 7 storey building frame (zone IV)**

Fig.7 shows the pushover curve for 5 storey building frame in seismic zone IV. From MCR 1.383 to MCR 1.932 it achieve constant displacement. Strength of structure increases with increasing MCR upto MCR 1.932

Fig.8 shows the pushover curve for 7 storey building frame in seismic zone IV. When MCR increases from 1.094 to 2.119 then displacement and strength also increases but rate of increment of displacement get slightly down from MCR 1.532.

**Table 5. Ductility and strength studies for 5 storey building (zone V)**

| Area of Steel (%) | MCR | Yield disp. in mm | Ultimate disp. in mm | Max strength in kN | Ductility |
|---|---|---|---|---|---|
| 1.19 | 1.162 | 46.5 | 478.59 | 688.387 | 10.29 |
| 1.50 | 1.299 | 49 | 420.47 | 730.927 | 8.58 |
| 1.86 | 1.453 | 50 | 599.85 | 782.797 | 11.97 |
| 2.25 | 1.623 | 50 | 600 | 835.268 | 12 |
| 2.91 | 1.907 | 49 | 600 | 914.507 | 12.24 |

**Table 6. Ductility and strength studies for 7 storey building (zone V)**

| Area of Steel (%) | MCR | Yield disp. in mm | Ultimate disp. in mm | Max strength in kN | Ductility |
|---|---|---|---|---|---|
| 0.97 | 0.812 | 34.31 | 400 | 291.887 | 11.66 |
| 1.23 | 1.375 | 39.21 | 840 | 280.118 | 21.42 |
| 1.52 | 1.536 | 39.21 | 840 | 292.745 | 21.42 |
| 1.84 | 1.778 | 39.21 | 840 | 297.241 | 21.42 |
| 2.38 | 2.165 | 39.21 | 840 | 303.391 | 21.42 |

**Table 7. Ductility and strength studies for 5 storey building (zone IV)**

| Area of Steel (%) | MCR | Yield disp. in mm | Ultimate disp. in mm | Max strength in kN | Ductility |
|---|---|---|---|---|---|
| 0.91 | 1.229 | 46.07 | 372.46 | 638.114 | 8.08 |
| 1.19 | 1.383 | 50 | 600 | 675.031 | 12 |
| 1.50 | 1.546 | 50 | 600 | 710.469 | 12 |
| 1.86 | 1.730 | 50 | 600 | 760.469 | 12 |
| 2.25 | 1.932 | 50 | 600 | 812.567 | 12 |

**Table 8. Ductility and strength studies for 7 storey building (zone IV)**

| Area of Steel (%) | MCR | Yield disp. in mm | Ultimate disp. in mm | Max strength in kN | Ductility |
|---|---|---|---|---|---|
| 0.97 | 1.094 | 19.85 | 252.72 | 1661.647 | 12.73 |
| 1.23 | 1.323 | 19.85 | 280.57 | 1729.40 | 14.13 |
| 1.52 | 1.532 | 18.38 | 272.64 | 1843.947 | 14.83 |
| 1.84 | 1.753 | 21.5 | 334.58 | 1847.099 | 15.56 |
| 2.38 | 2.119 | 23.28 | 446.35 | 1873.456 | 19.17 |

### 4.1. Ductility as a function of MCR

From the idealized pushover curve yield point and maximum deformation point can be found out and displacement ductility of the structure is calculated. Displacement ductility is equal to ratio of maximum deformation to yield deformation.

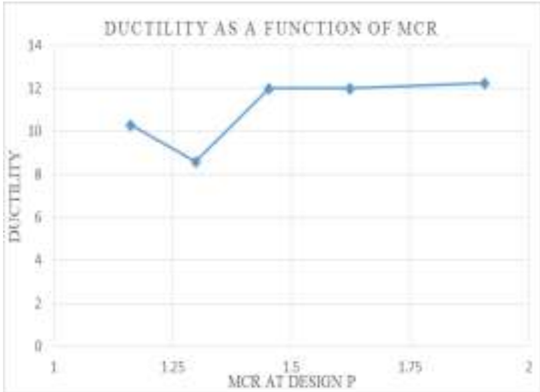


**Fig.9. G+5 zone V**

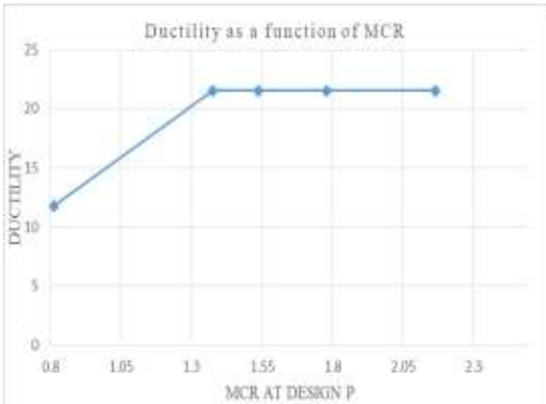


**Fig.10. G+7 zone V**

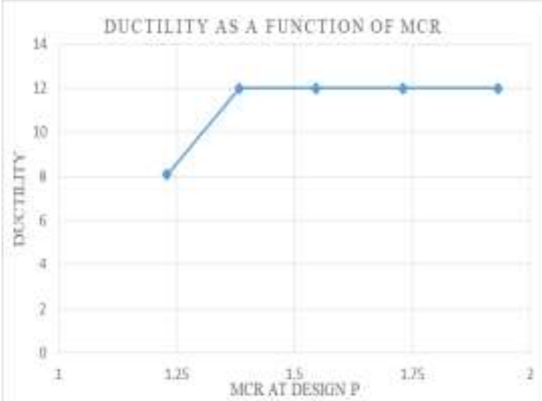


**Fig.11. G+5 zone IV**

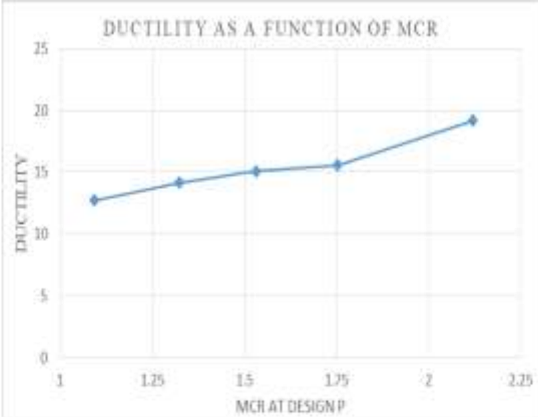


**Fig.12. G+7 zone IV**

### 4.2. Strength as a function of MCR

Maximum strength are also found out from the pushover curves.

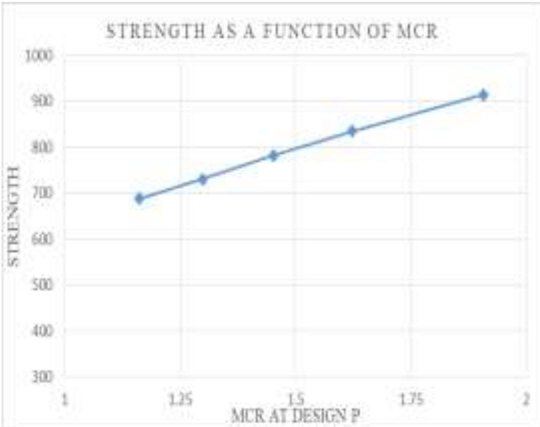


**Fig.13. G+5 zone V**

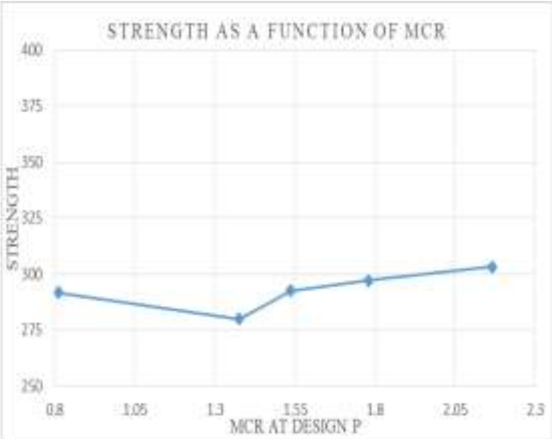


**Fig.14. G+7 zone V**

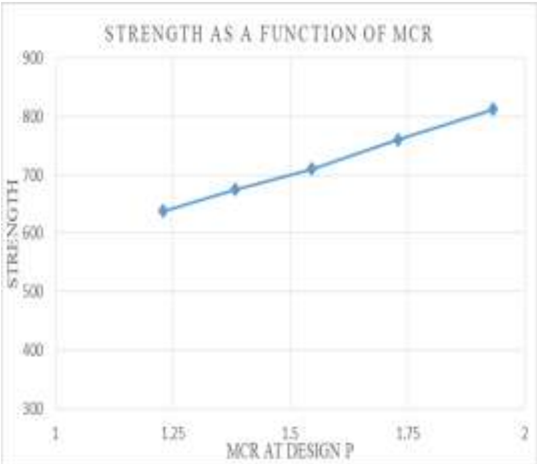


**Fig.15. G+5 zone IV**

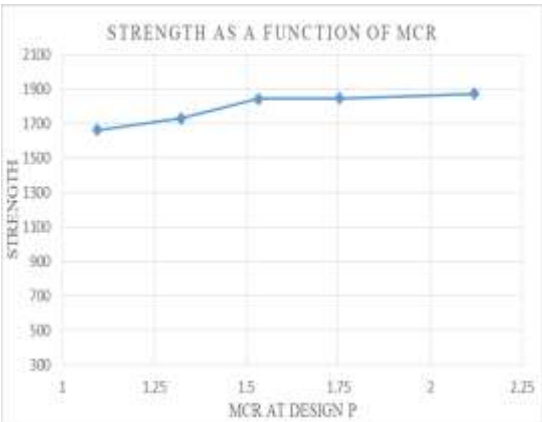


**Fig.16. G+7 zone IV**

## V. CONCLUSION

The effect of MCR on ductility and lateral strength of RC framed building was investigated using the pushover Analysis. The following conclusions can be drawn from the pushover analysis.

**1.** The pushover analysis is a relatively simple way to explore the non-linear behavior of buildings.

**2.** For 5 storey building (seismic zone V), ductility increases upto MCR 1.453. Later increase of MCR ductility remains constant but strength increases with increasing MCR.

**4.** For 7 storey building (seismic zone V), ductility increases upto MCR 1.375 further increase of MCR ductility remains constant.

**5.** For 5 storey building (seismic zone IV), ductility increases upto MCR 1.383 further increase of MCR ductility remains constant.

**6.** For 7 storey building (seismic zone IV), ductility increases upto MCR 1.323 further increase of MCR the rate of increment of ductility and strength is decreases. But strength increase with increasing MCR.

**7.** As a ductility point of view it is concluded that design a building at least MCR 1.4 for 5 storey and 7 storey building in seismic zone V and MCR 1.35 in seismic zone IV.

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