Probabilistic Risk Analysis of Seismic Irregular RC Structure Using Fragility Curve

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Abstract - *Most of the structures are designed for the vertical load only. If the structures are design with consideration of horizontal load (Seismic Load), it will expensive more than designed structure considering vertical load. So far as Probabilistic Risk Analysis has not been widely used for building Frames. Fragility Curve is an effective tool for vulnerability assessment of the structural system because it is estimate the Probability of failure vs Ground motion Parameter (Peak Ground Acceleration). Fragility Curve assessing Pre-earthquake disaster planning as well as post-earthquake recovery and retrofitting programs. In this paper Fragility curve plot for the irregular shaped structure in plan. Due to the asymmetric of the structure property of the structure change with respect to the geometry. So that Probabilistic risk analysis was taken considering both direction of irregular structure separately by using fragility curve.*

Key Words: Asymmetric RC Structure, Probabilistic Risk Analysis, Probability of Damage, Peak Ground Acceleration, Fragility curve.

1. INTRODUCTION

Reliability analysis of structures estimating the probabilities of a structure under various loading (seismic) for its intended period of use. Safety and reliability are both different concept. Safety is a more traditional concept, while reliability is a relatively new one and which means a probabilistic meaning to the traditional concept. Likewise risk analysis and reliability analysis of structures are simultaneously used to express their probabilities of failure. However, they are not actually one and the same thing. Risk analysis of structures is an extension of the reliability analysis to include the consequences of failure. Fragility analysis is used in connection with the seismic reliability or risk analysis of structures. Fragility analysis is aimed at finding the probability of failure of structures for various levels of PGA at the site and is closer to the seismic risk analysis of structures.

Fragility curve considered Uncertainty of earthquake, Uncertainties associated with seismic hazard estimates, Uncertainty of ground motion input, Uncertainty of modeling of structures. Uncertainty of analysis and Uncertainty of material property. Gerardo M. Verderame et at al., taken the Case study for various Building after the earthquake of Emilia. 5 different cases of building is taken for the analysis. Fragility Curve assessing Pre-earthquake disaster planning as well as post- earthquake recovery and retrofitting programs. The variation of the damage cause by the Change of PGA in the surface of the Earth[8].

Z.A. Lubkowski et at al., derived the relationship between Ss and s1 by using PGA. In this study PSHA of India also taken so no modification taken for the Empirical Equation[9]. Spectral acceleration can be obtained by S1 and SS parameter with respect to Euro Code. By using the spectral acceleration the fragility curve can be plotted and Seismic Hazard response spectrum curve can be plot by the empirical value.

C. M. Ravi Kumar et at al., proposed Methodology for Probabilistic Seismic Risk Evaluation of Building Structure Based on Pushover Analysis[11], which talks about Indian provision defines three types of soil i.e. hard soil, medium soil and soft soil based only on standard penetration test (SPT) N value. The standard penetration test has many limitations. It is difficult to determine the appropriate value of N for layered soil and soil profiles can and will have large variations for given region. Because of the limitations of this method, it is best to use the shear wave velocity as a supplement for the standard penetration test N values. Develop an analytical fragility estimates to quantify the seismic vulnerability of RC frame building. Prathibha S. Shetty et at al., estimates the fragility of Rc Building Using Etabs. Fragility curve can be plotted by using Bi linear Capacity spectrum. Damage state occur by Bilinear Capacity spectrum curve Variables. Fragility Curve shall be plotted with more accuracy by considering other uncertainty apart from push over analysis. By this method fragility curve shall be plotted for pre-existing as well as designed structure by only using Push over analysis.

2. DESCRIPTION OF MODEL

Four story (G+3) geometric irregular RC framed structure was made up with Structural Analysis Software shown in Fig1 which consist of M25 grade concrete and Fe415 steel are used throughout the structure. Cross sectional dimensions of beams 0.3mx0.45m. Cross sectional dimensions of column 0.3mx0.3m with 9 bars of 12mm dia bar and Slab thickness is 0.18m. Floor to Floor height of 3m, Length of the each bay is 6m, Live load of 4 kN/m^2 on all floors. Dead Load of the structure automatically calculated by

25 kN/m³ density of reinforced cement concrete in addition to the dead load of the beam, column, and slab.

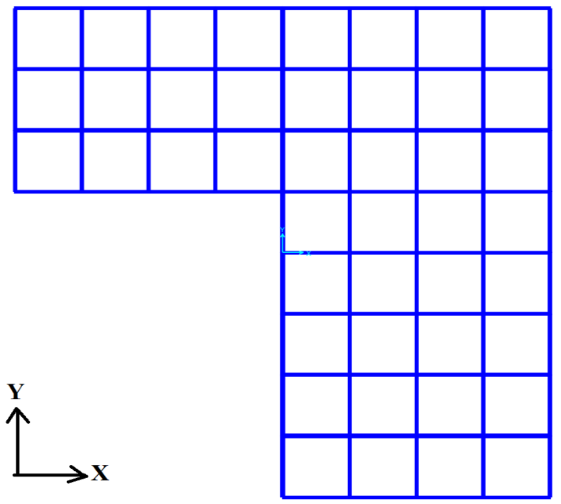

Fig -1: Plan of Irregular Structure

Stiffness of beam, column and slab are separately calculated then convert the 3D structure into 2D framed model. Stiffness of 2D frame is shown in Fig 2 which was consideration of elevation about X direction.

- k1=k2=k3=k4=k5=k6=k7=k8=k9=k10=k11=k12=k13=k14=k15= 22.5kN/m
- k16=k17=k18=k19=k20=k21=k22=k23=k24=k25=k26=k27=k28=k29=k30=k31=k32=k33=k34=k35=k36=12.5kN/m
- k37=k38=k39=k40=k41=k42=k43=k44=k45=k46=k47=k48= 324.675kN/m
- k49=k50=k51=k52=k53=k54=k55=k56=k57=k58=k59=k60=k61=k62=k63=k64=k65=k66=k67=k68=k69=k70=k71=k72=k73=k74=k75=k76=k77=k78=k79=k80=k81=k82=k83=k84=170.775kN/m

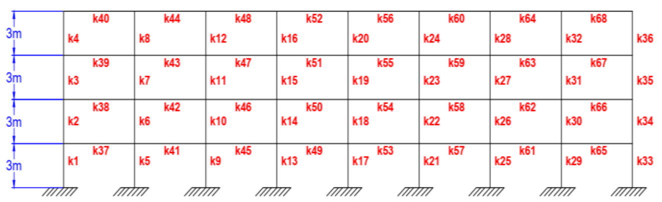

Fig -2: Elevation (X Direction)

Stiffness of 2D frame is shown in Fig 2 which was consideration of elevation about Y direction.

- k1=k2=k3=k4=k5=k6=k7=k8=k9=k10=k11=k12=k13=k14=k15=k16= 10 kN/m
- k17=k18=k19=k20=k21=k22=k23=k24=k25=k26=k27=k28=k29=k30=k31=k32=k33=k34=k35=k36=22.5kN/m
- k37=k38=k39=k40=k41=k42=k43=k44=k45=k46=k47=k48= k49=k50=k51=k52=132.3 kN/m
- k53=k54=k55=k56=k57=k58=k59=k60=k61=k62=k63=k64=k65=k66=k67=k68=k69=k70=k71=k72=k73=k74=k75=k76=k77=k78=k79=k80=k81=k82=k83=k84= 324.675 kN/m

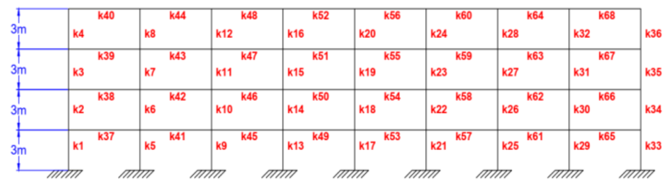

Fig -3: Elevation (Y Direction)

3. DEVELOPMENT OF FRAGILITY CURVE

3.1 Calculation of weight of the Structure

Weight of the beam at each floor =2075kN
Weight of the slab at each floor =7125kN
Weight of the column at each floor=384.75kN
Weight of Live Load at each floor =6336kN
Weight of wall at each floor =883.2kN
Total Weight at First Floor =16803.95kN
Total Weight at Second Floor =16803.95kN
Total Weight at Third Floor =16803.95kN
Total Weight at Fourth Floor =9833.975kN
Total Weight of the structure =60245.825kN

3.2 Calculation of Spectral Acceleration by PGA

Z.A. Lubkowski derived the relationship between Ss and S1 by using PGA[9]. In this study PSHA of India also taken so no modification taken for the Empirical Equation. Spectral acceleration can be obtained by S1 and SS parameter with respect to Euro Code. The structure is considered located in Zone A.

SS = PGA (0.3386 PGA + 2.1696)
S1 = PGA (0.5776 PGA + 0.5967)

Table -1: Spectral Acceleration

PGA (g)	S_S	S_1	SDS	SD1	Sa(%g)	Sa50	Sa84
0	0	0	0	0	0	0	0
0.05	0.11	0.03	0.06	0.02	0.05	0.02	0.04
0.1	0.22	0.07	0.12	0.03	0.10	0.05	0.08
0.15	0.33	0.10	0.18	0.05	0.15	0.08	0.13
0.2	0.45	0.14	0.24	0.08	0.20	0.10	0.17
0.25	0.56	0.19	0.30	0.10	0.26	0.13	0.22
0.3	0.68	0.23	0.36	0.12	0.31	0.16	0.26
0.35	0.80	0.28	0.43	0.15	0.37	0.18	0.31
0.4	0.92	0.33	0.49	0.18	0.42	0.21	0.35
0.45	1.04	0.39	0.56	0.21	0.23	0.24	0.40
0.5	1.17	0.44	0.62	0.24	0.26	0.27	0.45
0.55	1.30	0.50	0.69	0.27	0.30	0.30	0.50
0.6	1.42	0.57	0.76	0.30	0.33	0.33	0.55
0.65	1.55	0.63	0.83	0.34	0.37	0.36	0.61
0.7	1.68	0.70	0.90	0.37	0.41	0.39	0.66

3.3 Calculating Plastic Hinge point by Pushover Analysis

The irregular structures modelled and performed pushover analysis using software. Pushover analysis performed over both X and Y Direction.

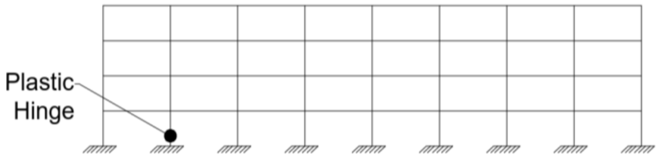

Fig -4: Pushover Analysis in X direction

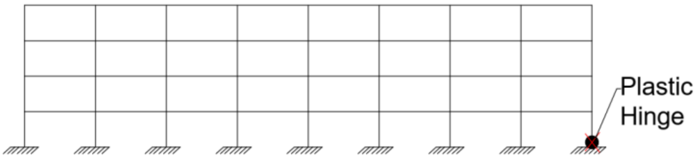

Fig -5: Pushover Analysis in Y direction

3.4 Calculation of Force at Each Floor

Considering the zone factor 0.16, Response Reduction Factor 3 and Importance Factor as 1.5 then found the Force at each floor by adopting method of seismic coefficient specified in IS 1893 part I.

Table -2: Base Shear

PGA(g)	A_h50	A_h84	V_b50(KN)	V_b84(KN)
0	0	0	0	0
0.05	0.01	0.02	603.69	1014.19
0.1	0.02	0.03	1220.18	2049.91
0.15	0.03	0.05	1849.49	3107.15
0.2	0.04	0.07	2491.62	4185.91
0.25	0.05	0.09	3146.55	5286.21
0.3	0.06	0.11	3814.30	6408.02
0.35	0.07	0.13	4494.86	7551.36
0.4	0.09	0.14	5188.23	8716.23
0.45	0.10	0.16	5894.42	9902.62
0.5	0.11	0.18	6613.41	11110.54
0.55	0.12	0.20	7345.22	12339.98
0.6	0.13	0.23	8089.85	13590.94
0.65	0.15	0.25	8847.28	14863.43
0.7	0.16	0.27	9617.53	16157.45

Table -3: Seismic Coefficient

Floor Number	Height (m)	W_i	$W_ih_i^2$	$W_ih_i^2 / \sum W_ih_i^2$
1	3	16803.95	151235.6	0.0428
2	6	16803.95	604942.2	0.1712
3	9	16803.95	1361120	0.3852
4	12	9833.975	1416092	0.4007

The outer dimension of structure along X and Y direction are same hence force at each floor can be same for both direction.

Table -4: Force at Each Floor

PGA (g)	Force in Each floor due to Sa50 (KN)			
	P1	***P2***	***P3***	***P4***
0	0.00	0.00	0.00	0.00
0.05	25.84	103.36	232.55	241.94
0.1	52.23	208.90	470.03	489.02
0.15	79.16	316.65	712.45	741.23
0.2	106.65	426.58	959.81	998.57
0.25	134.68	538.71	1212.10	1261.06
0.3	163.26	653.03	1469.33	1528.67
0.35	192.39	769.55	1731.49	1801.42
0.4	222.07	888.26	1998.59	2079.31
0.45	252.29	1009.17	2270.62	2362.33
0.5	283.07	1132.26	2547.59	2650.48
0.55	314.39	1257.55	2829.50	2943.77
0.6	346.26	1385.04	3116.34	3242.20
0.65	378.68	1514.72	3408.11	3545.76
0.7	411.65	1646.59	3704.83	3854.46

PGA (g)	Force in Each floor due to Sa84 (KN)			
	P1	***P2***	***P3***	***P4***
0	0	0	0	0
0.05	43.41	173.64	390.68	406.46
0.1	87.74	350.96	789.66	821.55
0.15	132.99	531.97	1196.92	1245.26
0.2	179.17	716.66	1612.48	1677.61
0.25	226.26	905.04	2036.33	2118.57
0.3	274.28	1097.1	2468.47	2568.17
0.35	323.21	1292.85	2908.91	3026.39
0.4	373.07	1492.28	3357.63	3493.24
0.45	423.85	1695.4	3814.65	3968.71
0.5	475.55	1902.2	4279.96	4452.81
0.55	528.18	2112.69	4753.56	4945.54
0.6	581.72	2326.86	5235.45	5446.9
0.65	636.18	2544.72	5725.63	5956.88
0.7	691.57	2766.27	6224.11	6475.49

3.5 Calculation of uncertainty Parameters

In this paper Simplified Probabilistic Risk Analysis of Structures (made by Shinozuka et al) method has been adopted[7]. And considered complete failure mechanism

Table -5: Moment at Hinge Point

PGA (g)	X Direction		Y Direction	
	M50	**M84**	**M50**	**M84**
0	0	0	0	0
0.05	702.76	1132.96	632.65	1062.86
0.1	1348.84	2218.38	1278.74	2148.28
0.15	2008.35	3326.35	1938.24	3256.25
0.2	2681.28	4456.89	2611.18	4386.78
0.25	3367.65	5609.98	3297.54	5539.87
0.3	4067.44	6785.62	3997.33	6715.52
0.35	4780.66	7983.83	4710.55	7913.73
0.4	5507.3	9204.59	5437.2	9134.49
0.45	6247.37	10447.92	6177.27	10377.81
0.5	7000.87	11713.8	6930.77	11643.69
0.55	7767.8	13002.23	7697.7	12932.13
0.6	8548.15	14313.23	8478.05	14243.13
0.65	9341.94	15646.78	9271.83	15576.68
0.7	10149.15	17002.89	10079.04	16932.79

Uncertainty by Ground Input F1 =1
Uncertainty by Soil and Structural Property F2 =1
Uncertainty by Analytical method F3 =0.25
Uncertainty by approximate analysis F4 =0.15
Uncertainty by Capacity of section F5 =1.34
(3%ductility)

Uncertainty by Overall Capacity F6 =1.13
Uncertainty by Material Strength F7 =1
$\bar{\beta}$ =0.548

4. RESULTS AND DISCUSSION

Fragility curve plotted for probability of occurrence of damage (Complete Fracture Mechanism) with Respect to the ground motion parameter (Peak Ground Acceleration). Fragility curve plotted for each direction separately.

Table -6: Probability of Failure (X Direction)

PGA (g)	M50=$\bar{R}$(KN)	$\bar{C}$(KNm)	ln($\bar{C}/\bar{R}$)	β	Pf
0	0	1103.85	0	0	0
0.05	702.758	1103.85	0.452	0.824	0.205
0.1	1348.839	1103.85	-0.2	-0.366	0.643
0.15	2008.348	1103.85	-0.599	-1.092	0.863
0.2	2681.284	1103.85	-0.887	-1.62	0.947
0.25	3367.647	1103.85	-1.115	-2.035	0.979
0.3	4067.438	1103.85	-1.304	-2.38	0.991
0.35	4780.656	1103.85	-1.466	-2.675	0.996
0.4	5507.301	1103.85	-1.607	-2.933	0.998
0.45	6247.374	1103.85	-1.733	-3.163	0.999
0.5	7000.873	1103.85	-1.847	-3.371	1
0.55	7767.801	1103.85	-1.951	-3.561	1
0.6	8548.155	1103.85	-2.047	-3.735	1
0.65	9341.937	1103.85	-2.136	-3.897	1
0.7	10149.15	1103.85	-2.219	-4.049	1

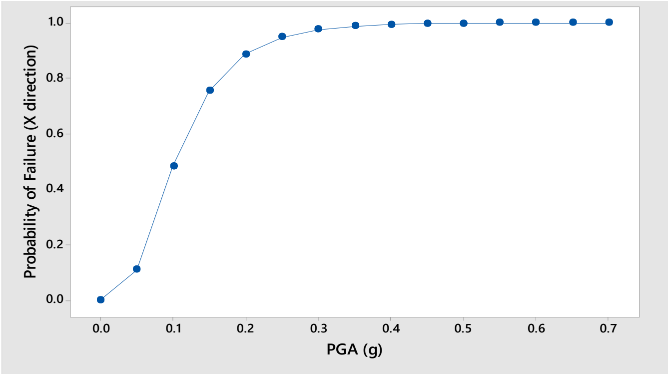

Chart -1: Probability of Failure (X Direction)

Table -7: Probability of Failure (X Direction)

PGA (g)	M50=$\bar{R}$ (KNm)	$\bar{C}$(KNm)	Ln($\bar{C}/\bar{R}$)	β	Pf
0	0	1379.815	0	0	0
0.05	632.654	1379.815	0.78	1.423	0.077
0.1	1278.735	1379.815	0.076	0.139	0.445
0.15	1938.244	1379.815	-0.34	-0.62	0.732
0.2	2611.18	1379.815	-0.638	-1.164	0.878
0.25	3297.543	1379.815	-0.871	-1.59	0.944
0.3	3997.334	1379.815	-1.064	-1.941	0.974
0.35	4710.552	1379.815	-1.228	-2.241	0.987
0.4	5437.197	1379.815	-1.371	-2.502	0.994
0.45	6177.27	1379.815	-1.499	-2.735	0.997
0.5	6930.769	1379.815	-1.614	-2.945	0.998
0.55	7697.697	1379.815	-1.719	-3.137	0.999
0.6	8478.051	1379.815	-1.816	-3.313	1
0.65	9271.833	1379.815	-1.905	-3.476	1
0.7	10079.04	1379.815	-1.989	-3.629	1

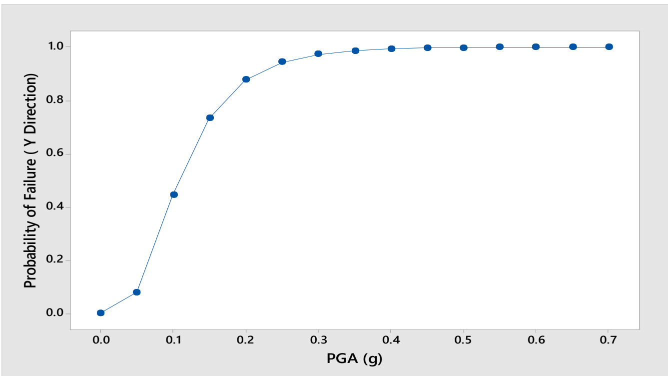

Chart -2: Probability of Failure (Y Direction)

5. CONCLUSIONS

In this paper, fragility curves are plotted for asymmetric concrete moment resisting frame structures and following conclusion can be stated

- Probability of failure can be calculated for both direction (X direction and Y direction) in the asymmetric RC structure because probability of failure varying with respect to geometrical asymmetry.
- By using Probabilistic Risk analysis we can connect the Probability of damage to the Ground motion Parameters such as Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV) and Peak ground displacement (PGD).
- When the PGA exceeds 0.3g, the above seismic irregular structure will more probably failure (more than 80%).
- In this analysis 7 combination of uncertainty was used, hence the probability of failure was more accurate.
- By using the Probabilistic Risk Analysis in the existing structure we can predict the amount of PGA which causes the structure Failure.
- Probability of the damage slightly lesser in Y direction, because moment of inertia is greater in Y direction.

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BIOGRAPHIES

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