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VULNERABILITY ASSESSMENT OF AN EXISTING BUILDING BY DAMAGE PROBABILITY MATRIX BASED ON PUSHOVER ANALYSIS

Mitu Das[1], Md. Jahir Bin Alam[2] and Mohammad Rafiqul Islam[3]

[1]Student, Department of Civil and Environmental Engineering, Shahjalal University of Science and Technology, Bangladesh, e-mail: mitudas52@gmail.com
[2]Professor, Department of Civil and Environmental Engineering,Shahjalal University of Science and Technology, Bangladesh, e-mail: jahiralam@yahoo.com
[3]Assistant Professor, Department of Civil and Environmental Engineering,Shahjalal University of Science and Technology, Bangladesh, e-mail: rafiqul-cee@sust.edu

ABSTRACT:

Bangladesh is extremely vulnerable to earthquake especially the Sylhet city. In order to predict the likely impact of an earthquake on an existing building it is essential to know the seismic vulnerability of that existing building on the affected areas.This paper mainly focus about the procedures of assessing the seismic vulnerability of existing R.C.C buildings in Sylhet city. The objective of the paper is to develop damage probability matrix which represent the vulnerability of a particular structure for our country. First of all, the types of the structures are reviewed anda classification of structure based on the available data with HAZUS technical manual is done. Then the seismic vulnerability will be assessed by pushover analysis using ETABS software (Extended Three Dimensional Analysis of Building System)-version 9.6. After this nonlinear analysis the value of spectral displacement, ultimate capacity and yield capacity can be determined from capacity spectrum curve. Third, the theoretical methodology of the vulnerability analysis using fragility curve parameters given by HAZUS for typical structure are presented and performance of structure is calculated by using capacity spectrum method. At last a damage probability matrix can be formed based on this available data.

Keywords: *Seismic vulnerability, damage probability matrix, pushover analysis, spectral displacement, capacity spectrum curve*.

1. INTRODUCTION:

Bangladesh is always vulnerable to earthquake. Since the whole Indian subcontinent is situated on the junction of Indo-Australian plate and Eurasian plate, the tectonic evaluation of Bangladesh can be explained as a result of collision of the north moving Indo- Australian plate with the Eurasian plate. Besides, there are several fault zones active in this junction area, which are the sources of earthquake. Sylhet is extremely vulnerable to earthquake especially due to the presence of SubDauki fault zone(Bolt.B.A, 1987) and is located in seismic zone 3 according to BNBC 2006. Recently developed earthquake catalogue for Bangladesh and surrounding areas show 765 earthquakes with M_s>4.0 have occurred from 1865 to 1999 within a 300km radius of Sylhet city(Sharfuddin, 2010).Among these,there are 28 earthquakes with M_s>6.0 which have resulted in over thousands deaths and caused enormous damage to property, assets and infrastructure. It is evident from past fatal earthquakes around the world that the existence of vulnerable building in high intensity areas has in most cases contributed the total human loss.From the studies it was found that, in Sylhet, a larger proportion of buildings are old, non-engineered, without foundation, without continuous lintel and irregular shaped, which are vulnerable to earthquake.On the other hand, most of the new buildings are unplanned and designed without considering earthquake risk(Ahmed M., Chowdhury, Ahmed, & Rahman, 2005).

In order to predict the likely impact of an earthquake on an existing building it is essential to know the seismic vulnerability of that existing building on the affected areas. Vulnerability assessment is also useful in estimation of consequences of building damage such as casualties and economic losses(Coburn & Spence, 2002). One of the best effective way of assessing seismic vulnerability of an existing building is nonlinear analysis called pushover analysis. This can be done by various software like ETABS, ABAQUS, SAP2000 etc. Through this nonlinear analysis yield and ultimate capacity of a structure can be easily determined which will be helpful to determine the probability of a structure of being vulnerable. Vulnerability assessment of such seismically active area helps local authorities in proper disaster management. In this paper, an attempt has been made to establish a procedure of assessing seismic vulnerability of an existing mid-rise and low rise building for a seismically active area like Sylhet.

2. METHODOLOGY:

Here the methodology adopted by HAZUS is used in this paper. The entire procedure can be divided into eight steps from the input requirement to the development of damage probability matrix.

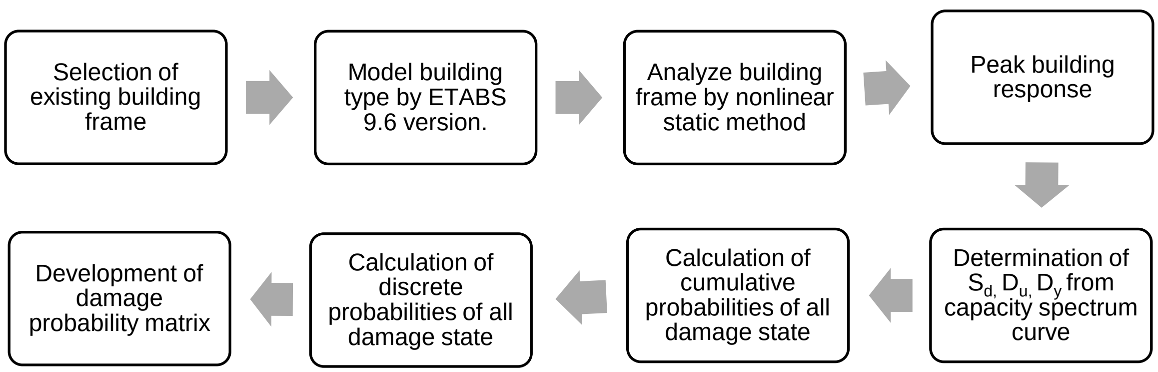


Figure 1: Flow chart of the working procedure

2.1 Building Classification:

The basic model building types are based on FEMA-178 (FEMA, 1992) building classes. Building height subclasses are added to reflect the variation of typical building periods and other design parameters with building height. A listing of structural building types, with corresponding labels, descriptions, and heights, according to HAZUS is provided in Table 1 and used in the development of Damage Probability Matrix.

Table 1: classification based on material and story height (HAZUS-MH, 2003)

NO.	Level	Description	Range	
			Name	Stories
1	C1L		Low-Rise	1 - 3
2	C1M	Concrete Moment Frame	Mid-Rise	4 - 7
3	C1H		High-Rise	8+

2.2 Selection of Building Frame:

The study work has been conducted for two existing building in Sylhet city.

1. One is C1M type normal R.C.C commercial building named “Rahman Mansion”. The floor plan and beam layout is shown in figure 2.
2. Another one is C1L type, flat slab,residential building. The floor plan is given in figure 3.

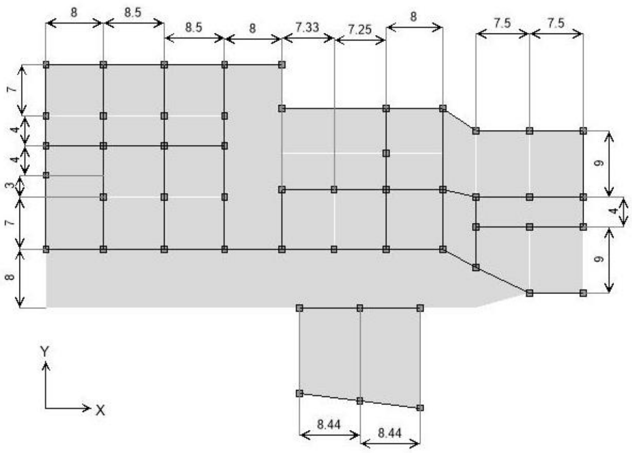


Figure 2: Floor plan of C1M type building

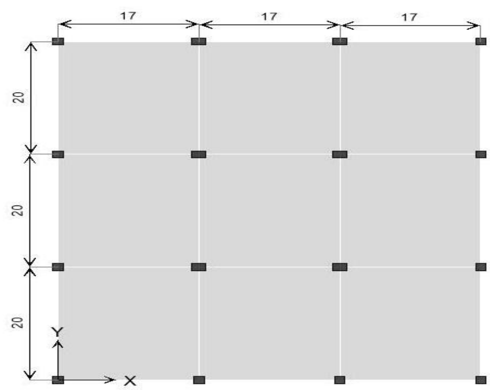
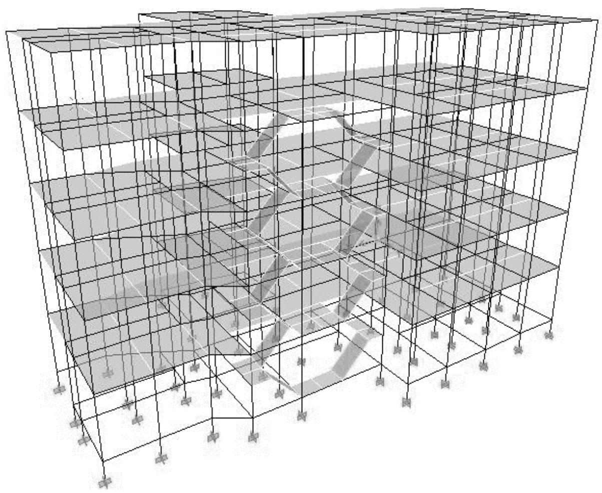


Figure 3: Floor plan for C1L type building

2.3 Model Data For Analysis:

Topic	C1M	C1L
Number of storey	5	1
Storey height	10 ft	10 ft
Type of frame	RC moment resisting frame fixed at base.	RC moment resisting frame fixed at base.
Size of corner column	10”×10”	15”×15”
Size of edge and mid column	10”×10”	20”×15”
No of bar of corner column both above and below GL	4 nos 5/8”	-
No of bar of edge and mid column both above and below GL	6 nos 5/8”	-
Typical beam dimension	10”×10”	-
Thickness of slab	4”	6”
Compressive strength of concrete, f_c’	4000 psi.	4000 psi.
Yield strength of steel, f_y’	60000 psi.	60000 psi.
Modulus of elasticity of concrete, E	3600 ksi.	3600 ksi.
Live load on slab	120 psf	40 psf
Floor finish	30 psf	30 psf
Live load on stair	100 psf	-

Earthquake loads are calculated directly by ETABS 9.6 in accordance to UBC-94.The model of these two type of buildings has been shown in figure 4 and 5 which has been established by ETABS-9.6.



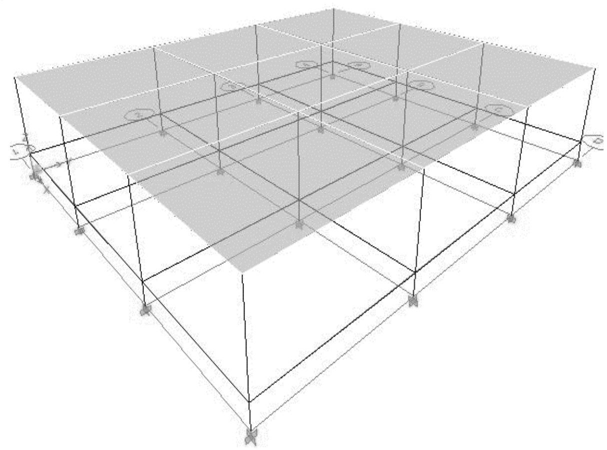


Figure 4: Final model of C1M type building Figure 5: Final model of C1L type building

2.4 Pushover Analysis:

Pushover analysis is a non-linear analysis procedure to estimate the strength capacity of a structure beyond its limit state up to its ultimate strength. It can help demonstrate howprogressive failure in building most probably occurs, and identify the mode of final failure. Pushover analysis can be useful under two situation:

- When an existing structure has deficiencies in seismic resisting capacity.
- When a building is to be retrofitted to meet the seismic demands, pushover analysis can show how much where the retrofitting is required and how much.

In ETABS more than one pushover case can be assigned. In this case two pushover cases are used. In first case, gravity loads (dead, live, FF) and in second case, lateral loads (EQ-X, EQ-Y) is used.

The pushover hinges on themodel by selecting one or more framemembers and assigning them one ormore hinge properties and hingelocations is located.

2.4.1 Pushover Curve:

After conducting non- linear analysis pushover curve is formed. Pushover curve is a plot of base shear (V_b) vs roof displacement (Δr_t). Roof displacement is the displacement at the center of mass of the general roof.

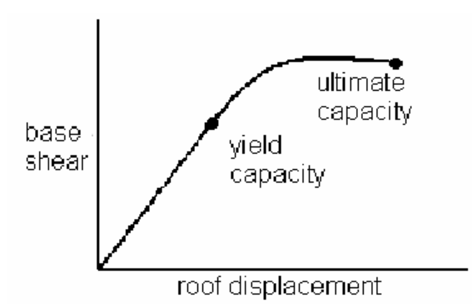


Figure 6: Typical pushover curve

After establishing pushover curve **capacity spectrum method** is used for post processing in this study as detailed in ATC-40.

2.4.2 Capacity Spectrum Curve:

Capacity spectrum curve is a plot of spectral acceleration (S_a) vs spectral displacement (S_d) which is a representation of a structure's ability to resist the seismic demand(Deepak S Bashetty, S. Veeramani, & Dr Krishnamoorthy, 2015). Spectral acceleration is a unit measured in g (acceleration due to earth's gravity) that describes the maximum acceleration in an earthquake on an object. The displacement in a single degree of freedom (SDoF) model due to spectral acceleration is called spectral displacement.

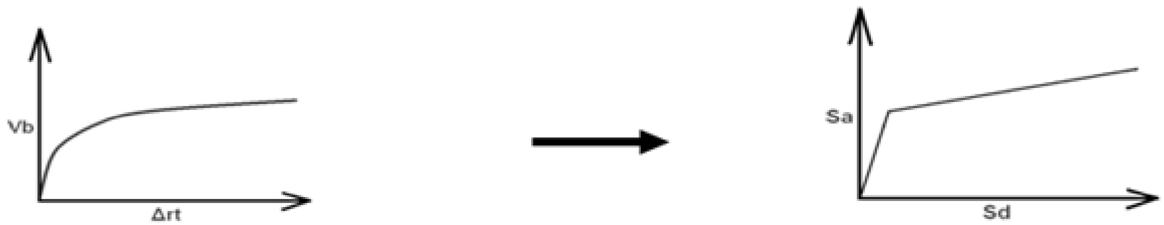


Figure 7: Converting pushover curve to capacity spectrum curve

The multi degree of freedom (MDoF) parameters ($V_b$and Δr_t)of pushover curve can be converted into single degree of freedom (SDoF) parameters ($S_a$and S_d) of capacity spectrum curve by the following equations:

$$Sa = (Vb / W) / \alpha 1 \quad (1)$$

$$Sd = \Delta rt / (PF1 \times \phi 1i, roof) \quad (2)$$

Where,

W= Total dead load of the building

α_1= Modal mass participation for first natural mode and relates base shear

PF_1= Modal participation factor for first natural mode and relates displacement to SDoF.

$\phi_{1i,roof}$=Amplitude of model 1 at level i.

2.4.3 Demand Spectrum Curve:

Demand spectrum curve is a plot of spectral acceleration (S_a) vs spectral displacement (S_d) which is a representation of earthquake ground motion.

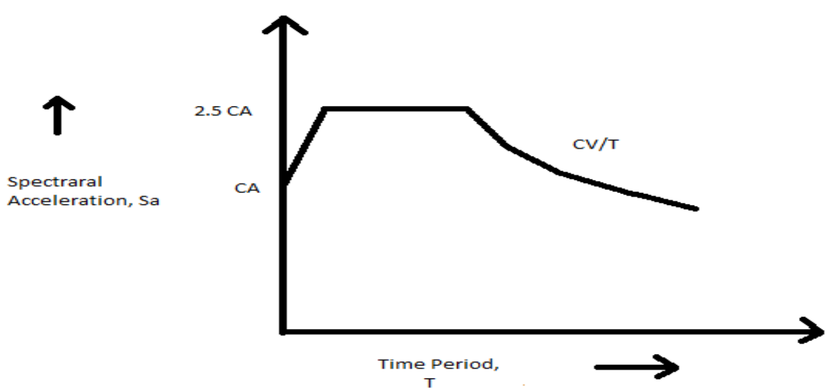


Figure 8: Typical demand spectrum curve

2.5 Performance Point or Peak Building Response:

Intersection point of capacity spectrum curve and demand spectrum curve for effective damping ratio is called performance point. That means, at this point the demand and capacity of a structure to resist the lateral force produced due to earthquake is met. It represents the maximum inelastic capacity of the structure.

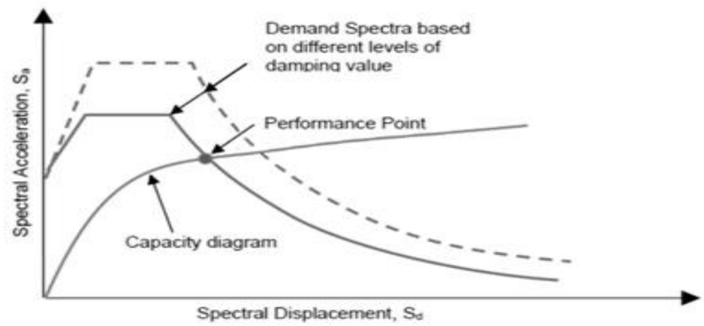


Figure 9: Intersection of capacity spectrum curve and demand spectrum curve

2.6 Determination of S_d, D_y, D_u:

- The data of spectral displacement, and ultimate displacement has been collected at the performance point which can be directly obtained from capacity and demand spectrum curve table.
- But the yield displacement can't be obtained directly from the table like the ultimate displacement. It has to be determined manually from the capacity curve. It is the value upto which the capacity curve remains linear or the slope of the curve remains equal.

2.7 Definition of Damage States:

According to HAZUS, damage states are divided in four classes as shown in Table 2.

Table 2: Damage states thresholds defineswith the agreement of capacity spectrum

Sd1= 0.7 D_y	**Slight**
Sd2= D_y	Moderate
Sd3= D_y+0.25(D_u-D_y)	Extensive
Sd4= D_u	Complete

Where,
S_d is spectral displacement and suffix 1, 2, 3, 4 show slight damage, moderate damage, extensive damage, and complete collapse respectively.
A_y = yield spectral acceleration
A_u = ultimate spectral acceleration.
D_y = yield spectral displacement
D_u = ultimate spectral displacement.

2.8 Cumulative Damage Probabilities:

For a given damage state, P [S | S_d], P [M| S_d], P [E | S_d], P [C | S_d] a fragility curve is well described by the following lognormal probability density function (Barbat, Lagomarsino, & Pujades , 2002), (HAZUS-MH, 2003).

$$P[ds|Sd] = \varphi[\frac{1}{\beta ds} ln\left\{\frac{Sd}{Sd,ds}\right\}] \quad (3)$$

Where $S_{d,ds}$is the threshold spectral displacement and Table2 shows how the threshold obtain from capacity spectrum (Barbat, Lagomarsino, & Pujades , 2002), β_{ds} is the lognormal standard deviation parameter which has been described in Table 3. Φ is the standard normal cumulative distribution function and the table has been provided in Table 4 and S_d is the spectral displacement of the structure.

Where,
P [S | S_d] = probability of being in or exceeding a slight damage state, S.
P [M | S_d] = probability of being in or exceeding a moderate damage state, M.
P [E | S_d] = probability of being in or exceeding an extensive damage state, E.
P [C | S_d] = probability of being in or exceeding a complete damage state, C.

Table 3: Structural Fragility Curve Parameters - High-Code Seismic Design Level (HAZUS-MH, 2003)

Type	**Slight, β_S**	**Moderate, β_M**	**Extensive, β_E**	**Complete, β_C**
C1	0.81	0.84	0.86	0.81
C2	0.68	0.67	0.68	0.81

Table 4: Table of the Standard Normal Cumulative Distribution Function Φ (*z*)

z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
-3.4	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0002
-3.3	0.0005	0.0005	0.0005	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0003
-3.2	0.0007	0.0007	0.0006	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005
-3.1	0.0010	0.0009	0.0009	0.0009	0.0008	0.0008	0.0008	0.0008	0.0007	0.0007
-3.0	0.0013	0.0013	0.0013	0.0012	0.0012	0.0011	0.0011	0.0011	0.0010	0.0010
-2.9	0.0019	0.0018	0.0018	0.0017	0.0016	0.0016	0.0015	0.0015	0.0014	0.0014
-2.8	0.0026	0.0025	0.0024	0.0023	0.0023	0.0022	0.0021	0.0021	0.0020	0.0019
-2.7	0.0035	0.0034	0.0033	0.0032	0.0031	0.0030	0.0029	0.0028	0.0027	0.0026
-2.6	0.0047	0.0045	0.0044	0.0043	0.0041	0.0040	0.0039	0.0038	0.0037	0.0036
-2.5	0.0062	0.0060	0.0059	0.0057	0.0055	0.0054	0.0052	0.0051	0.0049	0.0048
-2.4	0.0082	0.0080	0.0078	0.0075	0.0073	0.0071	0.0069	0.0068	0.0066	0.0064
-2.3	0.0107	0.0104	0.0102	0.0099	0.0096	0.0094	0.0091	0.0089	0.0087	0.0084
-2.2	0.0139	0.0136	0.0132	0.0129	0.0125	0.0122	0.0119	0.0116	0.0113	0.0110
-2.1	0.0179	0.0174	0.0170	0.0166	0.0162	0.0158	0.0154	0.0150	0.0146	0.0143
-2.0	0.0228	0.0222	0.0217	0.0212	0.0207	0.0202	0.0197	0.0192	0.0188	0.0183
-1.9	0.0287	0.0281	0.0274	0.0268	0.0262	0.0256	0.0250	0.0244	0.0239	0.0233
-1.8	0.0359	0.0351	0.0344	0.0336	0.0329	0.0322	0.0314	0.0307	0.0301	0.0294
-1.7	0.0446	0.0436	0.0427	0.0418	0.0409	0.0401	0.0392	0.0384	0.0375	0.0367
-1.6	0.0548	0.0537	0.0526	0.0516	0.0505	0.0495	0.0485	0.0475	0.0465	0.0455
-1.5	0.0668	0.0655	0.0643	0.0630	0.0618	0.0606	0.0594	0.0582	0.0571	0.0559
-1.4	0.0808	0.0793	0.0778	0.0764	0.0749	0.0735	0.0721	0.0708	0.0694	0.0681
-1.3	0.0968	0.0951	0.0934	0.0918	0.0901	0.0885	0.0869	0.0853	0.0838	0.0823
-1.2	0.1151	0.1131	0.1112	0.1093	0.1075	0.1056	0.1038	0.1020	0.1003	0.0985
-1.1	0.1357	0.1335	0.1314	0.1292	0.1271	0.1251	0.1230	0.1210	0.1190	0.1170
-1.0	0.1587	0.1562	0.1539	0.1515	0.1492	0.1469	0.1446	0.1423	0.1401	0.1379
-0.9	0.1841	0.1814	0.1788	0.1762	0.1736	0.1711	0.1685	0.1660	0.1635	0.1611
-0.8	0.2119	0.2090	0.2061	0.2033	0.2005	0.1977	0.1949	0.1922	0.1894	0.1867
-0.7	0.2420	0.2389	0.2358	0.2327	0.2296	0.2266	0.2236	0.2206	0.2177	0.2148
-0.6	0.2743	0.2709	0.2676	0.2643	0.2611	0.2578	0.2546	0.2514	0.2483	0.2451
-0.5	0.3085	0.3050	0.3015	0.2981	0.2946	0.2912	0.2877	0.2843	0.2810	0.2776
-0.4	0.3446	0.3409	0.3372	0.3336	0.3300	0.3264	0.3228	0.3192	0.3156	0.3121
-0.3	0.3821	0.3783	0.3745	0.3707	0.3669	0.3632	0.3594	0.3557	0.3520	0.3483

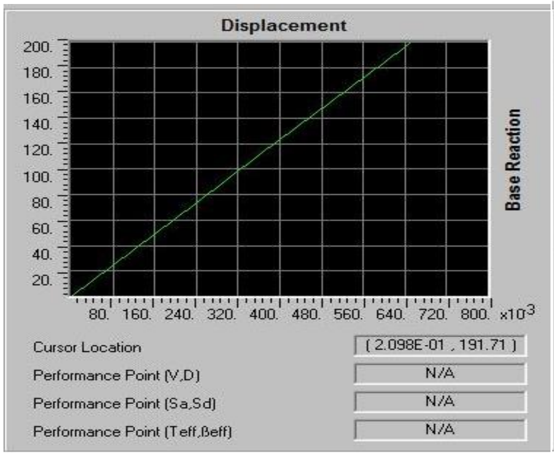
-0.2	0.4207	0.4168	0.4129	0.4090	0.4052	0.4013	0.3974	0.3936	0.3897	0.3859
-0.1	0.4602	0.4562	0.4522	0.4483	0.4443	0.4404	0.4364	0.4325	0.4286	0.4247
-0.0	0.5000	0.4960	0.4920	0.4880	0.4840	0.4801	0.4761	0.4721	0.4681	0.4641
0.0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359
0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753
0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517
0.4	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879
0.5	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224
0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549
0.7	0.7580	0.7611	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852
0.8	0.7881	0.7910	0.7939	0.7967	0.7995	0.8023	0.8051	0.8078	0.8106	0.8133
0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8315	0.8340	0.8365	0.8389
1.0	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621
1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830
1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015
1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177
1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319
1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633
1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767
2.0	0.9772	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817
2.1	0.9821	0.9826	0.9830	0.9834	0.9838	0.9842	0.9846	0.9850	0.9854	0.9857
2.2	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.9890
2.3	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916
2.4	0.9918	0.9920	0.9922	0.9925	0.9927	0.9929	0.9931	0.9932	0.9934	0.9936
2.5	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952
2.6	0.9953	0.9955	0.9956	0.9957	0.9959	0.9960	0.9961	0.9962	0.9963	0.9964
2.7	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972	0.9973	0.9974
2.8	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981
2.9	0.9981	0.9982	0.9982	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986
3.0	0.9987	0.9987	0.9987	0.9988	0.9988	0.9989	0.9989	0.9989	0.9990	0.9990
3.1	0.9990	0.9991	0.9991	0.9991	0.9992	0.9992	0.9992	0.9992	0.9993	0.9993
3.2	0.9993	0.9993	0.9994	0.9994	0.9994	0.9994	0.9994	0.9995	0.9995	0.9995
3.3	0.9995	0.9995	0.9995	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9997
3.4	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9998

2.9 Discrete Damage Probabilities:

Discrete damage probabilities can be calculated as follows:
Probability of complete damage, $P[C] = P[C \mid S_d]$
Probability of extensive damage, $P[E] = P[E \mid S_d] - P[C \mid S_d]$
Probability of moderate damage, $P[M] = P[M \mid S_d] - P[E \mid S_d]$
Probability of slight damage, $P[S] = P[S \mid S_d] - P[M \mid S_d]$
Probability of no damage, $P[None] = 1 - P[S \mid S_d]$

3. RESULTS:

3.1 Results Obtained From Pushover Analysis For C1M Model:



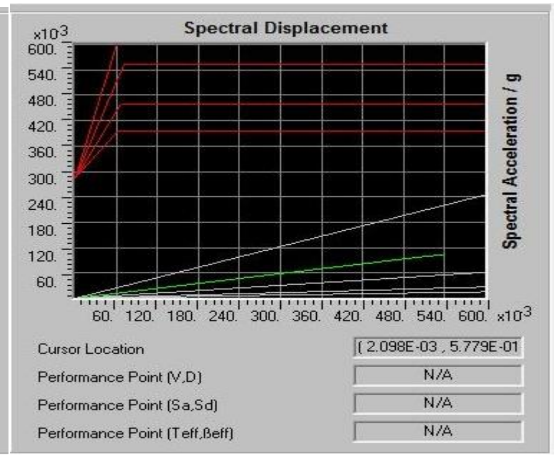


Figure 10: Pushover curve for C1M modelFigure 11: Capacity spectrum and Demand spectrum curve for C1M model

Table 5: Pushover Curve Data For C1M Model

File

Step	Displacement	Base Force	A-B	B-IO	IO-LS	LS-CP	CP-C	C-D	D-E	>E	TOTAL
0	0.0000	0.0000	2200	0	0	0	0	0	0	0	2200
1	0.2400	74.0557	2199	1	0	0	0	0	0	0	2200
2	0.3618	111.6309	2186	13	0	1	0	0	0	0	2200
3	0.6039	185.2674	2184	15	0	0	0	1	0	0	2200
4	0.6390	195.7270	2183	16	0	0	0	0	0	1	2200
5	0.6392	196.1143	2179	20	0	0	0	0	0	1	2200
6	0.6478	198.6822	2179	20	0	0	0	0	0	1	2200
7	0.6470	198.5111	2200	0	0	0	0	0	0	0	2200

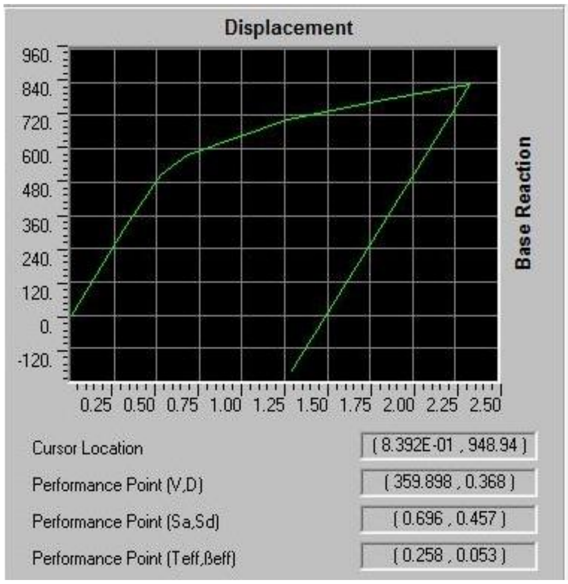
Table 6: Capacity Spectrum Curve and Demand Spectrum Curve Data For C1M Model

File

Step	Teff	ßeff	Sd(C)	Sa(C)	Sd(D)	Sa(D)	ALPHA	PF*Ø
0	0.719	0.050	0.000	0.000	2.709	0.535	1.000	1.000
1	0.719	0.050	0.198	0.039	2.709	0.535	1.628	1.213
2	0.719	0.050	0.298	0.059	2.709	0.535	1.628	1.213
3	0.724	0.053	0.500	0.098	2.685	0.524	1.630	1.207
4	0.725	0.054	0.530	0.103	2.679	0.521	1.631	1.206
5	0.728	0.058	0.534	0.103	2.643	0.510	1.635	1.196
6	0.728	0.058	0.542	0.104	2.644	0.510	1.635	1.196

The marked line in the above tables define performance point data. The step in which the value of T_{eff} and β_{eff} is equal or approximately equal to the performance point value obtained fromcapacity spectrum and demand spectrum curve (figure 11) is defined as step of performance point.

3.2 Results Obtained From Pushover Analysis For C1L Model:



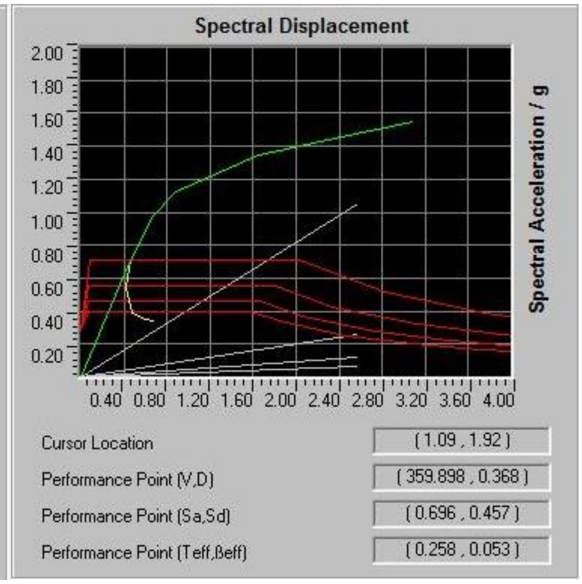


Figure 12: Pushover curve for C1L model Figure 13: Capacity spectrum and Demand spectrum curve for C1L model

Table 7: Pushover Curve Data For C1L Model

File

Step	Displacement	Base Force	A-B	B-IO	IO-LS	LS-CP	CP-C	C-D	D-E	>E	TOTAL
0	0.0000	0.0000	159	1	0	0	0	0	0	0	160
1	0.3275	323.5878	124	36	0	0	0	0	0	0	160
2	0.5278	504.6125	95	61	4	0	0	0	0	0	160
3	0.6860	579.5488	78	46	31	5	0	0	0	0	160
4	1.2680	703.5265	75	1	48	36	0	0	0	0	160
5	1.8389	776.4160	70	4	18	67	0	1	0	0	160
6	2.3304	831.3887	70	4	18	65	0	2	1	0	160
7	1.2834	-207.0752	160	0	0	0	0	0	0	0	160

Table 8: Capacity Spectrum Curve and Demand Spectrum Curve Data For C1L Model

File

Step	Teff	ßeff	Sd(C)	Sa(C)	Sd(D)	Sa(D)	ALPHA	PF*Ø
0	0.257	0.050	0.000	0.000	0.460	0.712	1.000	1.000
1	0.257	0.050	0.404	0.626	0.460	0.712	1.366	0.811
2	0.264	0.065	0.667	0.978	0.444	0.651	1.364	0.791
3	0.282	0.106	0.880	1.129	0.421	0.540	1.357	0.780
4	0.354	0.206	1.653	1.346	0.476	0.388	1.382	0.767
5	0.412	0.240	2.416	1.459	0.584	0.353	1.407	0.761
6	0.452	0.249	3.094	1.551	0.686	0.344	1.417	0.753

The marked line in the above tables define performance point data. The step in which the value of T_{eff} and β_{eff} is equal or approximately equal to the performance point value obtained from capacity spectrum and demand spectrum curve (figure 13) is defined as step of performance point.

Table 9: Performance Point Data for both model

BuildingBase Ultimate Yield Spectral Spectral Effective Effective Type Shear, Displacement, Displacement, Displacement, Acceleration, Time Damping V (kip) D_u (in) D_y (in) S_d (in) S_a (g) Period, Ratio, T_{eff} (sec) β_{eff}
C1M195.72700.63900.36180.5300.1030.7250.054
C1L504.61250.52780.32750.6670.9780.2640.065

Table 10: Calculation of Cumulative Probabilities

C1M							
				X		**Y**	
Damage State	**S_d (in)**	***$S_{d,ds}$***	**β_{ds}**	**S_d / *$S_{d,ds}$***	**ln(X)**	**ln(X) / β_{ds}**	**ϕ[Y]**
Slight	0.530	0.2533	0.68	2.09	0.737	1.08	0.8597
Moderate	0.530	0.3618	0.67	1.46	0.378	0.56	0.7120
Extensive	0.530	0.4311	0.68	1.23	0.207	0.30	0.6179
Complete	0.530	0.6390	0.81	0.83	-0.186	-0.23	0.4091

C1L							
				X		**Y**	
Damage State	**S_d (in)**	***$S_{d,ds}$***	**β_{ds}**	**S_d / *$S_{d,ds}$***	**ln(X)**	**ln(X) / β_{ds}**	**ϕ[Y]**
Slight	0.667	0.2293	0.81	2.91	1.07	1.32	0.9064
Moderate	0.667	0.3275	0.84	2.04	0.71	0.85	0.802
Extensive	0.667	0.3776	0.86	1.77	0.57	0.66	0.7451
Complete	0.667	0.5278	0.81	1.26	0.23	0.28	0.6102

Table 11: Damage Probability Matrix

Model Type	Slight P[S]	Moderate P[M]	Extensive P[E]	Complete P[C]
C1M	0.1477	0.0941	0.2088	0.4091
C1L	0.1044	0.0569	0.1349	0.6102

The damage probabilities of these two buildings can be shown by the following chart:

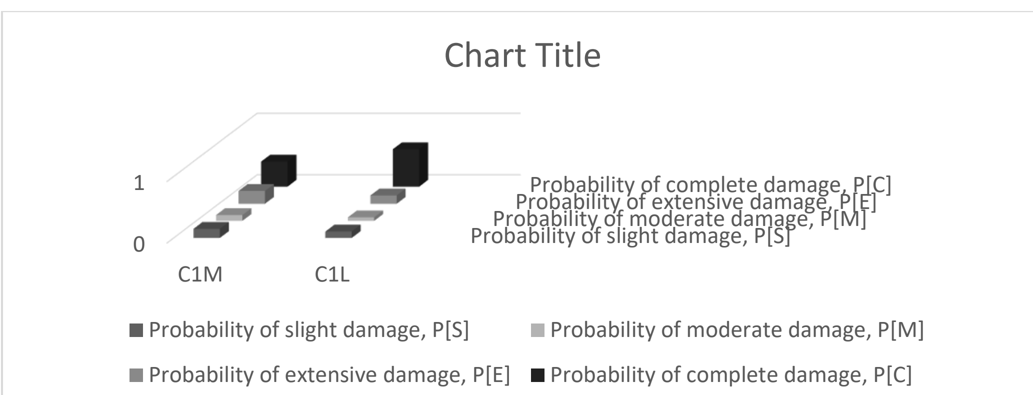


Figure 14: Damage probabilities of both model

4. CONCLUSION:

The probability of being damaged of both the buildings has been determined by pushover analysis. No performance point is availabe for C1M model. There is no intersection point between the capacity and demand curve as the capacity curve goes very low and demand curve goes very high which means the capacity of the building is very low but demand is very high.Still step 4 has been taken as performance point for C1M model. In this step one hinge forms at the level of >E, which represents ultimate collapse and in this stage, gravity loads can no longer be sustained. So, this step can be considered as most critical condition.As yield displacement can't be obtained directly, it has to be calculated manually from capacity curve. From table 3 and 5, it has been seen that, the slope of capacity curve remains equal for C1M model upto step 2 while that of remains equal for C1L model up to step 1.That's why the displacement of those step has been taken as yield displacement for both model respectively.From the above chart it can be understood that, both the buildings are really vulnerable as the probability of being completely damaged is proportioanlly very high for both these two building. That is how the seismic vulnerability of a mid rise and low rise building can be assessed.

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