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Seismic Fragility Curves of R.C.Framed Buildings Designed as per is Low, Medium and High Code

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***Abstract:** In India, the RC buildings codes of gravity and seismic loads have been revised over five decades. The adaptation of gravity and seismic loads combination were rarely taken into design consideration in low and mid-rise building. In the last five decades, low and mid-rise buildings have been constructed high in number in urban cities due to increasing more employment opportunity. The around 56% of the landmass is prone to moderate to severe the earthquake. Also, it evident, in Bhuj 2001 earthquake, many mid and low rise was suffered severely, and more life loss occurred. The seismic zone map has been updated from 1968-2016 and seismic demand increased manifold. The RC buildings have been designed different design philosophy over the period of time, and the urgent need for the assess the vulnerability buildings which have been designed different design codes. In this paper, an attempt made to derive the fragility curves of three and five story RC buildings with aspect ratio and designed as per IS 456-1964 (Low code), IS 456-1978 (Medium code) and IS-13920 (High code). The modelling and pushover analysis are carried out by using a numerical method. User-defined hinge properties for the column as P-M-M and beam as M3 curves have been derived and assigned column and beam elements. The displacement control is applied in pushover analysis. The fragility curves have been derived as per guidelines are given by HAZUS technical manual. Results are compared with design philosophies, aspect ratio and the number of storeys for a given intensity of the acceleration.*

***Keywords:** R.C.Building, Design Philosophy, Pushover analysis and Fragility curves.*

I. INTRODUCTION

In last three decades, India has witnessed several Medium earthquakes (Bihar-Nepal border (M 6.4) in 1988, Uttarkashi, Uttaranchal (M 6.6) in 1991, Latur, Maharashtra (M 6.3) in 1993, Jabalpur, Madhya Pradesh (M 6.0) in 1997, Chamoli,

Uttaranchal (M 6.8) in 1999, Bhuj, Gujarat (M 6.9) in 2001 and Muzafarrabad in 2005 causing over 1 lakh casualties due to collapse of structures. In order to predict the likely impact of an earthquake on the built environment in any part of the country, it is essential to know the seismic vulnerability of the built environment on the affected areas.

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The seismic zone maps have been updated from 1968 to 2016 and also RC design codes were also updated before and after 1978, 2000 for gravity loads, and gravity and later load for ductile design code, i.e. 13920. The building was constructed before the 1990s are Low rise RC, Brick masonry, Mudhouse and Stone Masonry buildings in India and after 1990s, low, mid and high rise RC buildings has been constructing. Unfortunately, low and mid-rise buildings were designed for gravity loads only and as seismic zone map was updated over five decades, seismic demand increases and the building were constructed before 1990 and after 1990 are in high vulnerable. The urgent need for the assess the vulnerability buildings which have been designed different design codes in India, and it can help to reduce life and property loss and also made insurance policies for existing buildings.

II. LITERATURE

Muhammad Tekin et al. (2015): In this study, the fragility curves were developed for one and two stories concrete (RC) residential buildings. Nonlinear pushover (NP) analysis was performed to eighty-four RC buildings that were divided into two teams. The buildings designed 1998 and later were considered to as Group-A. The building designed before 1998 was considered to as B. The buildings in type A have a lot of High code behaviour as compared to B.

Murat et al. (2006) are established the fragility curves for mid-rise RC frame buildings located in Istanbul, which were designed according to the 1975 version of the Turkish seismic design code. Buildings of 3, 5 and 7 stories were designed according to the Turkish seismic design code. To investigate the effect due to the number of stories of the building on fragility constraints and regression analysis was carried out between fragility parameters and the number of stories of the building. It was found that fragility parameters change widely due to the number of stories of the building. **Alex H. Barbat et al. (2015):** The author studies the influence on the vulnerability of RC frame structures of geometric structures like the slab thickness, the building height and plan configuration. The obtained results reveal that there is a directly proportional relationship between the slab thickness and the vulnerability of the structure. When the effect of the number of stories was considered, it was concluded that the structures with a smaller number of levels are less vulnerable. The influence of the plan configuration, the L shaped building, results shows the most vulnerability.

III. METHODOLOGY

In order to reveal the influence on the fragility curve of the design methods, aspect ratio and

a number of stories, several static nonlinear analyses (pushover analyses) were performed using computational models and computer programs like SAP2000 [6]. The result of a pushover analysis is the capacity curve which represents a relation between total base shear and the top displacement. The capacity curve is derived from pushover curves. The figure 1 shows the methodology of derive the fragility curves. This methodology is divided into seven steps from input requirement to the development of fragility curves.

The capacity curve of the structure is converted into capacity spectrum by means of relations provided by ATC-40 [7]. The capacity spectrum is expressed and graphically represented in spectral acceleration and spectral displacement coordinates (S*a*-S*d*); it is mostly used in its simplified bilinear form which is completely defined by the yielding point (*Dy*, *Ay*) and by the ultimate capacity point (*Du*, *Au*).

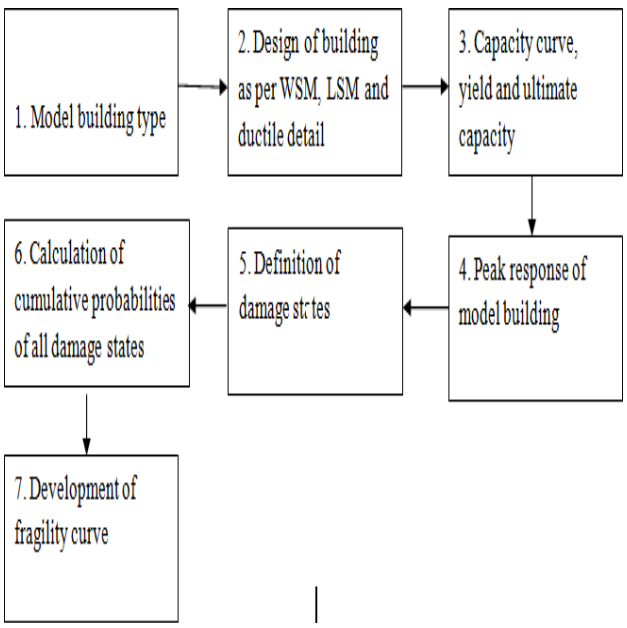


Fig.1. Steps involved in the methodology

Four damage states are considered with the aim of analyzing the expected damage, namely, slight (ds1), Medium (ds2), extensive (ds3) and collapse (ds4). The damage states thresholds are used to determine the fragility curves for each of these damage states.

ds1=0.7*Dy,ds2=Dy,ds3=ds2+0.25*(Ds4-Ds2) (1)
ds4=Du

The fragility curves express the probability that the expected global damage *of* a structure exceeds a given damage state dsi. The fragility curve is completely defined for each damage state by the following equation (2).

$$P\left(\frac{ds}{sd}\right) = Ø\left[\frac{1}{ßds}\ln\left[\frac{Sa}{Sa,ds}\right]\right] \quad (2)$$

Where Ø is the standard normal cumulative distribution function, S_{ads} is the threshold spectral acceleration, S_a spectral acceleration of the structure, $ß_{ds}$ is the standard deviation of the natural logarithmic of this spectral acceleration these values are taken from the HAZUZ MH MR5 [5].

IV.STRUCTURAL MODEL

In these two types of RC building model are selected. Namely, three-story and five-story building with an aspect ratio (AR) 1and 0.5 respectively. Based on the aspect ratio, the width of the building is calculated. The three-story building with an aspect ratio 0.5 and 1, the width of the building is 18m and 9m respectively, considering each bay width as 4.5m in both X and Y direction. Similarly, The five-story building with an aspect ratio 0.5 and 1, the width of the building is 30m and 15m respectively, considering each bay width as 5m. 3D views of considered models are shown in fig.2 and fig.3 for three and five store building. The M20 grade of concrete and Fe415 steel is considered. The slab

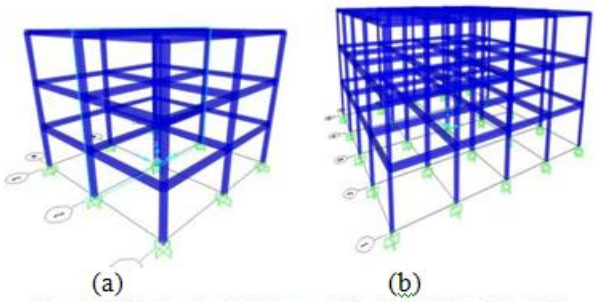
thickness is calculated based on IS 456:2000[8]. The purpose of the building is taken in this study as residential building and loads are taken as per IS 875 (Part-2), and load combinations are mentioned in table I for this study.

Table I. Loads and load combinations

Live load	2 kN/m^2
Floor finish load	1 kN/m^2
Wall load	10 KN/m
Parapet wall load	3 KN/m
Low code	(DL+LL)
Medium code	1.5(DL+LL)
High code	13 load combinations

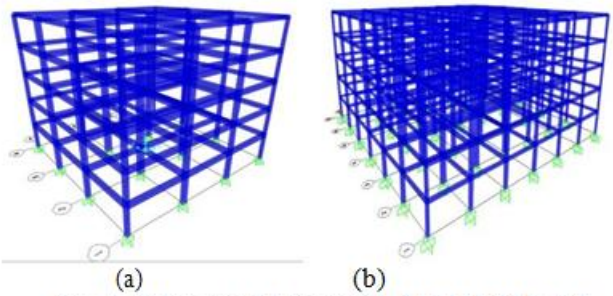
Cross-sections and reinforcement are designed as per working stress method (Low code), limit state method (Medium code) and ductile detailing (High code) based on IS 456:1964, IS 456:1978 [8] and IS 13920:1993 [9]. The

spacing of shear reinforcement is also calculated based on respective codes. The wall load 10 kN/m is applied on floor beams, and parapet wall load 3 kN/m is used on roof beams. The Hinges are assigned at start and end of beams, so moments are considered at ends to design cross-section and reinforcement details. In table II the rebar area 435/226 indicates top and bottom reinforcement, beams are designed as singly reinforced, so bottom hanging bars are provided with two 12 mm diameter. According to High code, area of steel provided bottom top and bottom face of the cross-section.



(a) (b)

Fig .2. 3D view of 3 story (a) AR-1 (b) AR-0.5



(a) (b)

Fig .3. 3D view of 5 story (a) AR-1 (b) AR-0.5

The column C1, C2 and C3 are centres, edge and corner are considered for this study. The cross-section and reinforcement details are the same for the building with aspect ratio 1 and 0.5. According to IS 13920:1993 [9], the minimum column dimension is taken 300mm. Table II and III shows a cross-section and reinforcement details of beam and column of 3 and 5 story models

From table II it is observed that cross-section of beam designed as per working stress method (WSM) is having more than the member designed as per Limit State method (LSM). The reinforcement area of WSM is less than the LSM.

Table II. Beam details of 3 and 5 storey building

Frame members		Three Storey			Five Storey		
		Cross-section (mm^2)	Rebar (mm^2)	Spacing (mm)	Cross-section (mm^2)	Rebar (mm^2)	Spacing (mm)
FBE	Low code (WSM)	230X460	435/226	6d@160	300X470	598/226	6d@135
	Medium code (LSM)	230X330	669/226	6d@135	230X385	669/226	6d@120
	High code (Ductile)	230X330	736/368	6d@100	230X385	880/450	8d@100
FBC	Low code (WSM)	305X495	624/226	6d@105	300X590	771/226	8d@160
	Medium code (LSM)	230X400	845/226	6d@100	230X430	1222/226	8d@135
	High code (Ductile)	230X400	867/434	8d@100	230X430	1355/630	8d@100
RBE	Low code (WSM)	230X375	358/226	6d@215	300X380	463/226	6d@210
	Medium code (LSM)	230X275	535/226	6d@185	230X350	530/226	6d@200
	High code (Ductile)	230X275	595/298	6d@100	230X350	530/360	8d@100
RBC	Low code (WSM)	230X465	442/226	6d@185	300X500	633/226	6d@155
	Medium code (LSM)	230X335	675/226	6d@135	230X410	842/226	6d@120
	High code (Ductile)	230X335	705/353	6d@100	230X410	853/510	8d@100

Table III. Geometry and area of steel of columns of 3 and 5 storey building

Frame members		Three Storey			Five Storey		
		Cross-section (mm^2)	Rebar (mm^2)	Spacing (mm)	Cross-section (mm^2)	Rebar (mm^2)	Spacing (mm)
C1	Low code (WSM)	300X360	1467	6d@192	380X600	3725	8d@250
	Medium code (LSM)						
	High code (Ductile)		1893	8d@75		6143	10d@75
C2	Low code (WSM)	230X275	758	6d@230	300X420	1889	6d@224
	Medium code (LSM)						
	High code (Ductile)	300X300	758	8d@75		2750	10d@75
C3	Low code (WSM)	230X230	500	6d@192	230X330	1062	6d@224
	Medium code (LSM)						
	High code (Ductile)	300X300	720	8d@75	300X300	1378	10d@75

V. RESULTS & DISCUSSIONS

Above mentioned cross-section sizes and reinforcement details are defined in section designer and assigned to respected beams and columns. The moment-curvature values of the cross-sections are taken from the section designer, used to define hinge properties, the defined hinges are assigned at start and end of beams as M3 and columns as P-M-M hinges. The typical moment-curvature curves of floor beam centre and edge column as shown in fig.(4a) and (4b). It is observed medium code has low moment carrying capacity and high ductility compared to low code. In low code, high moment carrying capacity and low ductility and in high code both moment and ductility is high as compared to both low and medium code. In column member, moment carrying capacity and ductility is same for low and medium code because of the same cross and reinforcement details and whereas high code moment and ductility is increased as compared to low to medium code. The nonlinear static analysis (pushover) has performed in the SAP2000 computer program. The displacement control with 4% of drift is applied for all models to perform the pushover analysis. The load combination of (DL+0.25 LL) is used for pushover analysis.

In order to study the influence of the design philosophy on the overall behaviour of the structure, the parameters referring to aspect ratio and the number of levels were kept constant, and only the design philosophy was varied during the performed analyses.

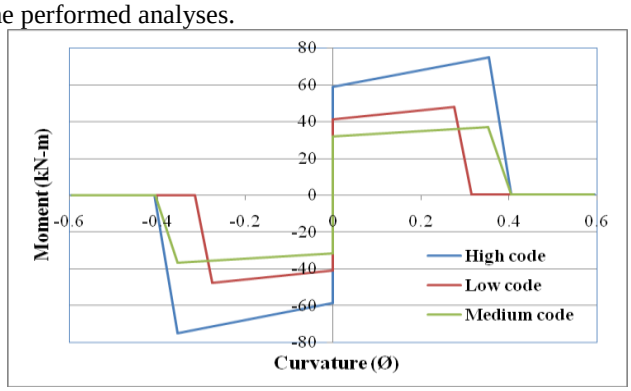


Fig.4a. Moment Curvature for floor beam centre of the three-storey building.

The fig. (5a**)** shows for the pushover curves considering the five-story structure of aspect ratio 1 and 0.5 with the low code, medium code and high code. It is observed, the maximum base shear and roof displacements are in high code and least low code.

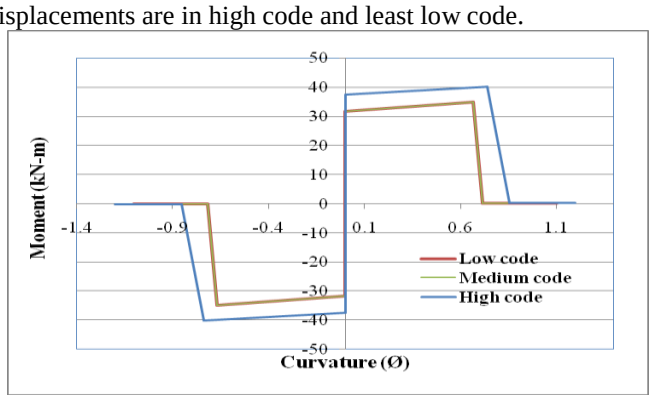


Fig.4b. Moment Curvature for edge column of three storeys building.

As aspect ratio 1 to 0.5, the base shear and roof displacement values increases and as well stiffness values also increases. As aspect ratio increase base shear is increasing because of number bays increases in both direction of the building. The maximum and minimum base shear and roof displacement values of a five-storey building with low to high code and AR-1 is 2043 kN and 1334 kN and 68 cm and 60 cm respectively. In AR-0.5, the maximum and minimum base shear is 8370kN and 4277kN, and maximum and minimum roof displacement is 68 cm and 60 cm respectively. The base shear values for AR-1 and high code is 1.53 times low code,

1.26 times medium code respectively. The base shear values for AR-0.5 and high code is 1.95 times low code, 1.57 times medium code respectively. It is observed that the roof displacement is slightly varying in low to high code and AR-1 to 05. The three-storey pushover curves for aspect ratio 1 and 0.5 and low to high code as shown in fig. (5b). It is observed the maximum base shear and roof displacements are in high code and least in low code. As aspect ratio 1 to 0.5, the base shear and roof displacement values increases and as well stiffness values also increases. As aspect ratio increase base shear is increasing because of number bays increases in both direction of the building. The maximum and minimum base shear and roof displacement values of a three-storey building with low to high code and AR-1 is 493kN and 243.60 kN and 38 cm and 35.90 cm respectively. In AR-0.5, the maximum and minimum base shear is 1910 kN and 1062 kN, and maximum and minimum roof displacement are similar to AR-1. The base shear values for AR-1 and high code is 2 times low code, 1.64 times medium code respectively. The base shear values for AR-0.5 and high code is 1.70 times low code and 1.58 times medium code respectively. It is observed that the AR-0.5 has the highest capacity curve and AR-1 has the lowest values for the capacity curve. This result is due to the fact that adding columns leads to stiffness and strength increase which, consequently, leads to better behaviour. As storey height increases, base shear and roof displacement increase and as design philosophy changed low to high code, base shear and roof displacement have been changed irrespective of aspect ratios.

The capacity curve is defined as a graphical representation of spectral displacement vs spectral acceleration. The capacity curve obtained from the pushover curve and conversion parameter are considered to convert pushover to capacity curve i.e. base shear, the weight of the structure, modal mass participation factor, modal mass, modal amplitude. The capacity curves are shown in fig.(6a) and (6b). After conversion capacity curve, in each modal, yield and ultimate spectral displacement and acceleration are noted.

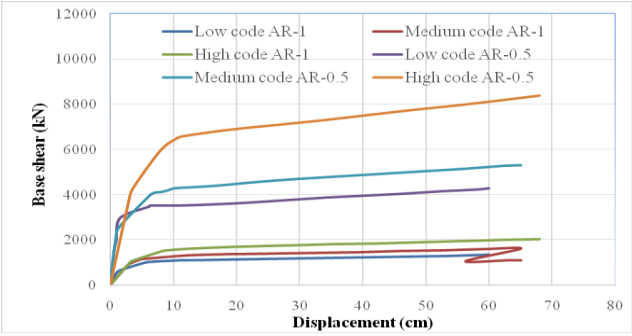


Fig.5a. Pushover curves for five storeys AR-1 & 0.5 for design philosophies low code, medium code and high code.

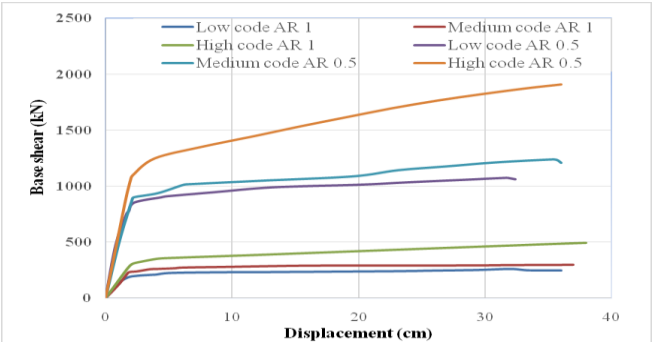


Fig .5b: Pushover curves for three-storey building AR-1 & 0.5 for low code, medium code and high code.

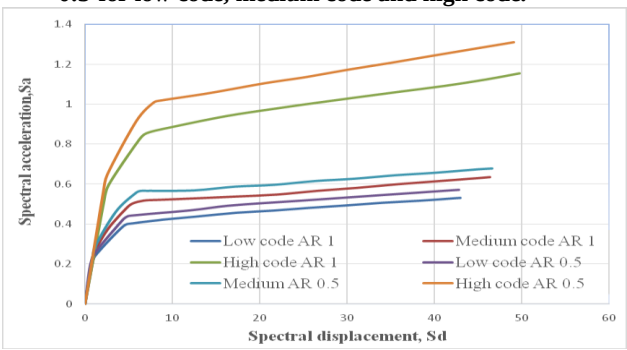


Fig.6a. Capacity curves for five-storey building AR-1 & 0.5 for low code, medium code and high code.

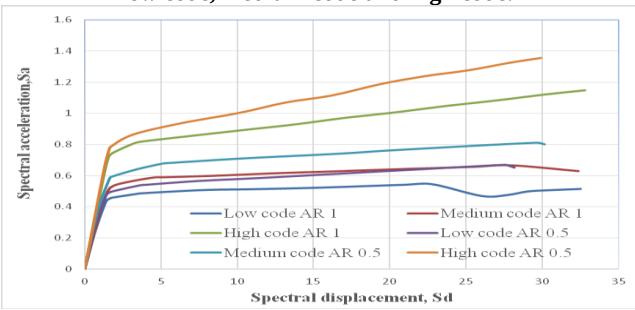
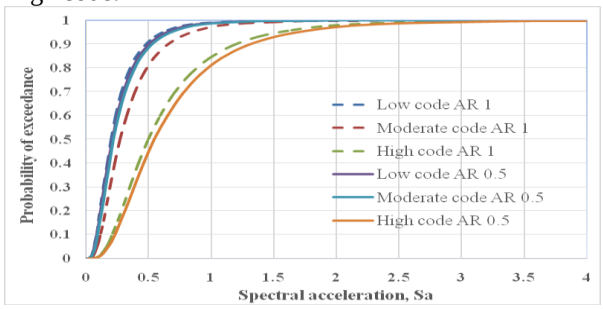


Fig .6b: Capacity curves for three-storey building AR-1 & 0.5 for low code, medium code and high code.

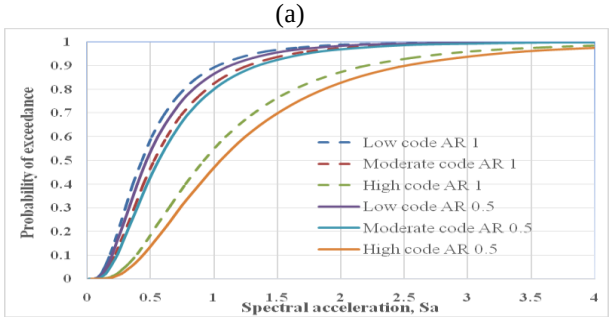
The damage states are calculated using equation 1for slight, moderate, extensive and collapse

state.The fragility curves are

derived using equation 2 and plotted in x-axis as spectral acceleration, and y-axis as the probability of exceedance is shown in fig.(7) and (8) for five and three storeys, designed with low, medium and high code. It observed low code as a higher probability of damage and high code has a low probability of damage for five and a three-storey building. The slight and moderate damage is the same for five-storey building for low and medium cod for aspect ratio 0.5. For aspect ratio-1, results show that probability damage is slightly greater than aspect ratio 0.5 for all spectral acceleration and as well all damage states. The aspect ratio decrease expected damage is decrease and also low code designed building more vulnerable than high code building. It also found that height building increase expected damage increase and also aspect ratio decrease expected damage also reduced in low, medium and high code.



(a)



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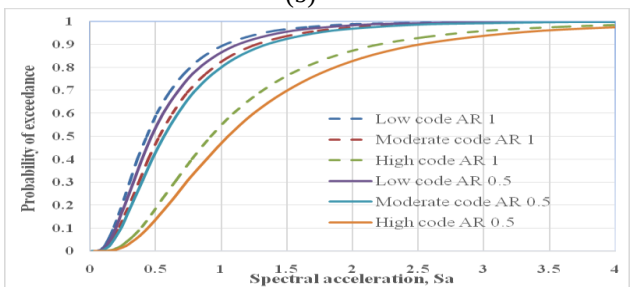
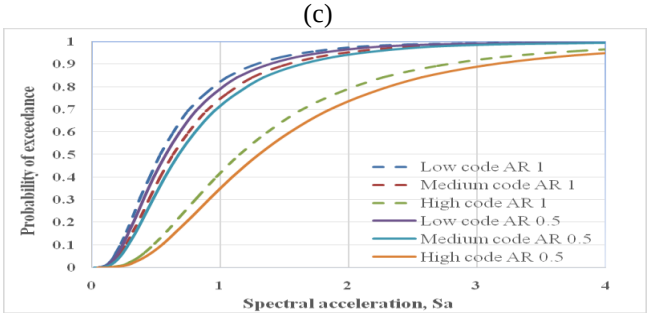
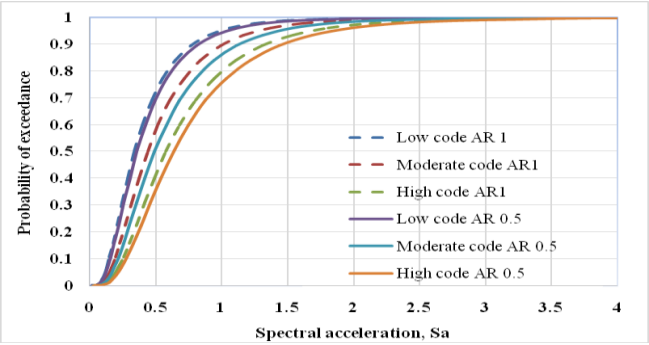


(c)

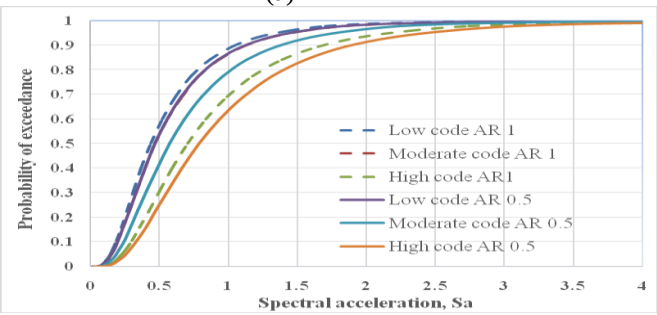


(d)

Fig.7. Fragility curves for a five-story building with different damage states (a) Slight, (b) Moderate, (c) Extensive and (d) Collapse.



(a)



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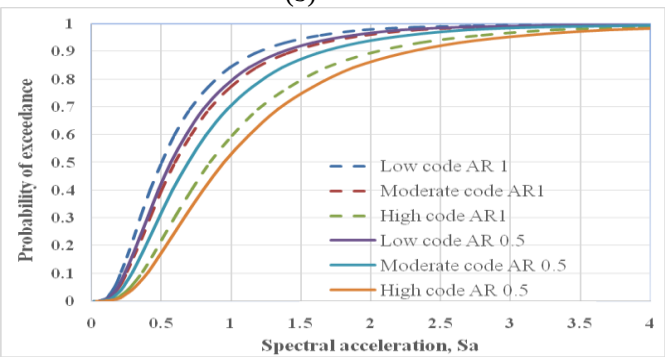
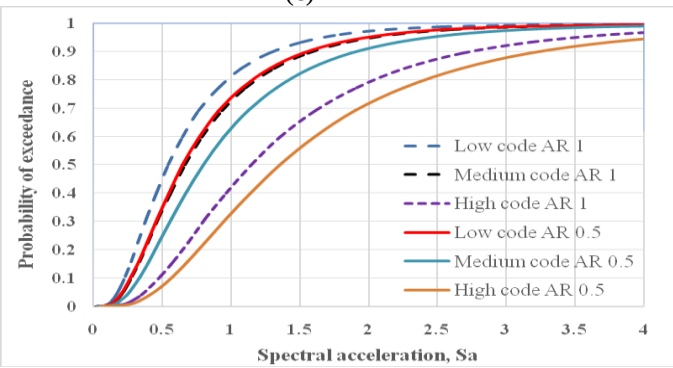


(c)



(d)

Fig.8: Fragility curves for a three-story building with different damage states (a) Slight, (b) Moderate, (c) Extensive and (d) Collapse.

Assumed the expected PGA=0.36g (seismic zone-V) is considered as per IS1893-2016

for all models. For collapse damage state, the expected probability damage of building for 5 storey building, AR-1 is 30.8%, 22.6% and 4.2% for Low, medium code and high code respectively. Similarly, for 5 storeys AR 0.5 is 24.63%, 17.6% and 2.94% for Low, medium code and high code respectively. In three-storey AR-1 of expected damage is 27%, 18% , 4% and AR-0.5 of expected damage is 19.2%, 12% and 2.56% for low, medium and high code respectively. It observed that a low percentage of damage in high code compared to medium and low code. The building design is as per IS high code much safer future event of the earthquake than the medium and low codes.

VI.CONCLUSIONS

- In this study, fragility curves are derived for the buildings designed as per low code, medium code and high code for three and five stories with aspect ratio 1 and 0.5.
- It is observed medium code has low moment carrying capacity and high ductility compared to low code. In low code, high moment carrying capacity and low ductility and in high code both moment and ductility is high as compared to both low and medium code. In column member, moment carrying capacity and ductility is the same for low and medium code because of the same cross and reinforcement details and whereas high code moment and ductility is increased.
- The obtained results reveal that there is a directly proportional relationship between the number of story and vulnerability of structure. The vulnerability increases with an increased number of stories. As aspect ratio decreases, probability damage is also decreased because of an increasing number of bays both directions.
- The obtained results confirm that building designed with high code have less probability of damage than to medium and low code. The building is designed high code gives better performance than medium and low code.

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