Journal of Civil Engineering and Environmental Technology
Print ISSN: 2349-8404; Online ISSN: 2349-879X; Volume 2, Number 6; April-June, 2015 pp. 520-522

http://www.krishisanskriti.org/jceet.html

Developing Fragility Curves for Vulnerability Assessment of RC Structures

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Abstract—*Here it's shown how to develop fragility curves , common methods of fragility curves , and assessing the vaulaunrebility of structures by conducting pushover analysis using SAP2000,And as well how the fragility curves differ for low rise, midrise and high rise buildings , with interpretation of SAP200 pushover analysis results, devolving fragility curves using HAZAUS method and Barbat (2008) suggested damage state threshold values ,calculating* β_{ds} *lognormal standard distribution values using HAZAUS MH-MR1-MR3 technical manuals with respect to rise of building seismic design code era.*

Introduction Since it's a rapid growing demand to know how the performance of existent and new building is. While knowing the performance (resistance) of a structure can help the owner to know what will happen if certain earthquake occurs, by understanding the damage state of building the owner can decide to enhance the building strength with appropriate retrofit strategy which leads to great victory of saving lives,

Day by day the urbanization moves up and we see high rise buildings to meet the rising population requirements, to meet these requirements safely and save the people from loss of life in heavy earthquakes like (Gujrat 2000),

So here is how to estimate the building loss for different rise of buildings,

For developing the loss estimation or fragility curves we need to do pushover analysis for concerned buildings using ATC-40 instruction for modeling and lateral loading.

After conducting the proper pushover analysis and getting the performance point (The intersection of demand & capacity curve), to develop the curves we use HAZAUS and Barbat et al (2008) methods

1. HAZAUS METHOD

The standard formula for loss estimation or the probability of being in or exceeding a given damage state is modeled as cumulative lognormal distribution.

$$P\left[\frac{ds}{Sd}\right] = \emptyset[\left(\frac{1}{\beta_{ds}}\right) * \ln\left(\frac{S_d}{\bar{S}_{ds,ds}}\right) \text{Eq (5.3) HAZAUS}$$

$\bar{S}_{d,ds}$= Is the median value of spectral displacement at which the building reached the threshold of damage state, ds.

β_{ds}= Is the standard deviation of natural logarithm of spectral displacement of damage state, ds.

$\emptyset$= Standard normal cumulative distribution function.

S_d= spectral displacement.

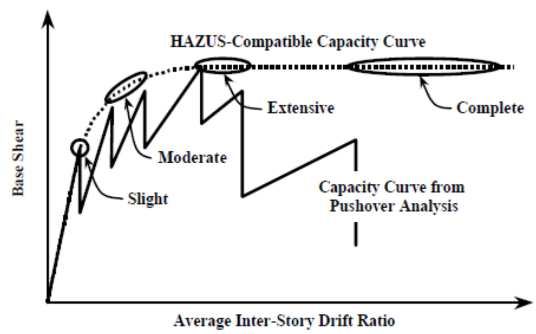

Fig. . 1: Example damage state medians of saw-tooth pushover curve.

So now in this formula we need to find out the $\bar{S}_{d,ds}$from pushover analysis result and β_{ds}form HAZAUS Technical manual (5.11-5.11d).

$$\bar{S}_{d,ds} = \Delta_{ds} * \alpha_2 * H_R \text{Eq(5.4) HAZAUS-MHR3}$$

Δ_{ds}= Drift ratio of damage stated threshold which can be found from pushover analysis (Fig. :1) base shear vs displacement , the Fig. .1 shows the first point when some elements start to yield is the Slight damage when the drift ratio moves on the damage states gets changes to Moderate, Extensive and Complete so the drift these threshold damage states can be taken from pushover analysis results of Base shear vs displacement so from this pushover curve the last four (4) values of displacement can be taken and divide each of them on H_R(Total height of building)

$$Drift\ ratio = \frac{Roof\ \ displacement}{Total\ \ building\ \ height}$$

So the Δ_{ds}(Drift ratios of damage state threshold) would be gotten.

α_2= Pushover modal factor which the fraction of building height at location of pushover model displacement which can be calculated according Eq (5-2) of HAZAUS-MHR1 and can be taken from HAZAUS-MHR3 Table 5.5 with respect to rise of buildings.

H_R=Total height of building for structural fragility curves we need to take the real height of building to get closer view of building response and for non-structural elements whether that's drift sensitive or acceleration sensitive we can use the model type building height from table (5.11-11d) because the nonstructural elements have the method of installation everywhere so it could be same sensitive to same magnitude of acceleration and drift ratio.

So calculating the Eq (5.4) will give us the damage sate threshold values for structural displacement.

β_{ds}= Is the lognormal standard deviation that describes the total variability for structural damage states.

Since the loss estimation is an approximate method so to get closer to real response and diminish more variability that's why we are using β_{ds} which is the combination of $\beta_c$variability in capacity of building, $\beta_D$variability in demand of building and $\beta_{T,ds}$ lognormal standard deviation that describes the variability of the threshold of the damage states, to overcome and diminish the variability we can convolve this with mathematical process and calculate

(SRSS) square root sum of squares with following relation.

$$\beta_{ds} = \sqrt{\left(Convo[\beta_D, \beta_{(D)}]\right)^2\Big) + \left(\beta_{T,ds}\right)^2}$$

β_C= variability in capacity of structural and non-structural elements ranges from (0.1-0.4) and $\beta_{T,ds}$variability in damages stated thresholds we can find out $\beta_{T,ds}$from Table (6.5-6.7) with respect to rise of buildings, degradation level and $\beta_C$variability value(0.1-0.4) for different damage variability (Small, Moderate, large) , so getting the $\beta_{T,ds}$ values from (6.5-6.7) table the $\beta_D = 0.45$ for short periods and $\beta_D = 0.5$ for long periods value are used for developing the table (6.5-6.7).

So doing the SRSS and convolution process will get the combined variability of damage states.

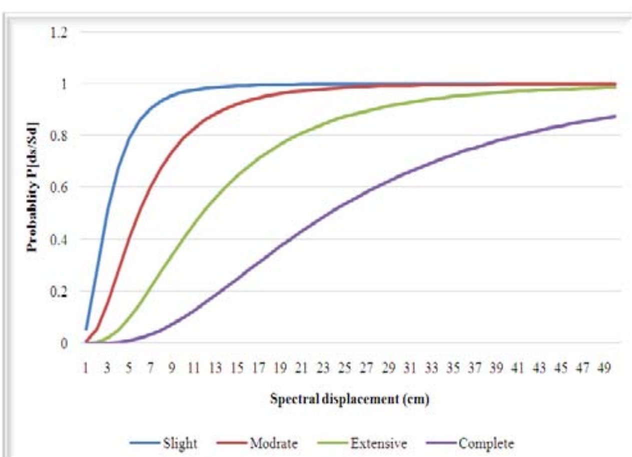

Fig. . 2: Fragility curves representation

Or we can get$\beta_{ds}$from table (5.11-5.11d) of HAZAUS-MHR3 with respect to rise of building and code era (high code, moderate code, low code, pre-code seismic design level) for different damage states (Slight, Moderate, Extensive, Complete).

After finding and choosing all those values concerned in standard formula Eq(5.3) Standard normal cumulative distribution function, we can write an excel sheet and MATLAB coding to draw the cumulative distribution function,

Which show the probability of damage states related to spectral displacement.

2. BARBAT METHOD (20008)

This method has been proposed by the framework of Risk UE-project (Risk UE-20004) and have been used for seismic risk studies of many European earthquake prone cites, the first expert opinion was suggested by Barbat, which relates the expected damages states with stiffness degradation of structure.

In this method tow states of building is considered for calculating damage stated medians, tow states are the

1: Yield point
2: Ultimate point

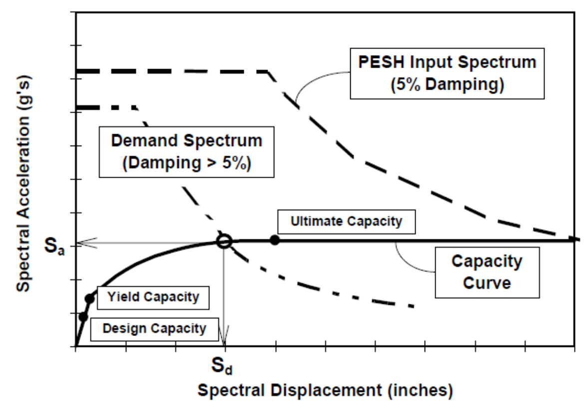

Fig. . 3: Building Capacity curve and Demand spectrum.

So here the D_y=Yield point of building and D_u=is the ultimate point of building, where both can be found from pushover analysis results of Capacity curve (ATC-40) by SAP2000, to find out D_y&D_u we need to plot the capacity spectrum from pushover analysis and choose the yielding point and ultimate point, here the user can judge according to Fig. 4 diagram to choose where the capacity curve changes its way to yield and the ultimate point is normally the end point of capacity spectrum, so whenever its decided about these point then we can switch D_y&D_u values in the following suggested expressions for damage state medians

Slight=0.7D_y

Moderate=D_y

Extensive=$D_y + 0.25(D_u - D_y)$

Complete= D_u

So after calculating these values for damage states medians, the β_{ds} lognormal standard deviation values can be found the same way described for HAZAUS method, or can be taken from HAZAUS-MHR3 Technical manual Table (5.11-5.11d) according to rise of buildings seismic code era (High code, moderate code, low code and pre-code).

And switching in the main loss function (5.3) equation and plotting it will give us the fragility curves. As in Fig. : 3

Fragility curves for drift sensitive non-structural elements.

Since for non-structural drift sensitive materials we can see Table2.4 of HAZAUS MHR1 for classification for drift sensitive and acceleration sensitive elements the curves are same for all same modal types of buildings.

To develop fragility curves for non-structural drift sensitive elements we can use table (5.11-5.11d) to get damage stated medians (slight, moderate, extensive and complete) directly from concerned tables with respect to rise and seismic code level of building.

And switch in to main (5.3) formula for cumulative distribution.

3. FRAGILITY CURVES FOR NON-STRUCTURAL ACCELERATION SENSITIVE.

To develop fragility curves for non-structural acceleration we can use Table (5.13-5.13d) to get the damage state medians and β_{ds} values for variability.

Here the acceleration values are directly equal to damage state medians of acceleration (Slight, Moderate, Extensive and Complete)

So switching all those median and Beta values in main (5.3) loss function will lead us the fragility curve.

4. CONCLUSION

The HAZAUS method is based on base shear vs displacement which needs to be converted to spectral displacement by using Eq: (5.4), the results from SAP2000 pushover analysis as in given Fig. : 4

TABLE: Pushover Curve - Push Y S3 Z4

Step	Displacement	BaseForce	AtoB	BtoIO	IOtoLS	LStoCP	CPtoC	CtoD	DtoE	BeyondE
	cm	KN								
0	0	0	518	0	0	0	0	0	0	0
1	0.864132	987.169	517	1	0	0	0	0	0	0
2	13.032119	9684.957	230	288	0	0	0	0	0	0
3	25.279938	15867.147	176	319	23	0	0	0	0	0
4	34.112458	20265.693	171	250	97	0	0	0	0	0
5	30.352383	15996.768	171	249	97	0	0	1	0	0

Fig. 4: From SAP2000 pushover curve V vs D

To get the damage state medians.

And Barbat method is based on spectral displacement yield point and ultimate point, from pushover analysis results of SAP2000, Fig. 5. The curves based on spectral displacement directly is more uniform than HAZAUS method and got smooth shape than HAZAUS and easy to develop but the results are not considerable different, having the same discrete damage states.

TABLE: Pushover Curve Demand Capacity - ATC40 - Push X S2 Z3

Step	Teff	Beff	SdCapacity	SaCapacity	SdDemand	SaDemand	Alpha	PFPhi
			cm		cm			
0	0.978471	0.05	0	0	9.7223	0.408801	1	1
1	0.978471	0.05	0.6692	0.028137	9.7223	0.408801	0.728325	1.155196
2	1.109563	0.057426	10.9957	0.359548	10.6464	0.348127	0.787629	1.190054
3	1.126779	0.059868	19.6486	0.623007	10.6957	0.339135	0.790292	1.201498

Fig. 5: Pushover curve demand capacity from SAP2000

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