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Development of Fragility Curves for Seismic Vulnerability of Asymmetric RC Buildings Resting on Sloping Ground

Pratima Patil[1], V.S. Patil[2]

[1]PG Student @ Civil Engg. Dept. Sanjay Ghodawat Institutes, Kolhapur, India.
[2]Associate Professor @ Civil Engg. Dept. Sanjay Ghodawat Institutes, Kolhapur, India.

Abstract - *This study presents probabilistic seismic response of asymmetric RC building by developing fragility curves. In this study, two building models are selected. These structures are resting on sloping ground with open storey. One of them is without infill and other building is having infill as a diagonal strut. Building models are designed and analyzed in software SAP2000 v15. Incremental dynamic analysis method is used for analysis due to its accuracy for determining building responses. To perform IDA, fifteen ground motions are selected and they are scaled to give comparable IDA results for all selected ground motions. The comparative study is made between different seismic damage limits. Fragility curves are developed based on the IDA results for the three limit states including immediate occupancy, life safety and collapse prevention to show the probabilistic comparison of seismic responses for buildings in both x and y directions. To show the probability of damage or exceeding any limit state, a fragility assessment is performed by creating fragility curves. It is observed from the fragility assessment results that presence of infill increases the capacity of building.*

***Key Words*: probabilistic seismic response, asymmetric, Incremental dynamic analysis, fragility curves etc.**

1. INTRODUCTION

Irregular buildings constitute a large portion of the modern urban infrastructure. This may lead to building structures with irregular distributions in their mass, stiffness and strength along the height of building. Any irregularity causes an abrupt change in strength or stiffness of the structure which is not desirable in an earthquake resistant system.
The Pacific Earthquake Engineering Research Center (PEER) aims to develop a methodology for performance based earthquake engineering. To fulfill this objective, the performance assessment and design process has been broken into logical elements. These elements of process include description, definition and quantification of earthquake intensity measures, engineering demand parameters, damage measures and decision variables.

Fragility curves are a useful tool for seismic risk analysis and loss estimation of structural systems. Fragility curves describe the probability of damage to building. They are lognormal functions that describe the probability of reaching or exceeding structural and nonstructural damage states. The curve shows the probability of failure verses peak ground acceleration.

1.1 Problem Statement

Two asymmetric reinforced concrete buildings are designed and their seismic responses are assessed and compared. The structures are resting on sloping ground having similar building configurations. Building model 1 is without infill and building model 2 is having infill as diagonal strut in one direction i.e. single strut. Plan of these two building model is as shown in figure 1.

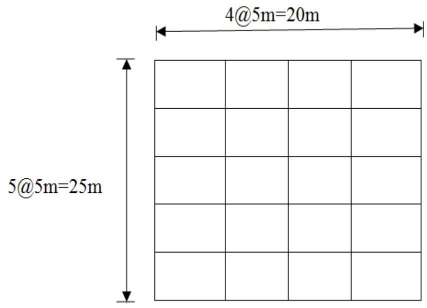

Fig 1: Plan layout of both building

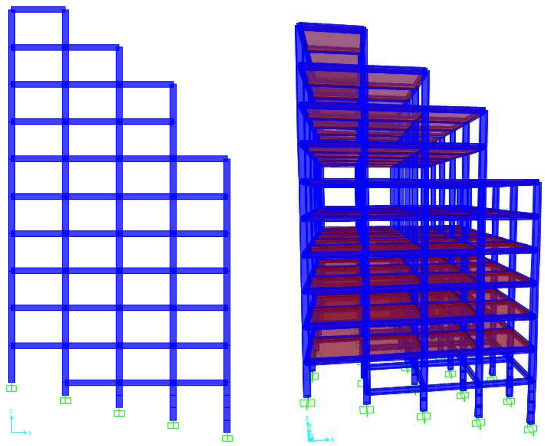

Fig 2: Elevation and 3D view of model 1

As shown in figure 2 and 3, the structures are also having vertical geometric asymmetry. It consists of 4 bays in X direction and 5 bays in Y direction. The elevation and 3D views of these structures are as shown in figure 2 and 3. The infill material used for model 2 is brick masonry. Other building details are described in table 1.

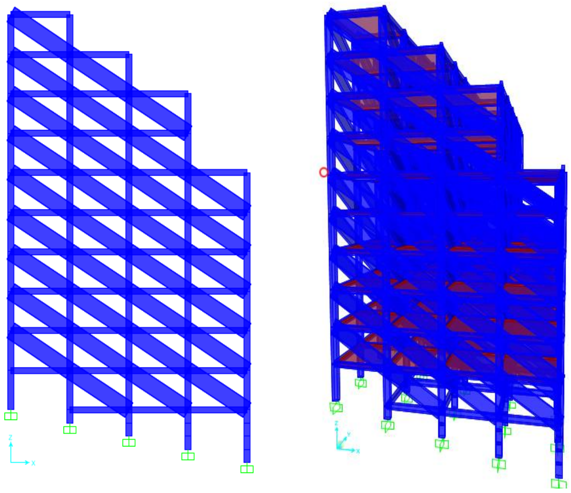

Fig 3: Elevation and 3D view of model 2

Table 1: Structural Details of Building Model

Specifications	Building 1 and 2
No. of stories	9
Parapet height	1.5 m
No. of lines in X dir	5
No. of lines in Y dir	5
No. of lines in Z dir	15
Spacing of frame in X dir	5 m
Spacing of frame in Y dir	5 m
Spacing of frame in Z dir	4m (bottom storey) 3m (remaining)
Size of Beam	0.35m X 0.55m 0.3m X 0.45m
Size of Column	0.35m X 0.45m
Grade of concrete	M20
Grade of Steel	Fe415
Slab Thickness	0.15 m
Wall Thickness	0.23 m

1.2 Gravity Loads On Beams:

The gravity loads on floors are calculated and are applied on the beams.

Dead wall load:

D_W = 12.19 KN/m for external walls
D_W = 7.95 KN/m for internal walls
D_W = 6.90 KN/m for roof due to parapet wall

Table 2: Other Details of building model

Specification	Value
Live load on floors	5 KN/m²
Live load on floors	3 KN/m²
Floor Finish	1 KN/m²
Zone Factor (Z)	0.36
Importance Factor (I)	1
Response Reduction Factor (R)	5
Seismic zone	v
Soil type	Medium
Damping ratio	5%

1.3 Width And Contact Lengths Of Strut:

The width of the strut is calculated by Paulay- Priestley equation,

$W_{eff.}$ = 0.25d
For Single Diagonal strut model:
Length of strut = 5.12m
W= 0.25d = 0.25x5.12 = 1.28m
$W_{eff.}$ = 1.28m is taken.

2. IDA RESULTS AND DISCUSSIONS

After analyzing the structure, IDA curves are plotted for different Damage Measure and Intensity Measure. In this study, the maximum inter-story drift ratio is considered as the DM and the spectral acceleration at the fundamental period is taken as the IM. Multi-record IDA curve are generated for all fifteen ground motions to locate their respective three limit states. The multi-record IDA curves of the asymmetric RC buildings resting on sloping ground with open storey for both directions are shown in Figure 4 to 7.

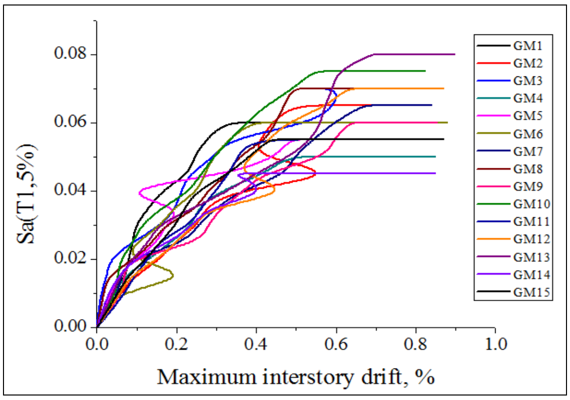

Fig 4: Multi-record IDA curve for Model 1 in X-Direction

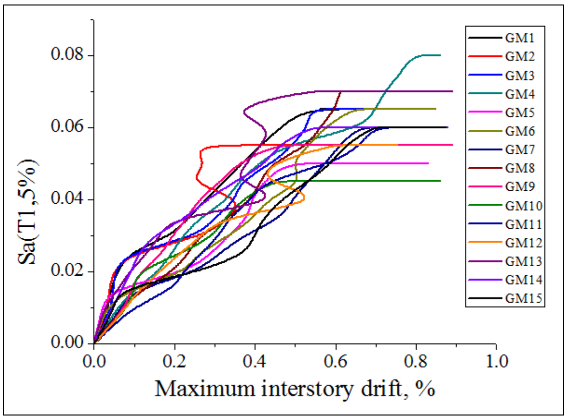

Fig 5: Multi-record IDA curve for Model 1 in Y-Direction

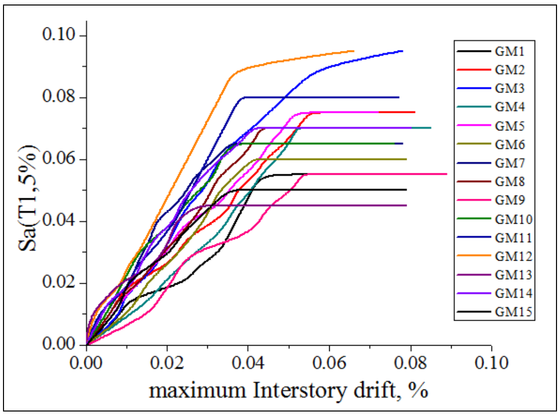

Fig 6: Multi-record IDA curve for Model 2 in X-Direction

From these Multi-record IDA curve, maximum interstory drift ratio i.e. ϴmax is considered for plotting IDA curve, As per FEMA 273:1997, for IO limit ϴmax is 1%, it is 2% for LS limit and 4% for CP limit. The values of all the limits for each ground motion along X and Y direction are calculated. These values are used for developing fragility curves.

2.1 Disperssions

IDA dispersion results are mentioned in table 3, It shows dispersion of cuvees along X direction in percentage and Y direction in terms of acceleration due to gravity. Model 1 and 2 is having less dispersion along X axis but more along Y axis. It can be concluded that if dispersion is less then the response of structure is more predictable.

Table 3: dispersions of IDA curves

Model no.	Direction	Dispersion	
		Along X (%)	Along Y(g)
1	X direction	0.67	0.047
	Y direction	0.49	0.048
2	X direction	0.045	0.067
	Y direction	0.062	0.13

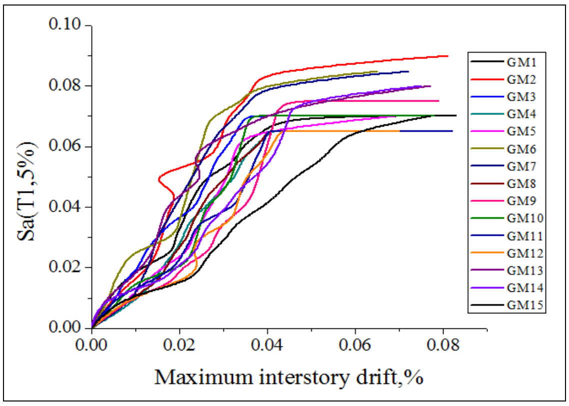

Fig 7: Multi-record IDA curve for Model 2 in Y-Direction

3. FRAGILITY CURVES

Based on the limit states identified from the IDA curves, a graphical statistical method is utilized to develop fragility curves that represent the probability of exceeding a certain limit state. Median and standard deviation values for all the building models along both directions are listed in table 4. In this study, fragility curves are plotted for immediate occupancy, life safety and collapse prevention states for the three building models in both directions against the spectral acceleration at the fundamental period with 5% damping Sa(T1,5%), the same used in the IDA curves. Fragility curves are expressed by assuming the log-normally distribution of the data points at Sa(T1,5%) on the fifteen IDA curves.

Table 4: Median and standard deviation values

Model no.	Damage limits	Median (λ)	Standard deviation (ζ)
1 X direction	IO	-4.3636	0.2418
	LS	-4.2982	0.2475
	CP	-4.1939	0.2109
1 Y direction	IO	-4.7211	0.5169
	LS	-4.6229	0.4771
	CP	-4.4761	0.4036
2 X direction	IO	-3.9120	0.2237
	LS	-3.5021	0.2053
	CP	-2.9907	0.2256
2 Y direction	IO	-3.9768	0.3184
	LS	-3.4877	0.2108
	CP	-2.9132	0.1489

3.1 Comparing Three Limit States Of The Same Building

Figure 7 to Figure 10 illustrate the fragility curves comparison of the same building at three limit states along both directions.

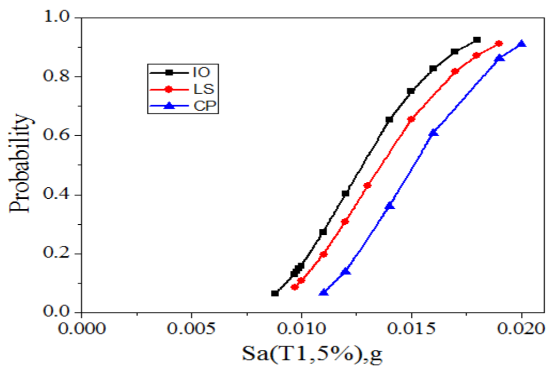

Figure 7: Fragility curves for IO, LS, and CP levels of building 1 in X dir

Referring to the figure 7 and 8, it can be concluded that at low ground motion intensity, structure occupies only IO limit but at moderate and high intensity, it occupies all the three damage limits.

Referring to the figure 9 and 10, it can be concluded that, at low ground motion intensity, structure occupies only IO limit at very less probability, at moderate intensity, it occupies IO and LS limit and high intensity earthquake it occupies all the three damage limits.

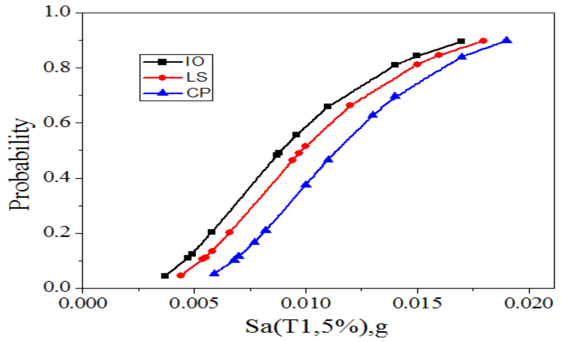

Figure 8: Fragility curves for IO, LS, and CP levels of building 1 in Y dir

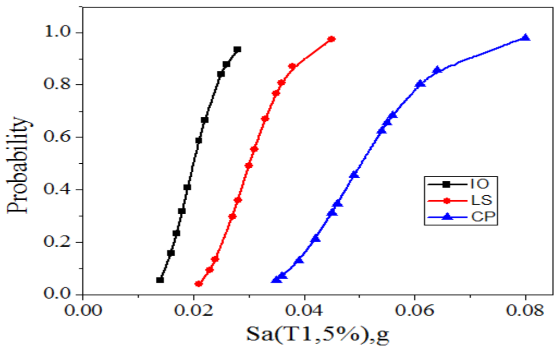

Figure 9: Fragility curves for IO, LS, and CP levels of building 2 in X dir

As shown in Figure 7 to Figure 10, fragility curves for life safety limit state are located in the middle between the immediate occupancy and the collapse prevention limit states curves for both building model along both directions. It is noted that the three damage limits are close to each other for building model 1 along both directions. But the damage limits are far away from each other for building model 2 along both directions.

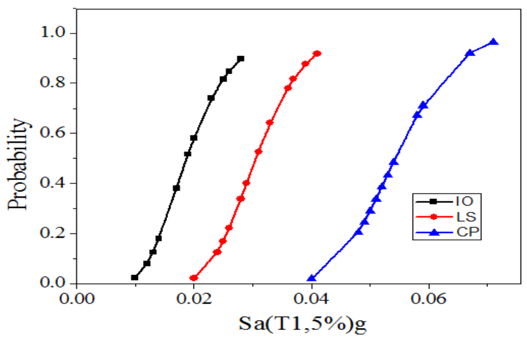

Figure 10: Fragility curves for IO, LS, and CP levels of building 2 in Y dir

3.2 Comparing The Same Limit States Of Two Buildings

Fragility curves of the same limit state of the three building models are plotted on the same graph to compare their seismic performances (Figure 11 to Figure 16) along both directions.

1) Fragility Curves for IO of 2 Buildings in X & Y Direction

Referring to the figure 11, it can be concluded that probability of getting damage is only in building 4. But it is very negligible at low ground motion intensity and at high intensity, probability of getting damage is 50%. Similarly according to figure 12, Probability of getting damage in building 1 is 55% but very negligible in building 2. At high intensity earthquake, probability is 60% for both buildings.

2) Fragility Curves for LS of 2 Buildings in X & Y Direction

According to fragility curves developed for life safety limit state in both directions of two asymmetric buildings as shown in figure 13 & 14. Building model 2 requires larger ground motion intensity to cause diagonal hair cracks in most of the structural elements. However, building model 1 requires smallest ground motion intensity to exceed its life safety limit state.

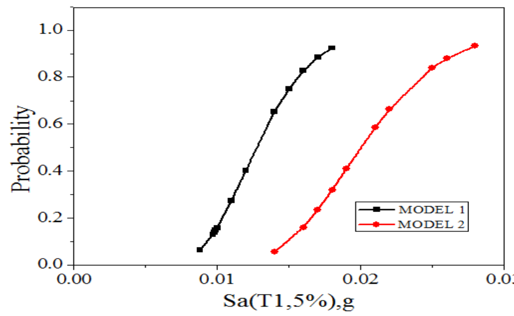

Figure 11: Fragility curves for IO of 2 buildings in X Direction

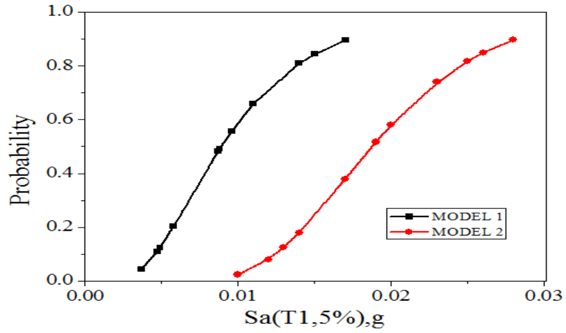

Figure 12: Fragility curves for IO of 2 buildings in Y Direction

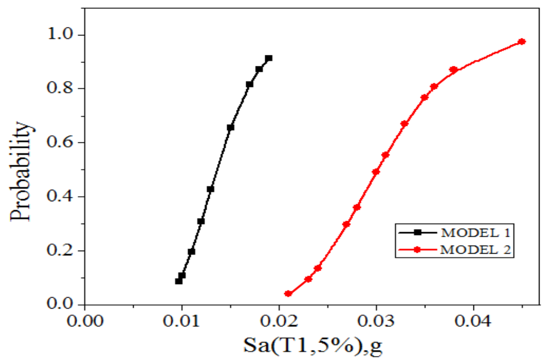

Figure 13: Fragility curves for LS of 2 buildings in X Direction

Referring to figure 13, at low ground motion intensity; there is 60% probability of getting damage only in building model 1. There will not be any structural damage in model 2. But at high ground motion intensity, probability is 50 % for both building models.

Similarly, according to figure 14, there is 55% probability of getting damage only in building model 1 at low ground motion intensity. Model 2 is safe at this intensity. But at high intensity earthquake, probability is 40 % for both building models.

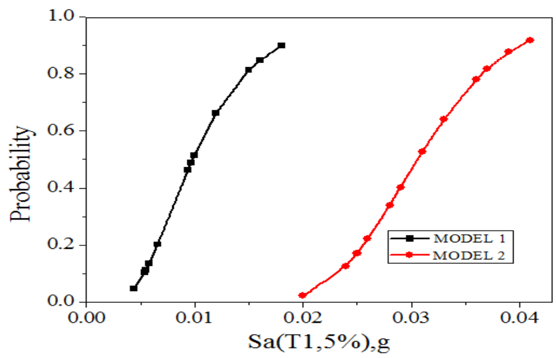

Figure 14: Fragility curves for LS of 2 buildings in Y Direction

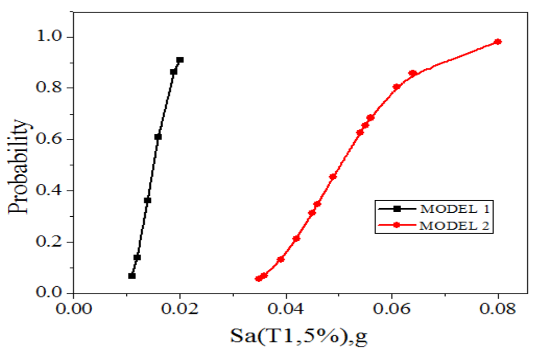

Figure 15: Fragility curves for CP of 2 buildings in X direction

3) Fragility Curves for CP of 2 Buildings In X & Y Direction

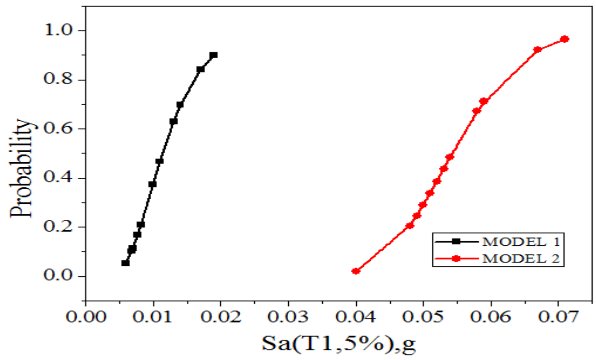

Figure 16: Fragility curves for CP of 2 buildings in Y direction

Based on fragility curves for collapse prevention limit state in both directions of two building models are as shown in figure 15 and 16. Fragility curves of building model 1 for X and Y direction is vertically straight.

On other hand the nature of graph for building model 2 is curvilinear. This means that both buildings require different earthquake intensity to collapse the buildings. As building 2 has larger stiffness, it requires high earthquake intensity to collapse, as compared to other building. Therefore, design & recommendation of code should be strictly followed for reducing torsional moment due to asymmetry.

4. CONCLUSIONS

1. Modal analysis confirmed that introducing infill wall in the building resulted in decreased fundamental period due to increased stiffness.

2. In case of asymmetric building resting on sloping ground with open storey, building without infill is more vulnerable to seismic ground motions.

3. Building resting on sloping ground with open storey having infill walls is stiffer and seismically resistant than Building without infill, for all damage limit states. i.e. building model 2 is stiffest than building model 1.

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