DESIGN OF RC FRAMED BUILDING CONSIDERING MCRs RECOMMENDED IN VARIOUS INTERNATIONAL CODES

A thesis

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By

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CERTIFICATE

This is to certify that the thesis entitled "**Design of RC Framed Building considering MCRs recommended in various international codes**" submitted by **Avula Ravi Teja Reddy**in partial fulfilment of the requirement for the award of **Bachelor of Technology** degree in **Civil Engineering** to the National Institute of Technology, Rourkela is an authentic record of research work carried out by him under my supervision. The contents of this thesis have not been submitted in full or in parts, to any other Institute or University for the award of any other degree elsewhere to the best of my knowledge.

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ABSTRACT

Under seismic loading the structural systems that should be designed to ensure proper energy dissipation capacity are Reinforced concrete moment resisting frames (RCMRF). “Strong-column - weak-beam” design is currently in practice, demands to have collapse mechanism in the structure. RC column-beam connections display ductile behaviour,when the response of a structure is controlled by the flexural strength of beams. The failure mode where the beams forms hinges is considered as most recommended mode for guaranteeing good global energy-dissipation without much degradation of capacity at the connections. In spite of the fact that numerous universal codes prescribe the moment capacity ratio at beam column joint to be more than one, still there are many errors among these codes and Indian standard is quiet on this viewpoint.

The objective of this project work is to compare the design and resulting performances of framed building for various MCRs recommended in international codes and its effect on design (BOQ). In the present work using SAP 2000, pushover analysis is done for increasing moment capacity ratio at column beam joints and the effect on design (BOQ) and the resulting performances of the building are studied.

Keywords: pushover, moment capacity ratio, BOQ, RCMR

CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

RC Frame	Reinforced Concrete Frame
IS	Indian Standard
MCR	Moment capacity Ratio
ACI	American concrete Institute
SCWB	strong column weak beam
NZS	New Zealand standard
PA	Pushover analysis

CHAPTER 1

INTRODUCTION

1.1 GENERAL

The global phenomenon which occurs frequently and is no more considered as an act of God is Earthquake.In an earthquake, motion of the ground is in both horizontally and vertically directions. This causes thevibrations in the structure and inertial forces are induced in them. Analysis of damages incurred in moment resisting RC framed structures which are subjected to the earthquake in the past, show that the failure is mostly due to the usage of concrete not having sufficient resistance, improper anchorage,soft storey, column failure causing storey mechanism. When a structure is subjected to seismic loading, column-beam connection is considered as the potentially weaker components. Figures of some of the column collapses and columnbeam joint failure in the past earthquakes are shown in Fig. 1. So, rectificationof the failure in column and jointis needed.

(a) **(b)**

(c) **(d)**

Fig.1.1:Buildings failure due to storey mechanism: (a) & (b) shows buildings which failed due to column storey mechanism during past Earthquake,(c) & (d) shows building which due to beam column joint during past Earthquakes

1.2 STRONG COLUMN WEAK BEAM DESIGN CONCEPT (SCWB)

The project will be uneconomical if a building is designed to behave elastically during an earthquake without being damaged.So the philosophy of earthquake-resistant design allows damages in some predetermined structural components. Capacity design procedure sets strength hierarchy first at the member level and then at the structure level. So, it is necessary to adjust column strength to be more than the beams framing into it at a joint. Mathematically it can be expressed as

$$M_{n,c} \geq M_{n,b}$$

Where $M_{n,c}$ and $M_{n,b}$ are moment capacities of column and beam at a joint respectively.

1.3 CAPACITY DESIGN CONCEPT

The design process is based on two parameters one is the stress resultants which is obtained from linear structural analysis that is subjected to code specified design lateral forces and the second is equilibrium compatible stress resultants which is obtained from pre-determined collapse mechanism. Basedon the overall structural response of a structure to earthquake forces, the flexural capacities of members are determined. For this purpose, within a structural system the objects which can be permitted to yield before failure otherwise known as ductile components and the objects which will remain elastic and will collapse immediately without warning known as brittle components are chosen. After deciding the brittle and ductile systems, the design procedure proceeds asfollows:

- The design of ductile components should be performed with sufficient deformation capacity necessary to havegood energy dissipationso as to satisfy displacement-based demand-capacity ratio.
- The design of brittle components should be performedin order to achieve sufficient strength levels at least to satisfy strength-based demand-capacity ratio.

This process primarily aims at setting the strength hierarchy at member level. So thedesign of the beam should have shear capacity more than the limiting equilibriumcompatible shear that arises at the two ends because of under-reinforced flexural action.

1.4 OBJECTIVE OF STUDY

The main objectives of the present research are as follows:

- To compare the design and resulting performances of framed building for various MCRs recommended in international codes.
- Effect of different MCR on the design (BOQ) and the resulting performances are to be studied.

1.5 SCOPE OF STUDY

The scope of present research work is as follows:

- RC building frame is selected. Vertical and plan irregularity of the building is kept out of the scope of present study.
- Three building variant is designed considering the MCR recommended in ACI 318M-02, NZS3101:1995 and EN1998-1:2003.
- Design of all the three buildings are done against earthquake loading in combination with gravity loading as per IS1893:2002.
- All the column ends are fixed.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

Literature review in the present study is discussed on reviews of various international codes on moment capacity ratio at column-beam joint and an overview on the pushover analysis of multi-storied RC building fame.

Hatzigeorgiou(2009) observed the mathematical relation shown in equation (2.1a), which represents the relation between moment capacities of beamsand columns.

$$\Sigma M_{n,c} \geq 1.3\ \Sigma M_{n,b} \qquad \text{(2.1a)}$$

Jain *et. al.*, (2006) observed the mathematical relation shown in equation (2.1b), which represents the relation between moment capacities of beamsand columns

$$\Sigma M_{n,c} \geq 1.1\ \Sigma M_{n,b} \qquad \text{(2.1b)}$$

Sugano *et. al*.,(1988) developed design consideration to ensure good collapse mechanism and also observed the ductility of plastic hinges by conducting experiments on 30-storey RC framed building in Japan.

2.2 REVIEW OF CODES

Some international codes suggest expressions to prevent storey mechanism of collapse due to possible damage locations (hinge formations) in columns.

2.2.1 American Standard

ACI 318M-02suggests the mathematical relation shown in equation (2.2a), which represents the relation between moment capacities of beamsand columns.

$$\sum M_{n,c} \geq 1.2 \times \sum M_{n,b} \quad \text{...} \quad (2.2a)$$

In equation (2.2a), *Mn,c* and *Mn,b* represent moment capacities of columns and beams framing into a joint, calculated at joint face.

2.2.2New Zealand Standard

New Zealand Standard (NZS3101:1995) recommends the mathematical relation shown in equation (2.2b), which represents the relation between moment capacities of beamsand columns

$$\sum M_{n,c} \geq 1.4 \times \sum \Omega \times M_{n,b} \text{..} \quad (2.2b)$$

In equation (2.2b) Ω is over strength factor for beams. The over strength of steel reinforcement is considered as 1.25 and strength reduction factor is taken as 0.85. So the total over strength factor considered for beams is 1.47.

2.2.3 European Standard

EN1998-1:2003 recommends the mathematical relation shown in equation (2.2c), which represents the relation between moment capacities of beamsand columns:

$$\sum M_{n,c} \geq 1.3 \times \sum M_{n,b} \quad \text{...} \quad (2.2c)$$

2.2.4 Indian Standard

IS 1893 Part-I: 2002, this code does not suggests any numerical value of moment capacity ratio required for design of a building as specified by other international codes, but other Indian codes such as IS13920-draft (2014), IS 800:2007 (Steel) suggests some numerical value for the MCR.

IS13920-draft (2014), suggeststhe mathematical relation shown in equation (2.2d), which represents the relation between moment capacities of beamsand columns. The design moment of resistances of beam shall be calculated as per the IS 456:2000.

$$\sum M_{n,c} \geq 1.4 \times \sum M_{n,b} \quad \text{.. (2.2d)}$$

IS 800:2007 (Steel), recommends the mathematical relation shown in equation (2.2e), which represents the relation between moment capacities of beamsand columns:

$$\sum M_{n,c} \geq 1.2 \times \sum M_{n,b} \quad \text{.. (2.2e).}$$

2.3 SUMMARY

From different standard codes available in the world, the relation between the Moment capacities of column and beam for seismic analysis is given below.

$$\sum M_c \geq \eta \times \sum M_b$$

Where, M_c = Moment capacity of column

M_b = Moment capacity of beam

η = Multiplying factor or column over strength factor

- ACI 318M-02→η = 1.2
- IS 800:2007 →η = 1.2 (Steel)
- EN1998-1:2003→η = 1.3
- IS 13920-draft (2014) →η = 1.4
- NZS3101:1995→η = 1.4×Ω (Ω=over strength factor=1.47)
- IS 1893 Part-I: 2002→η=?

CHAPTER 3

PROBLEM STATEMENT

Analyse a four storied RC building plane frame and then compare the design and resulting performance of the building considering different MCR values from various international codes. Brick infill of width 230mm is also considered.

Given

- Number of stories : 4 (each of height 3.2m)
- Number of bays : 4 (each of width 5m)
- Floor weight : 3.75 kN/m^2
- Live load : 3 kN/m^2

The seismic parameters of building site are as follows

- Seismic zone: 5
- Zone factor (Z): 0.36
- Response reduction factor: 3
- Importance factor: 1
- Damping ratio: 5%

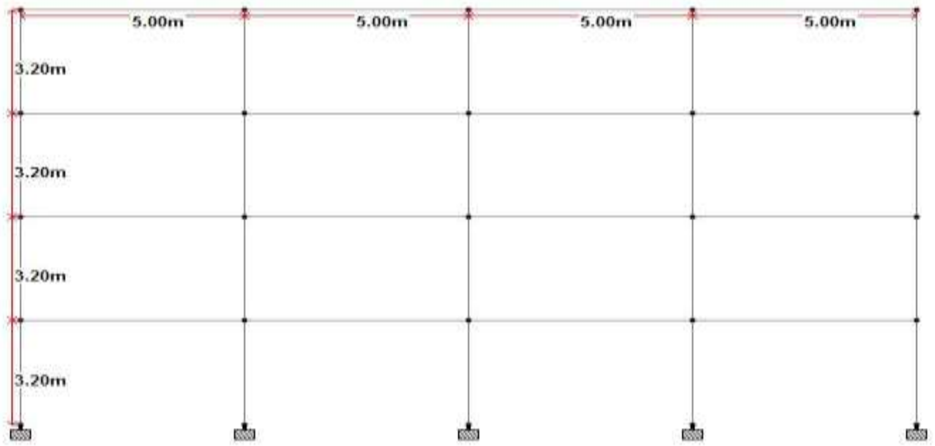


Fig.3.1 Elevation of the building frame (Front view)

CHAPTER 4

METHODOLOGY

The following are the steps to be followed while doing the project:

- 4 storeyed RC building (plane frame) is analysed and designed using STAAD-Pro.
- Ultimate moment capacity of beam (*Mbu*) is determined from the design data obtained from STAAD-Pro.
- Column reinforcement in the building is progressively increased keeping the beam reinforcement constant to obtain different column to beam moment capacity ratio(MCR).
- The beam and column reinforcement is considered and the same building is modelled usingSAP2000 and nonlinear static analysis is performed.

4.1 BUILDING DESIGN AND MODELLING

The buildings were designed using STAAD-Pro. The input data required for the design of these buildings are presented in Table 4.1 (a-c).

Table 4.1(a) Building and location details

Structure	4 storey RC building frame
Type of soil	Medium soil
Zone	V
Damping	5%
Storey height	3.2m
Bay width	5m
Design philosophy	Limit state method confirming to IS 456:2000

Table 4.1(b) Materials and section property details

Beam	450mm × 550mm
Column	500mm × 550mm
Concrete	f_{ck}= 25 MPa Density = 25 kN/mm3 Poisons ratio = ν =0.3 E_c = 5000 $\sqrt{f_{ck}}$ =27390 MPa
Steel	f_y= 415 MPa E_s = 2 $\times 10^5$MPa

Table 4.1(c) Details of loading for the design

Dead load(DL)	3.75 kN/m^2
Live load(LL)	3 kN/m^2
Equivalent lateral loads	as per IS 1893 (Part I):2002

4.2 PUSHOVER ANALYSIS

From the design of doubly reinforced beam using STAAD-Pro, ultimate moment capacity of beam obtained for the four storey building, *Mb1* =220 kNm (top storey), *Mb2* = 350kNm (other 3 storeys).

Keeping the reinforcement of beam fixed and increasing the column reinforcements progressively, the buildings are modelled in SAP2000.

The performance of any structure during earthquake depends on the performance of combination of structural and non-structural components. The FEMA 273 defines three structural performance levels and acceptance criteria that relates the earthquake-induced forces and deformations in the structure directly depend on these performance levels which are basically three types as

- Life Safety (LS)
- Collapse Prevention (CP)
- Immediate Occupancy (IO)

4.2.1 Steps used in Pushover Analysis

- The building is modelled using SAP2000 and the hinge properties are defined and assigned as per FEMA 356 and ATC 40 guidelines.
- 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 pushover under displacement control to achieve the target ultimate displacement or final collapse.
- The lateral load pattern to be used in the pushover may be in the form of a specified mode shape, uniform acceleration in specified direction, or a user defined static load case. Here the distribution of lateral force employed is in form of the first mode shape *i.e.* the structure is going to vibrate in its fundamental mode.
- In the model, beams and columns were modelled using frame elements, into which the hinges were inserted.

CHAPTER 5

RESULTS AND DISCUSSION

The results obtained from the analysis are:

5.1DESIGN FORCE IN THE BEAMS AND THE COLUMNS:

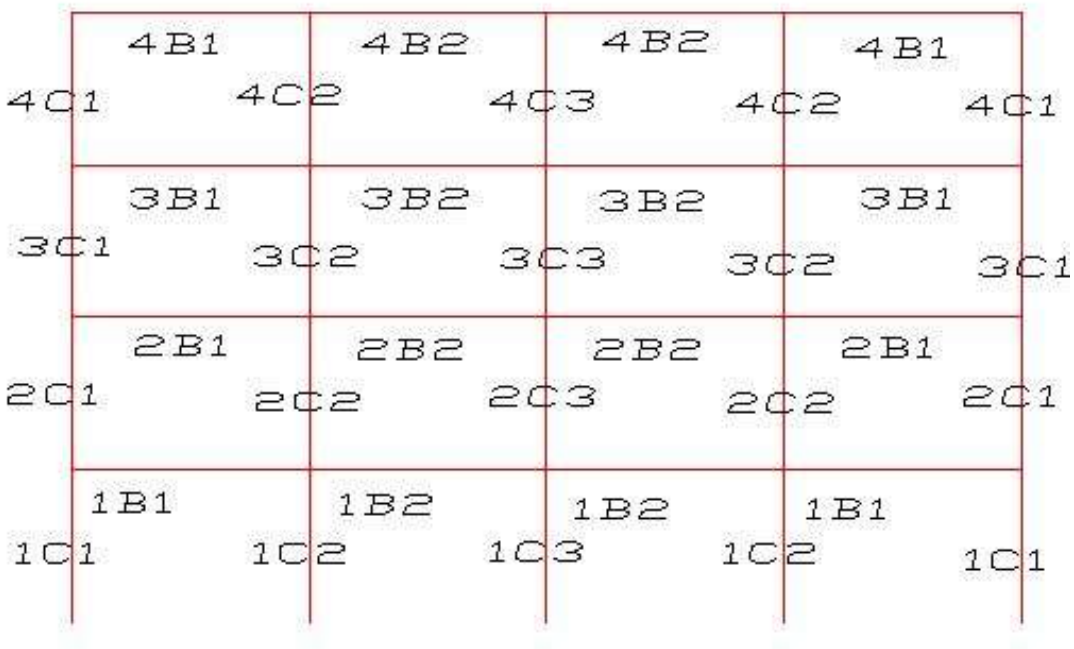


Fig. 5.1 Representation of beams and columns

Where

IBJ = J^{th} beam in I^{th} storey

ICJ = J^{th} column in I^{th} storey

The design forces in Beams and Columns are shown in the tables 5.1(a) and 5.1(b) respectively

5.1.1 FOR BEAMS:

Table 5.1(a) Design forces in beams

BEAMS	LOAD CASE KN	BENDING MOMENT (Mz) KNm	SHEAR FORCE (V) KN
1B1	1	-414.62	-158.02
	5	600.42	56.87
1B2	1	-353.26	140.77
	5	-571.08	345.69
2B1	1	-419.35	-160.60
	5	-601.49	369.95
2B2	1	-368.71	147.22
	5	-587.23	353.30
3B1	1	-313.08	-120.11
	5	-480.89	318.72
3B2	1	-283.44	113.33
	5	-489.35	314.02
4B1	1	-160.83	-59.72
	5	-313.21	254.82
4B2	1	-136.87	54.74
	5	-311.77	242.39

5.1.2 FOR COLUMNS:

Table 5.1(b) Design forces in column

COLUMNS	LOAD CASE	AXIAL FORCE (P) KN	BENDING MOMENT (Mz) KNm	SHEAR FORCE (V) KN
1C1	1	-498.45	443.11	190.80
	4	1344.70	32.59	-69.70
	5	477.62	504.06	202.89
1C2	1	42.39	505.85	251.25
	4	2249.25	0.00	0.28
	5	1850.26	606.31	301.28
1C3	1	0.00	502.46	247.68
	4	2243.62	0.00	0.00
	5	1794.90	602.95	297.22
2C1	1	-340.43	247.18	153.07
	4	999.90	55.72	-87.38
	5	-391.40	139.10	223.87
2C2	1	25.14	427.89	264.13
	4	1672.28	0.02	-0.66
	5	1367.99	515.13	317.48
2C3	1	0.00	416.41	257.69
	4	1672.78	0.00	0.00
	5	1338.22	499.69	309.23
3C1	1	179.83	244.07	-131.50
	4	650.07	84.03	53.58
	5	304.26	142.10	114.93
3C2	1	-11.76	383.57	-224.16
	4	1101.03	9.26	4.96
	5	894.94	395.20	265.02
3C3	1	0.00	380.96	-221.93
	4	1100.57	0.00	0.00

	5	880.46	0.00	266.32
4C1	1	59.72	160.83	-71.82
	4	96.93	142.74	76.10
	5	165.89	2.18	25.31
4C2	1	-4.97	274.60	-144.29
	4	533.97	2.20	-0.42
	5	433.15	223.89	173.49
4C3	1	0.00	273.73	-143.64
	4	526.58	0.00	0.00
	5	421.27	223.10	172.37

5.2REINFORCEMENT DETAILS:

From Fig. 5.1 we know that

- Length of the beam is 5m.
- Length of the column is 3.2m.
- All the dimensions in the table are in ‘m’

The reinforcement details based on MCR values for various international codes are provided in Table 5.2 (a-c).

5.2.1 COLUMNAND BEAM REINFORCEMENT (for ACI 318M-02, MCR=1.2)

Table 5.2(a) Reinforcement details for ACI 318M-02

S.NO	Beam	Beam Reinforcement		Column	Reinforcement (distributed equally on all sides)	Lateral ties
		TOP	BOTTOM			
1	1B1	4 Y25	4 Y25	1C1	14 Y32	Y10 @450 c/c
	1B2	4 Y25	4 Y25	1C2	10 Y25	Y8 @350 c/c
				1C3	10 Y25	Y8 @350 c/c
2	2B1	4 Y25	4 Y25	2C1	14 Y32	Y10 @450 c/c
	2B2	4 Y25	4 Y25	2C2	10 Y25	Y8 @350 c/c
				2C3	10 Y25	Y8 @350 c/c
3	3B1	4 Y25	4 Y25	3C1	14 Y32	Y10 @450 c/c
	3B2	4 Y25	4 Y25	3C2	10 Y25	Y8 @350 c/c
				3C3	10 Y25	Y8 @350 c/c
4	4B1	4 Y25	4 Y25	4C1	6 Y25	Y8 @350 c/c
	4B2	4 Y25	4 Y25	4C2	10 Y25	Y8 @350 c/c
				4C3	10 Y25	Y8 @350 c/c

5.2.2 COLUMNAND BEAM REINFORCEMENT (for EN1998-1:2003, MCR=1.3)

Table 5.2(b) Reinforcement details for EN1998-1:2003

S.NO	**Beam**	**Beam Reinforcement**		**Column**	**Reinforcement (distributed equally on all sides)**	**Lateral ties**
		TOP	**BOTTOM**			
1	1B1	4 Y25	4 Y25	1C1	16 Y32	Y10 @450 c/c
	1B2	4 Y25	4 Y25	1C2	10 Y25	Y8 @350 c/c
				1C3	10 Y25	Y8 @350 c/c
2	2B1	4 Y25	4 Y25	2C1	16 Y32	Y10 @450 c/c
	2B2	4 Y25	4 Y25	2C2	10 Y25	Y8 @350 c/c
				2C3	10 Y25	Y8 @350 c/c
3	3B1	4 Y25	4 Y25	3C1	16 Y32	Y10 @450 c/c
	3B2	4 Y25	4 Y25	3C2	10 Y25	Y8 @350 c/c
				3C3	10 Y25	Y8 @350 c/c
4	4B1	4 Y25	4 Y25	4C1	8 Y32	Y8 @350 c/c
	4B2	4 Y25	4 Y25	4C2	10 Y25	Y8 @350 c/c
				4C3	10 Y25	Y8 @350 c/c

5.2.3 COLUMNAND BEAM REINFORCEMENT (for NZS 3101:1995, MCR=2.06)

Table 5.2(c) Reinforcement details for NZS 3101:1995

S.NO	**Beam**	**Beam Reinforcement**		**Column**	**Reinforcement (distributed equally on all sides)**	**Lateral ties**
		TOP	**BOTTOM**			
1	1B1	4 Y25	4 Y25	1C1	20 Y32	Y10 @450 c/c
	1B2	4 Y25	4 Y25	1C2	12 Y32	Y10 @450 c/c
				1C3	12 Y32	Y10 @450 c/c
2	2B1	4 Y25	4 Y25	2C1	20 Y32	Y10 @450 c/c
	2B2	4 Y25	4 Y25	2C2	12 Y32	Y10 @450 c/c
				2C3	12 Y32	Y10 @450 c/c
3	3B1	4 Y25	4 Y25	3C1	20 Y32	Y10 @450 c/c
	3B2	4 Y25	4 Y25	3C2	12 Y32	Y10 @450 c/c
				3C3	12 Y32	Y10 @450 c/c
4	4B1	4 Y25	4 Y25	4C1	12 Y25	Y8 @350 c/c
	4B2	4 Y25	4 Y25	4C2	12 Y32	Y10 @450 c/c
				4C3	12 Y32	Y10 @450 c/c

5.3 EFFECT OF MCR ON THE BOQ (BILL OF QUANTITIES)

In present study, the main concept of BOQ is to find the amount of steel required for one frame of a building. Table 5.2 represents the amount of steel (in kg) required for construction of one frame of the building for different MCR values based on various international codes.

Table 5.3 Effect of MCR on BOQ

S.NO	CODES	MCR	Steel required for one frame (kg)
1	Indian Design (IS 456:2000,IS 13920:1993)	varying	4955.81
2	ACI 318M-02	1.2	5466.67
3	EN1998-1:2003	1.3	5829.24
4	IS 13920-draft (2014)	1.4	6049.75
5	NZS3101:1995	2.06	7922.66

From the table we can see that, increase in MCR value leads to increase in quantity of steel required for construction of one frame of the building. It can be inferred from the table that the quantity of steel required is less for Indian design than compared to all other international codes as there is no particular value for MCR in Indian design code.

It is found from this study that there can be a variation of 38% in reinforcement quantity due to the variation of MCR recommended in different design codes.

5.4 PUSHOVER CURVES

The curve plotted between base shear on Y-axis and roof displacement on X-axis is called pushover curve. Assuming the fundamental mode of vibration to be predominant this curve represents the first mode of response of the structure. This assumption holds good for structures with fundamental period up to about one second. The pushover curves for 4-storey framed building for American standard, European standard and New Zealand is shown in Fig. 5.2

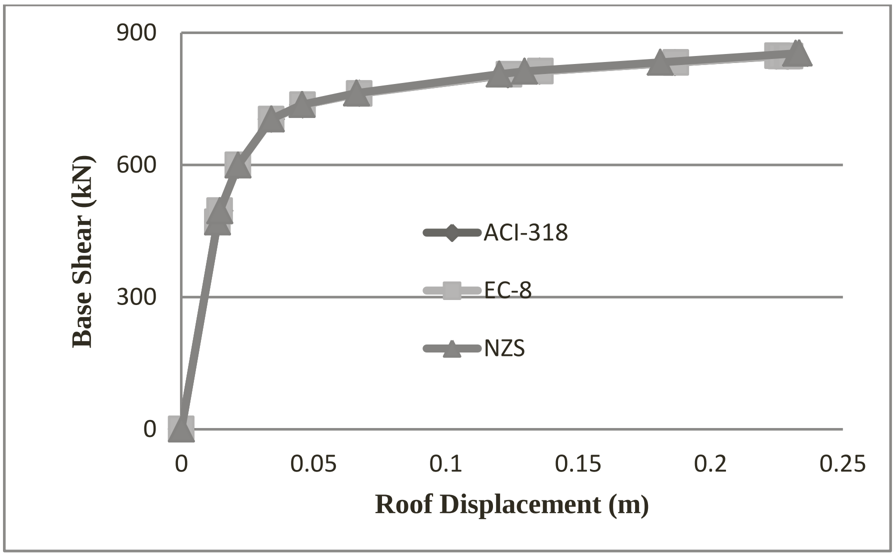


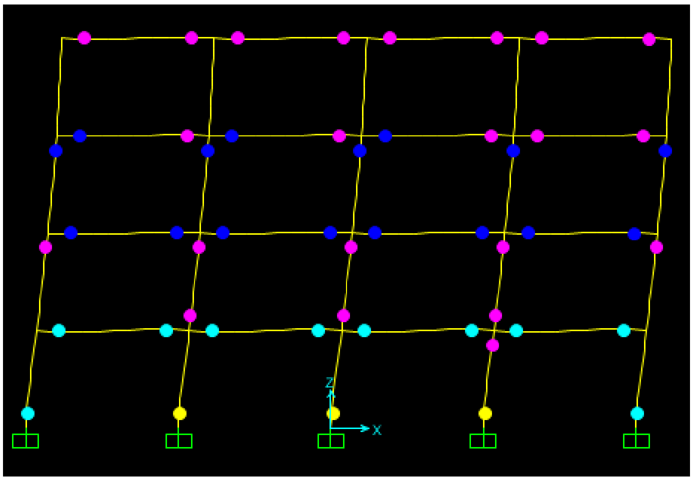
Fig. 5.2 Pushover curves for ACI-318, EC-8, and NZS

Additional reinforcement in column is provided in order to improve the performance of the building. However, pushover analyses show that this additional reinforcement does not reflect in the performance of the buildings.

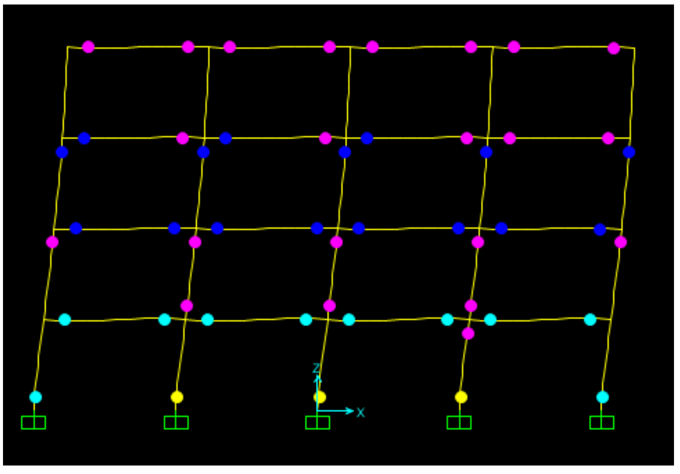
5.5FAILURE MECHANISM

By applying pushover loads to the members in a structure initially they remain elastic up to a certain moment M_p that is the maximum moment of resistance of a fully yielded section.

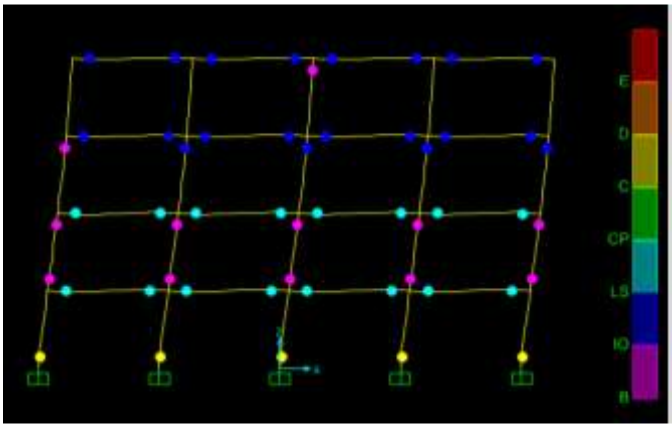
For a good failure mode the plastic hinges are to be distributed uniformly throughout the structure so that energy dissipation involves maximum members. Plastic hinge formation showing different failure mechanisms are obtained considering different MCR values. The final step of hinging at failure after attaining the target displacements are shown in the figure below.



(a)ACI-318, MCR=1.2



(b)EC-8, MCR=1.3



(c)NZS, MCR=2.06

Fig 5.3 Distribution of hinge formations at collapse for different MCR for the 4 storey building.

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

6.1 CONCLUSION

- Three building variant is designed considering the MCR recommended in ACI 318M-02, NZS3101:1995 and EN1998-1:2003.
- By increasing MCR a preferable collapse mechanism can be achieved.
- Effect of different MCR on the design (BOQ) and the resulting performances are studied.
- It is found from this study that there can be a variation of 38% in reinforcement quantity due to the variation of MCR recommended in different design codes.
- Additional reinforcement in column is provided in order to improve the performance of the building. However, pushover analyses show that this additional reinforcement does not reflect in the performance of the buildings.

6.2 FUTURE SCOPE

- By taking more MCR values the analysis can be done for more number of buildings.
- Here only regular RC framed buildings are considered. The analysis can be extended for irregular building having torsion effects.
- The analysis can be extended by considering more number of buildings with different varying parameters

CHAPTER 7

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