PROBABILITY OF FAILURE OF BUILDING WITH VARIOUS MCR VALUES AT BEAM-COLUMN JOINT IN REGUALR AND IRREGULAR BUILDING

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ABSTRACT

Reinforced concrete moment resisting frames (RCMRF) are structural systems that should be designed to ensure proper energy dissipation capacity when subjected to seismic loading. In this design philosophy, the capacity design approach that is currently used in practice demands “strong-column / weak-beam” design to have good ductility and a preferable collapse mechanism in the structure. When only the flexural strength of longitudinal beams controls the overall response of a structure, RC beam-column connections display ductile behaviour (with the joint panel region essentially remaining elastic).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 degradation of capacity at the connections. Though many international codes recommend the moment capacity ratio at beam column joint to be more than one, still there are lots of discrepancies among these codes and Indian standard is silent on this aspect.So in the present work pushover analysis is being done using SAP2000 for increasing moment capacity ratio at beam column joints and its effect on the global ductility and lateral strength of the structure is studied.To incorporate the uncertainties in material properties, a probabilistic approach is followed to observe the effect of ground motion intensity on probability of exceedance of any specific damage state for structures designed considering different moment capacity ratios (MCR) at the connections. For this objective fragility curves are developed considering the pushover curves obtained from the nonlinear static analysis.Ductility of the structure increases with increase of MCR. Also the buildings designed with lesser MCR values are found to be more fragile compared to the building with higher MCR.

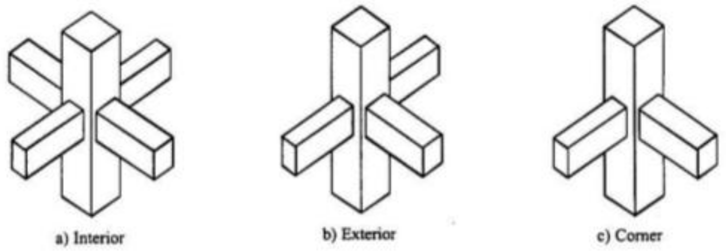
Keywords: Regular and irregular buildings, Pushover, moment capacity ratio, ductility , lateral strength, Fragility curves.

1. INTRODUCTION

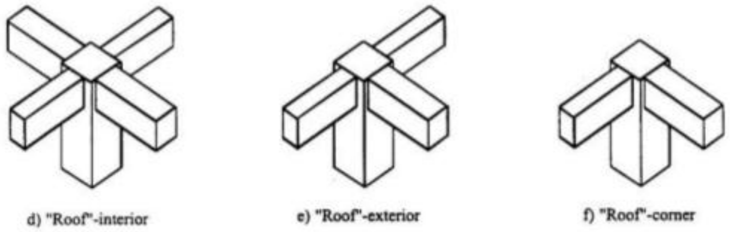
During earthquake, ground motions occur both horizontally and vertically in random fashions which causes structure to vibrate and induce inertia forces in them. Designing a building to behave elastically during earthquake without any damages will make the project uneconomical. So the earthquake-resistant design philosophy allows damages in some predetermined structural components. One of the most important requirements of building to withstand any type of earthquakes is not the more force it can resist but the more deformation it can take before collapse. Beam-column connection is considered to be one of potentially weaker components when a structure is subjected to seismic loading. Capacity design procedure sets strength hierarchy first at the member level and then at structure level. So, its needs adjusting of column strength to be more than the beams framing into it at a joint mathematically it can be expressed as

$$M_c \geq M_b \ldots\ldots\ldots\ldots(1)$$

Where M_c and M_b sum of moment capacities at the end of column and beam meeting at a joint in a particular direction.



a) Interior b) Exterior c) Corner



d) "Roof"-interior e) "Roof"-exterior f) "Roof"-corner

Fig 1.1; Different types of beam-column joint

1.1Fragility curves

Most of the studies regarding performance based seismic design are based on deterministic approach. But since lots of uncertainties are associated with material strength and earthquake loads so a probabilistic approach seems to be a more rational way for performance assessment of a structure. The present studyfocuses on the background information regarding formulation of fragility curve and the methods used for its development.Seismic vulnerability or fragility of a structure is defined as its susceptibility to damage by the earthquake loading of a given intensity. The fragility curves can be regarded as one of the most useful tool for performance based design of structures for design of new buildings and also for assessing performance of existing buildings situated in the earthquake prone area all over the world. Evaluation of damage state probability is very important in estimating earthquake losses. It is expressed as probability of attaining or exceeding a certain damage state in terms of ground motion severity that may be PGA or spectral displacement. A number of approaches are available for developing the fragility curves for different types of building considering either the empirical data from past earthquakes or using the data obtained from analytical simulations. In the present work HAZUS methodology is used to develop fragility curves for the regular, plan irregular and vertical irregular building frames considered. This method considers spectral displacement or acceleration as the ground motion parameter unlike the methods recommended by ATC which describes ground motion in terms of PGA.HAZUS damage functions for ground shaking includes 2 components:1) capacity curve based on engineering parameters like yield strength and ultimate strength obtained from pushover analysis 2) fragility curves describing probability of damage to building for four physical damage states such as slight, moderate, extensive and complete damage states

1.2 DEVELOPMENT OF FRAGILITY CURVES

Fragility curves may be defined as the log normal distributions representing the probability of attaining or exceeding a given structural or nonstructural damage state with median estimate of spectral response (spectral displacement in the present work) being known. This is mathematically expressed as shown in equation (5.1)

$$P[d_s/S_d] = \emptyset[\frac{1}{\beta_{ds}} ln\left(\frac{S_d}{\bar{S}_{d,ds}}\right)] \quad \text{……………………5.1}$$

Where Ø = normal cumulative distribution function.
pds = variability parameter obtained from standard deviation of natural logarithm of the spectral displacement for damage state ds.
Sd, ds = median spectral displacement at which building reaches the threshold of damage state ds

Damage states

Damage states give an idea of building physical conditions which is related to various loss parameters like economic loss, functional loss etc. The damage states defined by Barbat(2006) based on yield and ultimate spectral displacements of a building are used in the present work.

Gr3	Extensive damage	Sdy+0.25(Sdu-Sdy)
Gr4	Complete damage	Sdu

Sdu= ultimate spectral displacemnt Sdy=yield spectral displacement

2.REVIEW OF LITERATURE

2.1 GENERAL

In the present study literature discussed includes review of various international codes on moment capacity ratio at beam-column joint .
Sugano (1988) conducted experimental program on 30-storey RC framed building in Japan and developed design consideration to ensure good collapse mechanism and also observed the ductility of plastic hinges.Nakashima (2000) observed for steel building that the column over strength factor

increases with increase in ground motion amplitude for ensuring column-elastic response. Also for frames in which column-elastic behaviour is ensured, the maximum story drift angle is 1.5 to 2.5 times as large as the maximum overall drift angle.Dooley and Bracci (2001) investigated the influence of the COF at the joints in two RC frame structures under seismic excitation using inelastic time-history dynamic analyses. Jain (2006) proposed that, when a reinforced concrete moment resisting frame is subjected to seismic loads, at beam-column joint, summation of moment of resistances of columns should be greater than or equal to 1.1 times summation of moment of resistance of beams framing into it as in equation 2.2

$$\Sigma Mn,c > \mathit{1.1}\ \Sigma Mnib \ldots\ldots\ldots\ldots\ldots\ldots(2.1)$$

Hatzigeorgiou(2009) performed an extensive parametric study on inelastic behaviour of reinforced concrete frames under reverse cyclic ground motions and observed the relationship as shown in equation 2.1

$$\Sigma Mn,c > \mathit{1.3}\Sigma Mnib \ldots\ldots\ldots\ldots\ldots\ldots(2.2)$$

Many studies also have been conducted so far by the researchers in search of dominant collapse modes of the frames and designing strong column weak beam frames. Hibino and Ichinose (2005) presented a numerical study of the effect of flexural strength ratio of column to beam on the global energy dissipation of beams and columns in fish-bone-type steel moment frames. The major parameters considered are number of stories, strengths of columns, strengths of beams and ground motion. Findings of the study show that with the increase of the beam to column strength ratio the energy contributing to story mechanism decreases. Seismic damage assessment can be done by means of fragility curves. Various approaches for damage evaluation, like first-order reliability and a fuzzy random method, were reviewed by **F.Colangelo** (2008). These methods were used for deterministic analysis of infill reinforced- concrete frame, and the fragility curves obtained were compared. It was concluded that randomness of the capacity is essential. If any damage state is assessed with a deterministic drift range, then fragility sharply increases with increase in peak ground acceleration of ground motion and hence it is quite overestimated. Seismic fragility curves of RC buildings are studied by **Alexander Papailia** (2011). The analysis performed for the estimation of the peak response quantities was according to Eurocode 8 (Parts 1 and 3) with certain simplifying assumptions for the frames. The design and the evaluation of the building performance was based on the results of linear elastic (equivalent) static analysis, for a lateral force pattern that is distributed over the height as per an assumed linear mode shape, termed as “lateral force method” in Euro code 8. The median value for the probabilistic distribution corresponding to a given damage state and damage measure of interest was obtained. The dispersion (P value) of the fragility curve was taken into account explicitly the model uncertainty for the estimation of the damage measure given the intensity measure and the uncertainty of the capacity in terms of the damage measure.**Sharfuddin** (2010) evaluated the COF requirement that ensure probabilistically the preferable entire beam hinging failure mode and avoid undesirable storey collapse modes of the frame structure during earthquakes. It is found that under same reliability level target COF requirement increases with number of storey and it decreases with the increase in the reliability level. **Milutinovic & Trendafiloski** (2003) developed the fragility curves for buildings considered within the RISK-UE project. Building classifications were taken from the stock in the project application sites, ~~i.e.,~~ Barcelona, Bitola, Bucharest, Catania, Nice, Sofia and Thessaloniki. Both empirical as well as analytical procedures were employed. Different damage scales were considered for each approach and a correlation between them was proposed. For steel, wood and reinforced masonry structures, the HAZUS vulnerability curves were adopted. Empirical curves obtained using damage probability matrices which were generated from vulnerability index that accounts for structural characteristics and local conditions.

3. METHODOLOGY

In the present study linear static analysis is carried out in ETABS and non linear static analysis in SAP2000. Three different types of building are considered for analysis purpose regular, plan irregular and vertical irregular RC frame

a) Regular, plan irregular and vertical irregular RC framed buildings are designed using commercial software ETABS.
b) Ultimate flexural capacity of beam $(M_{r,b})$ is determined from the design data obtained.
c) Column reinforcement in the buildings is progressively increased to attain different column to beam moment capacity ratio (MCR) at design axial load.
d) Considering the beam and column reinforcement, the same building is modelled using SAP2000 and nonlinear static analysis is being done.
e) The building is modelled using SAP2000 and the hinge properties are defined and in the model, beams and columns were modelled using frame elements, into which the hinges were assigned as per FEMA 356 and ATC 40 guidelines..
f) First gravity pushover is applied incrementally under force control for the combination of DL+0.25LL and then later pushover is applied after the end condition of gravity pushover to achieve target displacement Here the distribution of lateral force employed is in form of the user defined static load case
g) Fragility curves are developed for damage state Gr3 and Gr4 since the building lies in strong earthquakevzone

Table 1: Structural data for RCC structure

Dimension of building	30m X 16m		
Building type	Regular	Plan irregular	Vertical irregular
Number of storeys	G+15	G+15	G+115
Height of each floor	3.1m	3.1m	3.1m
Beam dimension	300 X 500 mm	300 X 500 mm	300 X 500 mm
Column dimension	600 X 600 mm	600 X 600 mm	600 X 600 mm
Thickness of slab	150 mm	150 mm	150 mm
Thickness of exterior wall	230mm	230mm	230mm
Grade of steel	Fe500	Fe500	Fe500
Seismic zone	V	V	V
Zone factor	0.36	0.36	0.36
Importance factor	1	1	1
Type of soil	Medium soil	Medium soil	Medium soil
Response reduction factor	5	5	5
Live load	3kN/m^2	3kN/m^2	3kN/m^2
Floor finish	1.5 kN/m^2	1.5 kN/m^2	1.5 kN/m^2
Wall load on exterior beam	12 kN/m	12kN/m	12kN/m
Grade of concrete(column)	M40	M40	M40
Grade of concrete(beam and slab)	M25	M25	M25

4. Results and discussion

The building used for analysis are modelled in Sap2000 as showed below respectively :

Fig 3.1 (a) represents regular building without infill

Fig 3.1 (b) represents plan irregular building without infill

Fig 3.1 (c) represents vertical irregular building without infill

Fig 3.1 (d) represents regular building with infill

Fig 3.1 (e) represents plan irregular building with infill

Fig 3.1 (f) represents vertical ir regular building with infill

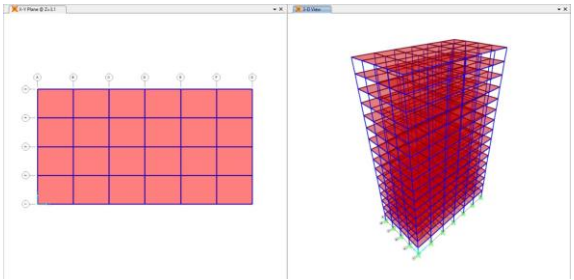
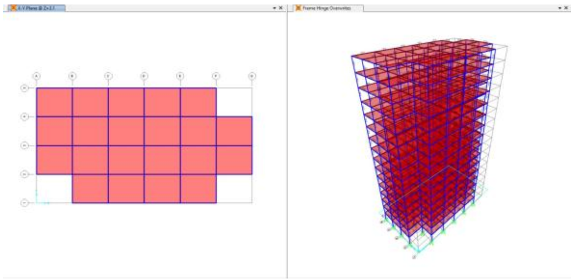


Fig 3.1 (a)



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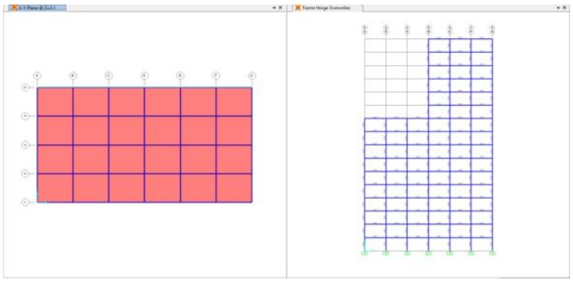
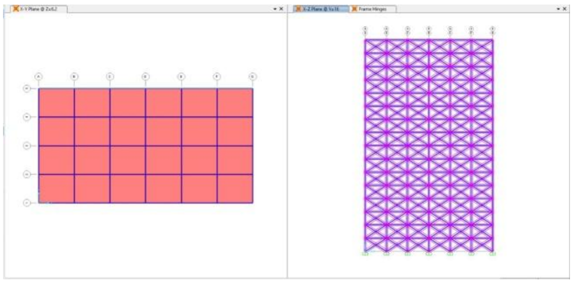


Fig 3.1 (c)



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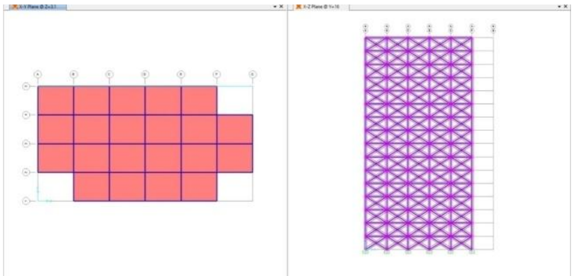

Fig 3.1 (e)

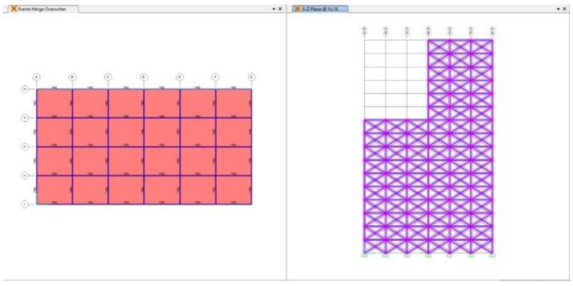

Fig 3.1 (f)

Table 2: Strength and ductility studies for regular building

Column steel (%)	MCR At Design load	Yield displacement in mm	Ultimate displacement in mm	Yield strength in kN	Max strength in kN	Ductility factor
1.4	1.12	113	840	5108	6050	7.43
1.74	1.26	113	873	5131	6182	7.73
2.09	1.54	125	954	5164	6314	7.63
2.45	1.70	125	1001	5241	6446	8.01
2.72	1.94	125	1054	5293	6612	8.50

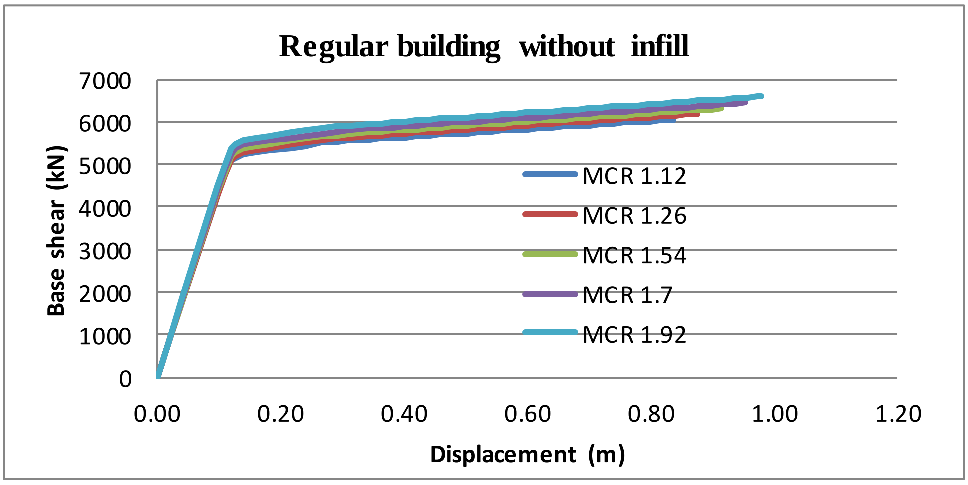

Fig 3.2 (a): Base shear vs displacement for various MCR Values for regular building

Table 3: Strength and ductility studies for plan irregular building

Column steel (%)	MCR At Design load	Yield displacement in mm	Ultimate displacement in mm	Yield strength in kN	Max strength in kN	Ductility factor
1.4	1.12	115	800	4629	5509	6.96
1.74	1.26	115	863	4722	5673	7.50
2.09	1.54	120	904	4814	5821	7.53
2.45	1.70	120	1030	4953	5946	8.58
2.72	1.94	120	1198	5046	6014	9.98

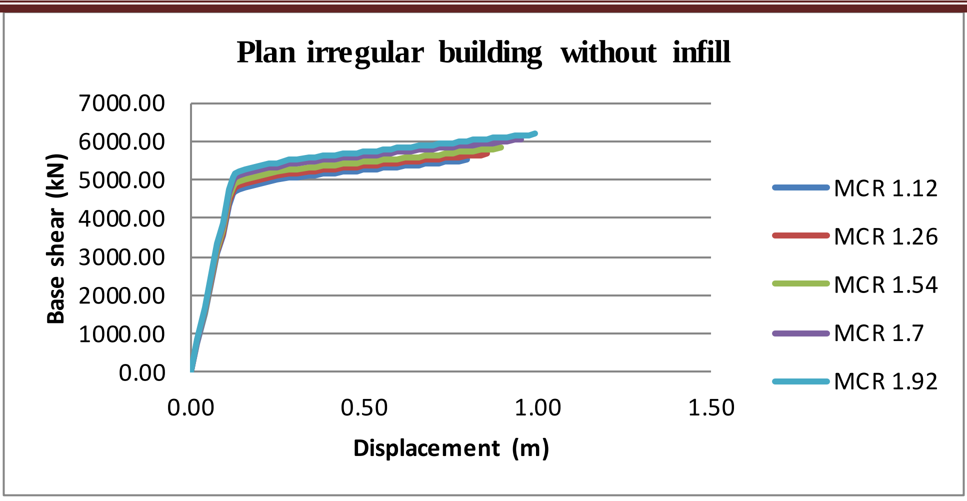

Fig 3.3 (a): Base shear vs displacement for various MCR Values for plan irregular building

Table 4: Strength and ductility studies for vertical irregular building

Column steel (%)	MCR	Yield displacement in mm	Ultimate displacement in mm	Yield strength in kN	Max strength in kN	Ductility Factor
	At Design load					
1.4	1.12	95	872	2548	3346	8.99
1.74	1.26	90	905	2574	3425	10.19
2.09	1.54	100	955	2612	3492	9.60
2.45	1.72	100	1042	2663	3577	10.42
2.72	1.94	100	1123	2713	3661	11.23

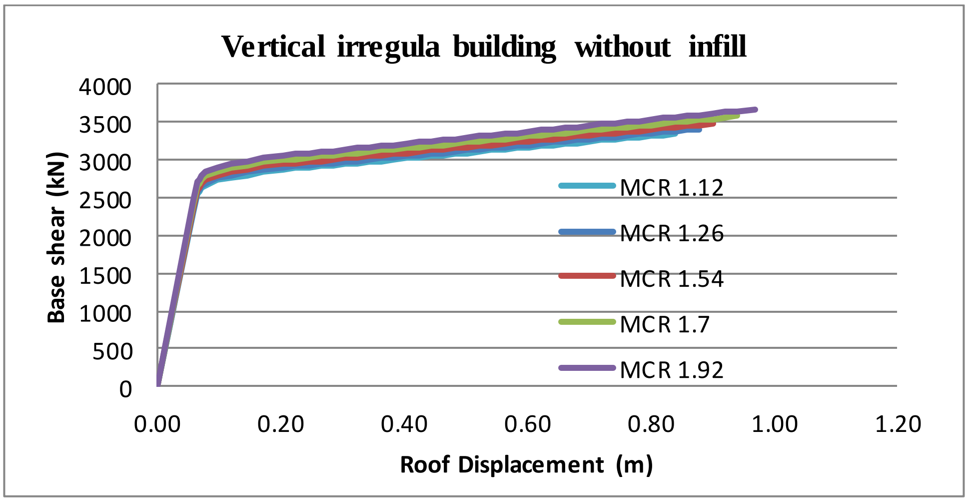

Fig 3.4(a): Base shear vs displacement for various MCR Values for vertical irregular building

Similarly pushover analysis is carried out for the buildings considered for various moment capacity ratio (MCR) as shown above.

Fragility curves for Gr4 and Gr3 state

Table 5: Median spectral displacement (mm) corresponding to different damages grades

MCR	1.12		1.26		1.54		1.7		1.94	
DAMAGE STATES	Gr3	Gr4	Gr3	Gr4	Gr3	Gr4	Gr3	Gr4	Gr3	Gr4
RG	304	724	316	751	328	764	345	781	357	792

Table 6: Median spectral displacement (mm) corresponding to different damages grades

MCR	1.12		1.26		1.54		1.70		1.92	
DAMAGE STATES	Gr3	Gr4	Gr3	Gr4	Gr3	Gr4	Gr3	Gr4	Gr3	Gr4
VIRB	250	827	265	859	286	896	301	939	315	958
PIRB	264	812	286	836	297	847	309	904	318	957

Using the Table 5.3 and 5.4 median spectral displacements for different damage states are obtained. Only damage states of Gr3 and Gr4 are considered in the present study for developing fragility curves. From the spectral displacements obtained for pushover analysis median spectral displacement (S_{ds}) are obtained. Median spectral response shows the threshold limit of a given damage state. Then using the normal distribution function probability of equal or exceeding a given damage state can be obtained.The slope of fragility curve developed depends on the log normal standard deviation value p. Smaller value of β indicates lesser variability of damage state and hence steeper fragility curve is generated. So the Gr3 curves are stiffer than Gr4 curves (β of Gr3 = 0.75 and for Gr 4 it is 0.85)

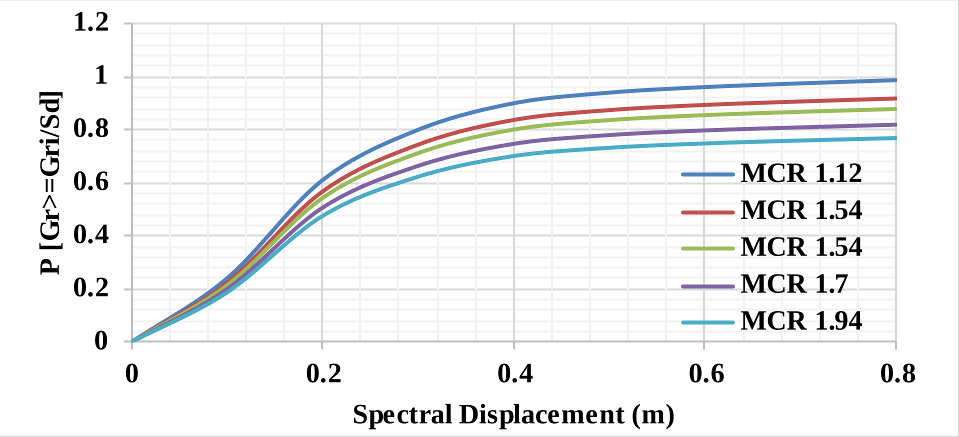

Fig 3.5: Fragility curve for Regular RC Frame for Gr3 damage state

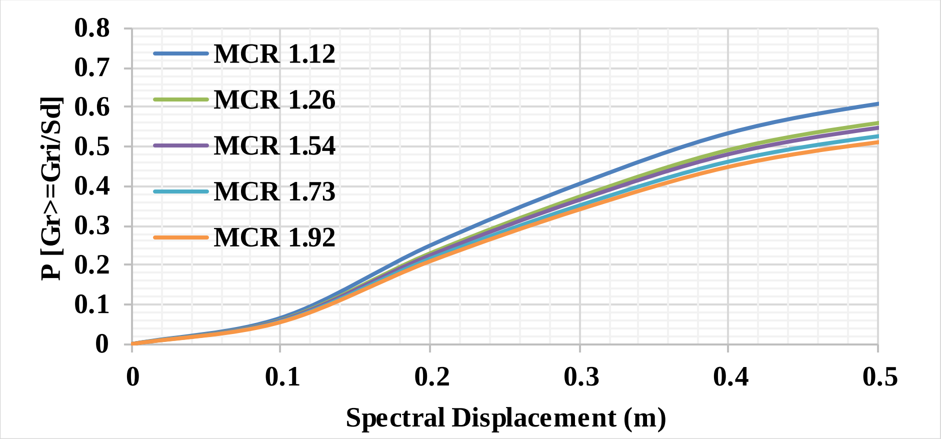

Fig 3.6: Fragility curve for regular RC frame for Gr4 damage state

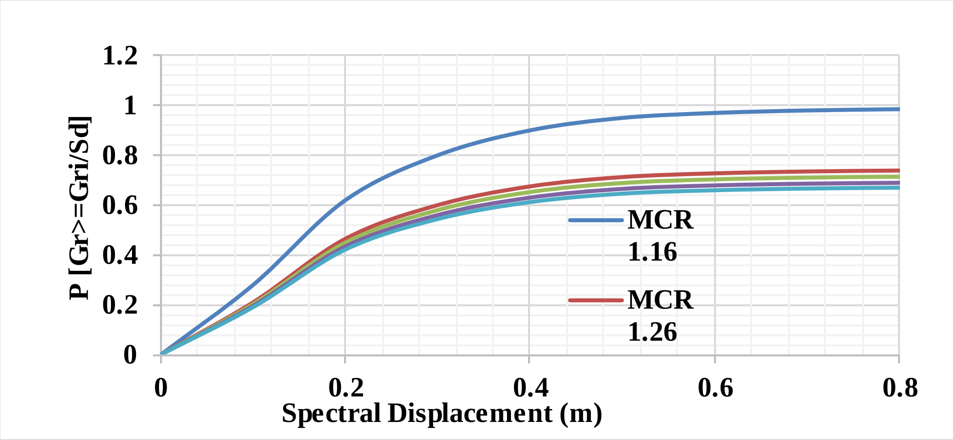

Fig 3.7: Fragility curve for plan irregular RC Frame for Gr3 damage state

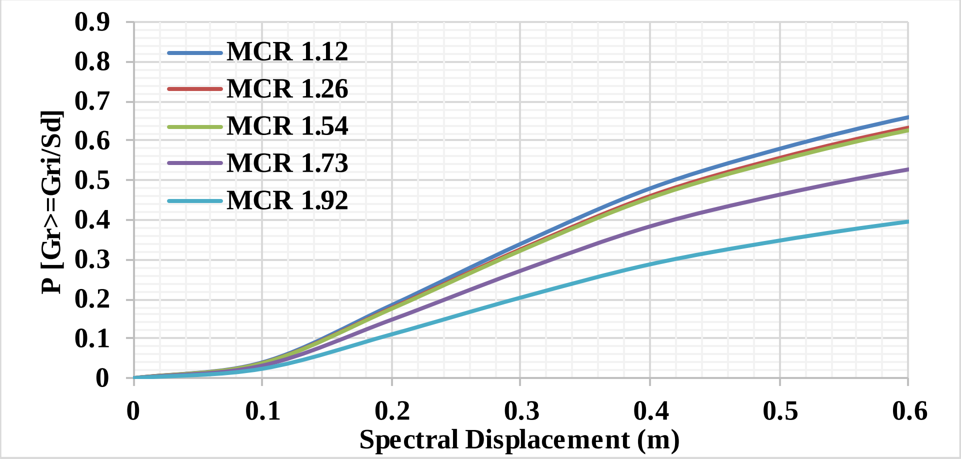

Fig 3.8: Fragility curve for plan irregular RC Frame for Gr4 damage state

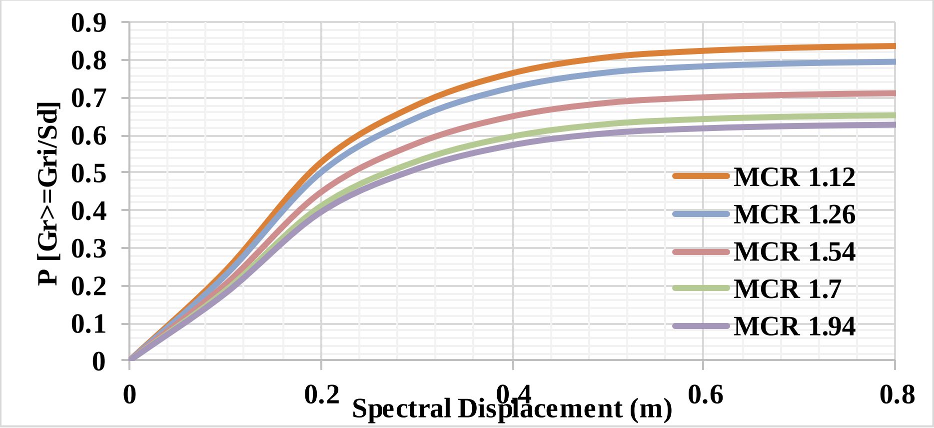

Fig 3.9: Fragility curve for vertical irregular RC Frame for Gr3 damage state

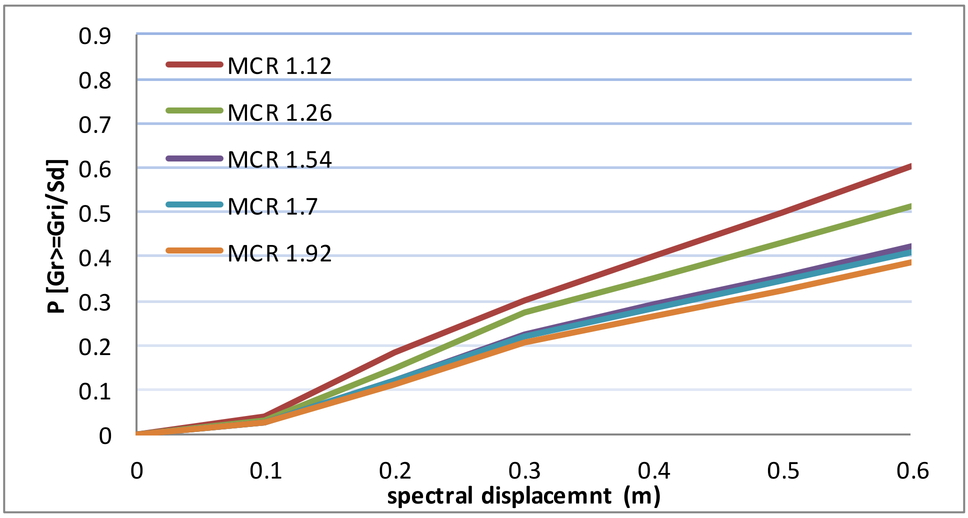

Fig 3.10:Fragility curve for vertical irregular RC Frame for Gr4 damage state

From the tables and graphs the following observations are made in G+ 15 storeys buildings: The performance of regular RC framed buildings is considered by developing fragility curves as per HAZUS (2003). Uncertainties in concrete and steel material properties are considered. Regular, plan irregular and vertical irregular buildings are modelled for different MCR values by increasing the column reinforcement. Damage state definition is considered from Barbat (2006).Variability parameters are considered as per HAZUS (2003).The fragility curves are developed to find out the vulnerability of buildings designed as per strong column weak beam concept. The fragility curves for different progressively increasing MCR values are compared for different damage state for a given spectral displacement. It is observed that a structure designed with lower MCR (e.g. 1.12) shows much higher damage probabilities. Fragility of a structure decreases if the columns are made stronger than beams maintained by increasing MCR values.The results for regular building show little different trend than other two building category .The damage probabilities for regular building do not show much variation for varying MCR. For plan irregular building frame the probability of exceedance of a given damage state shows a continuous decreasing trend 0with higher MCR. However the

variation of MCR 1.12 after is comparatively less. Vertical irregular building frame also shows the similar trend as a plan irregular frame. Probability of exceedance of given state shows a decreasing trend with higher MCR. Variation from 1.12 to 1.26 is less and for 1.54 is more and MCR from 1.54 to 1.7 wider variation compared to MCR 1.7 to 1.94.Gr4 damage state that considers complete damage of the structure shows flatter slope as compared to Gr3 which is extensive damage state due to higher variability associated with it.

6. Conclusions:

Probabilistic analysis is done to evaluate the damage statistics, and distinguish the buildings on the basis of their relative seismic performance. From the fragility analysis of different building using the capacity curves obtained from pushover analysis the conclusions can be drawn.The fragility curves indicate much higher damage probabilities for building designed with considering very low MCR value of 1.12.The incorporation of higher MCR values reduces the damage probabilities irrespective of number of storey and damage level.For regular building increase of MCR does not decrease the probability of damage to an appreciable extent. For plan irregular building wider variation of damage probability is observed from MCR 1.12 and 1.26 to MCR 1.54 for a given spectral displacement. From MCR 1.54 to 1.7 the probability of exceedance of a given damage state decrease but the difference is comparatively less. For MCR 1.7 to MCR 1.94 almost same damage probability is observed.Vertical irregular building also shows same trend of fragility curves as of irregular building frame.So from the fragility analysis of the three type of buildings it can be concluded that, for regular building increase in MCR seems to be giving a lesser probability of damage. But for plan irregular and vertical irregular building, higher MCR may be appropriate to have good performance under strong earthquake shaking.The MCR value depends on number of storeys and it may be higher when number of storeys increases.A probabilistic framework gives complete insight into the expected performance of a building..

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