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Seismic Performance of RC Buildings with Different Positions of Lift Core Wall and Added Shear Walls

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Abstract

Nepal is situated in an area with considerable seismic activity. It is important to choose structural systems that can withstand the lateral loads. In a dual system of reinforced concrete structures, the placement of shear walls optimally increases the stiffness of the buildings. The lateral rigidity of RC buildings may be improved by strategically placing lift core walls. Buildings would be more useful if they had easy access to an elevator and stairs. Torsional irregularity in buildings would be caused by the lift core wall's eccentric location. For these kinds of structures, a bidirectional seismic excitation study is required. In design, IS 1893:2016 is applied. Drift limitations are obtained from FEMA 356 2000 for different damage conditions and median displacement values are taken as per HAZUS 4.2 SP3. This research work presents the vulnerability due to eccentric positioning of lift core in symmetrical reinforced concrete frame. The torsional irregularities are needed to be removed with optimum positioning of extra shear walls. The reduction in vulnerability of buildings due to added walls is also studied.

Keywords: *Reinforced concrete, shear wall, lift core, torsional irregularity, bidirectional earthquake, vulnerability.*

1. Introduction:

A shear wall with RC frame will encounter the effects of lateral loads acting on a structure due to earthquake, wind etc. The size of the columns gets reduced considerably and can be changed to a large extent at different floors with the use of shear wall in frame [1]. Lateral forces are decreased when shear walls are put at the proper positions to frames [2]. With the addition of a shear wall, base shear increases and lateral displacement decreases [3]. Proper positioning of shear walls increases the strength and stiffness of a structure and can significantly impact the seismic behavior of frame structures [4]. Square shaped shear wall is the most effective with comparison to channel shaped, T shaped and I Shaped [5]. Constructing building with shear wall in short span at corner is economical [6]. L type shear wall is best in comparison with cross type shear wall and shear wall at periphery for G+5 symmetrical building with plan 16m*16m [7]. For rectangular sections, the fiber method predicts the nonlinear behavior of the structure at acceptable level [8]. Since the fiber model can replicate the development of plastification within the plastic hinge region, it is more accurate for simulating hysteretic behavior using fibre model than the assumption of a single element with concentrated hinges [9]. Location of shear wall at the edge of building resulted in heavy axial loads in columns with increase in drift and displacement of building [10]. Better seismic evaluation will be possible with the combination of nonlinear time history analysis and probabilistic assessment. Seismic performance of building and vulnerability assessment has been the interest with the increase of the computational efficiency. Staircases and elevators are to be provided in buildings at such location such that they more easily accessed. But the position of core wall may increase the eccentricity in the buildings giving the more torsional effects. So, extra shear walls are to be located in building to decrease the eccentricity and hence control the torsion. The torsional irregularities due to shifting of the lift core wall are to be analyzed and the analysis of building after balancing the torsion is also an important work to be done.

Objectives:

a) To determine the seismic performance of G+6 RC buildings with lift core wall at various positions.

b) To determine the vulnerability of G+6 RC buildings with lift core wall considering effect of additional shear walls using fragility curve

2. Methodology:

During initial phase of study some midrise buildings were surveyed in Kathmandu city. For initial assumption of slab thickness, shear wall thickness, beam and column dimensions those surveys helped .A symmetrical RC frame has no eccentricity in both direction in plan, so for this reason a symmetrical RC frame is selected. Number of bays were taken similar to those which were taken in similar type of works done in past. Since this study deals with variation in seismic performance due to change in lift core wall positions, door opening in lift core hasn't been considered and staircases are not modeled, which are the limitations of the study. Dual system of G+6 Symmetrical moment resisting frame of 5*5 bays with equal bay lengths of 4.5 m in both direction with constant storey height of 3m, with beam sizes 14"*18" and columns sizes 16"*16" and lift core wall of size 3m * 2.5m in X and Y direction at centre position in plan (11.25,11.25) from base to top with thickness of 250mm is selected as a base model (Model 1) as shown in figure 1. The grade of concrete is M25, and that of steel is Fe500, thickness of slab is 125mm. The seismic zone considered is V, response reduction factor is 5, soil type medium, and importance factor is 1. The modal damping is at 5%. The lift core wall is shifted in three different positions. Model 2, Model 3 and Model 4 have lift core's centre at position (11.25, 21.375), (15.75,21.375) and (20.25, 21.375) respectively. Beams and columns are modeled as frame elements, slabs as shell elements and shear walls as wall elements in ETABS V18.1. For nonlinear modeling, plastic hinges are assigned to beams and columns as per ASCE 41-17 at 0.45m from the ends and fiber hinges are assigned in wall sections. These models have been designed for the design combinations as per IS 456:2000 and IS 1893 (part1): 2016 ,used in this study as these buildings codes have been widely used in research and field works in Nepal from a very beginning. Moreover IS 1893:2016 has two criteria for a building to have torsional irregularities. The torsional irregularities in the building models are balanced from the approach of torsional sensitivity that is higher modal mass participation due to rotation in first two fundamental modes of vibration are removed with addition of extra shear walls at optimum positions.

Model 5, model 6, model 7 and model 8 are the models after balancing the torsional irregularities of models 1, models 2, models 3 and model 4 respectively by adding extra shear walls of 250mm thickness at suitable locations such that eccentricities will be less than 5% and the modal mass participation in first two fundamental modes are purely translations. In Model 5 the length of extra added walls are 2.5 m in X direction and 5 m in Y direction. In model 6 length shear wall is added is 4.5m at bay 3, at centre of edge opposite to liftcore. In model 7 the added wall are at corner (0, 0), 3.635m in X direction and 2.0625m in Y direction. In Model 8 the added walls are at corner (0, 0), 3.75m in X direction and 3 m in Y direction. Site specific seven earthquakes are selected from PEER databases and matched to the target response spectrum from IS 1893 (part1):2016 in Seismo match version 2021. Bidirectional earthquake load cases for fast nonlinear analysis, used because of its faster computation, for various levels of 0.2, 0.4, 0.6, 0.8, and 1 PGAs so that logarithmic interpolation can be done at 0.05 intervals of PGAs, has been used. The median values of displacements and beta values for midrise building category of concrete shear wall building are taken from HAZUS 4.2 SP3. The drift limits from FEMA 356 2000 for immediate occupancy (IO), Life Safety (LS), and collapse prevention (CP) are 0.5%, 1% and 2% respectively. The fragility curves are plotted for both cases. The peak ground acceleration (PGA) for Kathmandu city is 0.4g [11, 12], so comparisons of vulnerability through fragility curves are done at

0.4g PGA value. The eccentricity is increased with shifting the lift core away from the centre of building. Model 1 has zero eccentricity. Model 4 has greatest eccentricities in both directions. Models 6, 7 and 8 are such that the eccentricity values are less than 5% in both directions.

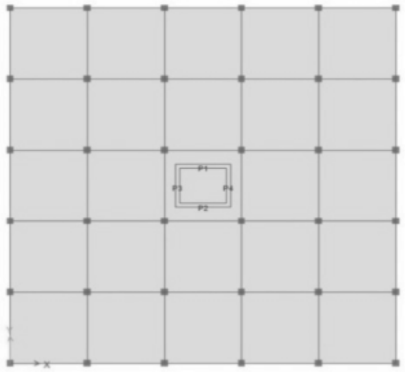

Figure 1: Model 1 (lift core at centre)

4. Results

4.1 Eccentricity:

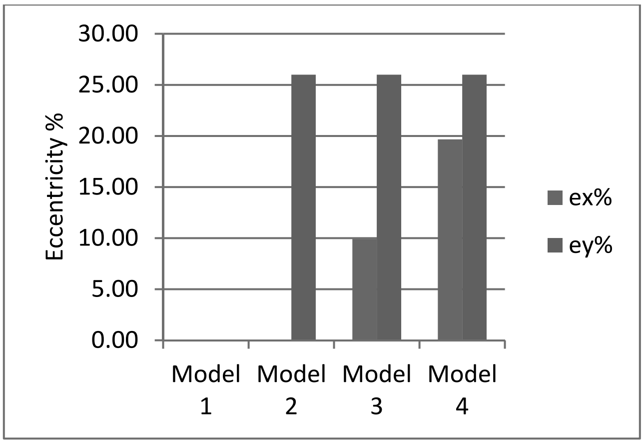

Figure 2: Eccentricity results

The eccentricity is increased with shifting the lift core away from the centre of building. Since model 1 has symmetrical frame systems and the lift core is symmetric about both axes the eccentricity in both direction were 0%, the greatest eccentric model was when the lift core wall was placed at the corner of the building and that was 19.67% and 26% in X and Y direction respectively.

4.2 Modal mass participation ratios:

Table 1: Modal mass participation ratios for Models 1 and 2

	Model 1			Model 2		
Mode	Ux	Uy	Rz	Ux	Uy	Rz
1	0	0	0.837	0.49	0	0.3332
2	0	0.7124	0	0	0.7084	0
3	0.706	0	0	0.24	0	0.4576
Sum	0.706	0.7124	0.837	0.73	0.7084	0.7908

Table 2: Modal mass participation ratios for Models 3 and 4

Case	**Model 3**			**Model 4**		
Mode	Ux	Uy	Rz	Ux	Uy	Rz
1	0.425	0.0996	0.301	0.3086	0.2781	0.2388
2	0.0998	0.6017	0.0068	0.2851	0.412	0.01
3	0.2027	0.0122	0.4768	0.1275	0.0342	0.5199
Sum	0.7275	0.7135	0.7846	0.7212	0.7243	0.7687

Modal 1 has torsional irregularity as the fundamental first mode of vibration is dominated by the torsion. The other two modes of vibration in Model 1 are translational. In models 2 and 3 we can see that in the first mode of vibration, translation in X direction is coupled with rotation however the first modes are dominated by the translation in X direction. In modal 4, first mode of vibration has coupled translation in both direction and torsion. The translations in both directions are coupled in 2nd mode of vibration but there is no rotational participation.

Table 3: Modal mass participation for Models 5 and 6

Case	**Model 5**			**Model 6**		
Mode	Ux	Uy	Rz	Ux	Uy	Rz
1	0.6247	0.0778	0	0	0.7053	0
2	0.077	0.6216	0	0.66	0	0.0364
3	0	0	0.725	0.04	0	0.6666
Sum	0.7017	0.6994	0.725	0.69	0.7053	0.703

Table 4: Modal mass participation for Models 7 and 8

Case	**Model 7**			**Model 8**		
Mode	Ux	Uy	Rz	Ux	Uy	Rz
1	0.0202	0.6805	0.0004	0.0761	0.624	0.0006
2	0.6733	0.0203	0.0023	0.6192	0.0757	0.0021
3	0.0021	0.0002	0.6974	0.0018	0.0022	0.6952
Sum	0.6956	0.701	0.7001	0.6971	0.7019	0.6979

After the shear walls have been added in the initial models of buildings with lift core wall only, the mode participation mass ratio has been changed such that the first two modes of vibration are translational and the coupled translation and coupling of translation with rotation has been removed from the first two modes. All models the sum of modal mass participation for the first three modes has exceeded 65% in both X and Y direction, this means the models don't have irregular modes of oscillations.

4.3 Displacement ratios:

Table 5 presents the maximum displacement of top storey at one end and minimum displacement at the far end both in X direction for the linear static load cases EQX with eccentricity considered and the ratio is calculated to find if the building models suffer torsional irregularity.

Table 5: Ratios of maximum to minimum top floor displacements

Model	Maximum Displacements(mm)	Minimum Displacements(mm)	Ratio	Remarks
Model 1	32.107	22.534	1.425	Torsionally Regular
Model 2	63.806	17.141	3.722	Torsionally Irregular
Model 3	81.273	12.308	6.603	Torsionally Irregular
Model 4	91.47	9.499	9.629	Torsionally Irregular
Model 5	27.956	22.978	1.217	Torsionally Regular
Model 6	21.059	15.119	1.393	Torsionally Regular
Model 7	21.256	16.885	1.259	Torsionally Regular
Model 8	20.376	18.499	1.101	Torsionally Regular

4.4 Fragility Analysis:

The interstorey drift ratios from the output of incremental dynamic analysis has been expressed as the probability of exceeding the damage states of FEMA 356 2000.

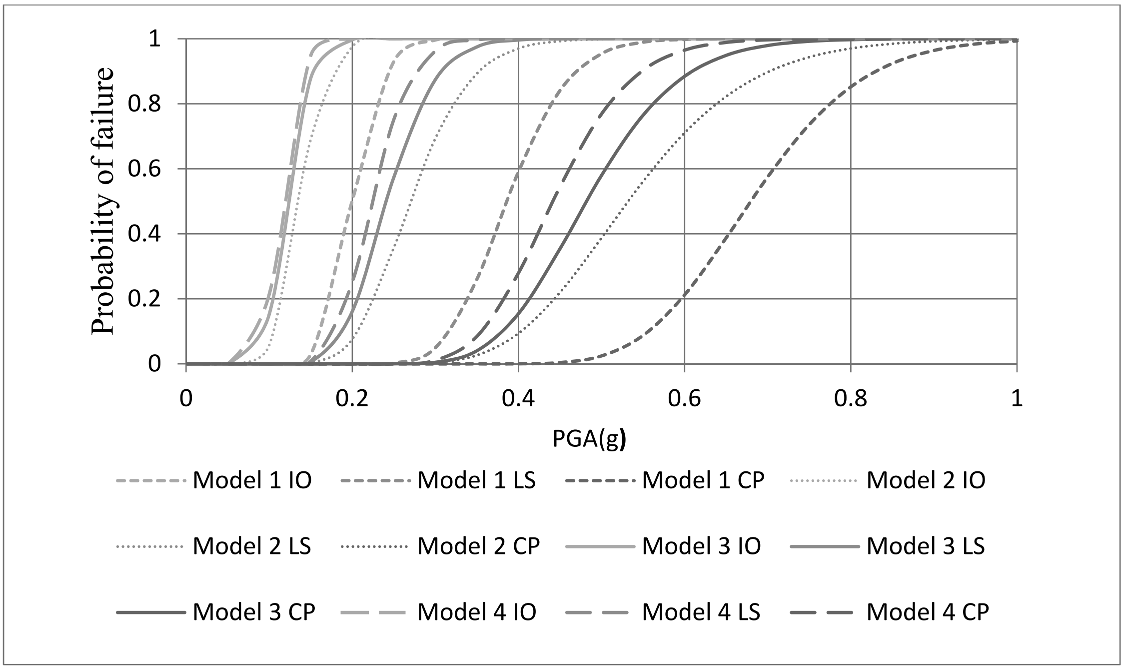

Figure 3: Fragility curves as per FEMA 356 2000

Similarly the fragility curves for probability of exceeding the displacements for HAZUS 4.2 SP3 have been plotted.

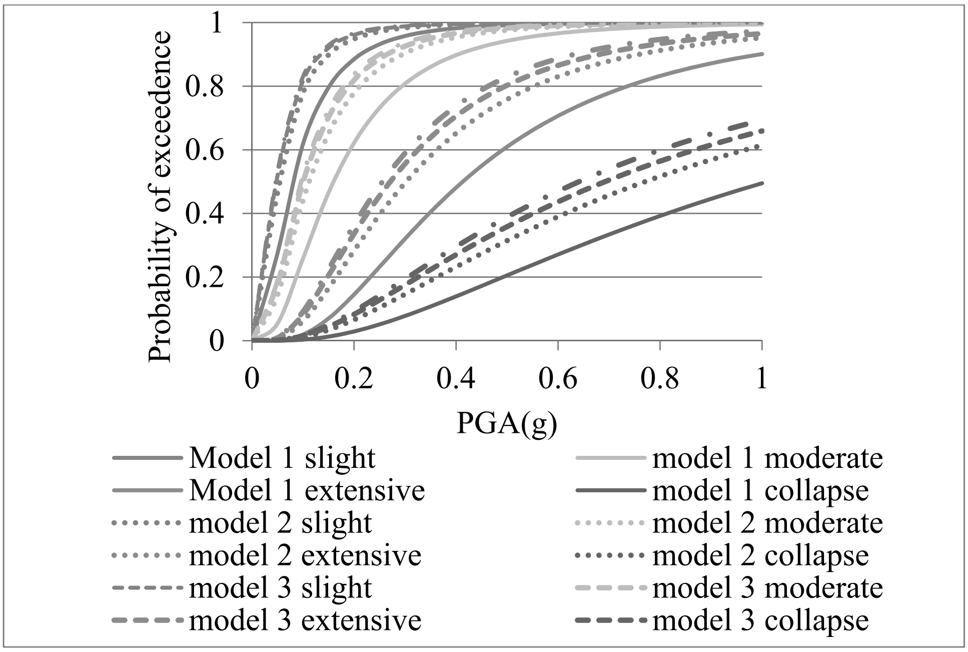

Figure 4: Fragility Curves as per HAZUS 4.2 SP3

Since the criteria for the collapse damage states of both FEMA 356 2000 and HAZUS 4.2 SP3 are similar, comparison of the fragility curves have been done at collapse damage states.

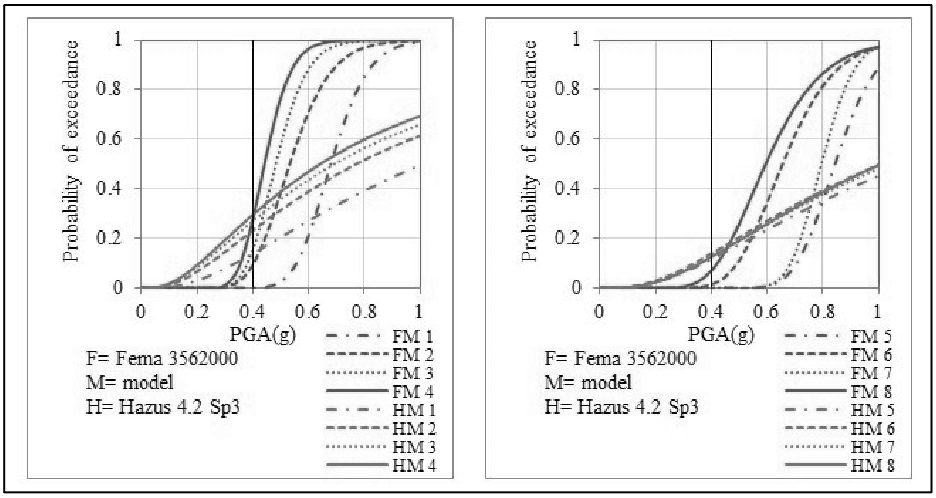

Figure 5: Fragility curves comparisons at collapse damage states

The above fragility curves depict that the probability of exceeding the drift limits at collapse damage states are lesser for FEMA 356 2000 than the displacement limits from HAZUS 4.2 SP3 for 0.4g PGA. For the average of all the fragility curves plotted, the probability of collapse at FEMA damage state is 67.78% lower than that at HAZUS for 0.4g PGA. At lower PGAs value less than 0.3g the probability of exceedance of collapse prevention damage states are very small nearly zero for FEMA's drift limit of 2% .The fragility curves for drift limits have the probability of exceedance sharply increasing with increase in PGA while that for displacement are increasing uniformly. Slope of fragility curves from HAZUS 4.2 SP3 are lower than that for FEMA 356 2000 drift limits. At higher values of peak ground acceleration the probabilities of exceeding drift limits are higher.

The added shear walls to the models with lift core wall only, the displacement have been decreased due to increase in stiffness of the building, removal of torsional irregularities and increased mass participation ratios. The overall effectiveness can be studied through reduction in vulnerability. Since HAZUS gave the higher probabilities of failures, comparisons in reduction are made according to HAZUS's damage states.

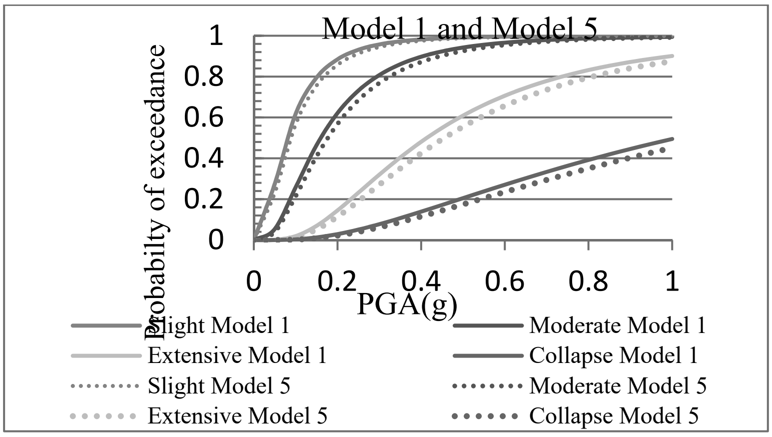

Figure 6: Fragility Curves for Model 1 and 5

After addition of shear walls, the vulnerability of building with lift core at centre have been reduced by 0.64%, 2.87%, 11.54%, and 16.83% for damage states slight moderate extensive and collapse respectively at 0.4g PGA. Increased lateral stiffness reduced the lateral displacement of building for time history analysis. So, the vulnerability of building i.e. fragility curves has been shifted down.

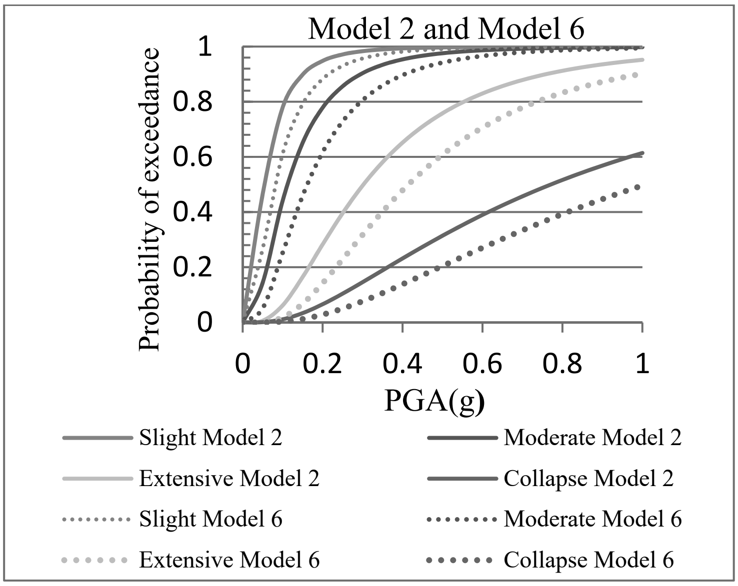

Figure 7: Fragility curves for model 2 and model 6

For the model with lift core at centre of edge (Model 2), added shear wall to remove the torsional irregularity has influence to reduce the fragility by 1.18%, 5.9%, 26.45% and 40.28% for slight, moderate, extensive and collapse damage states.

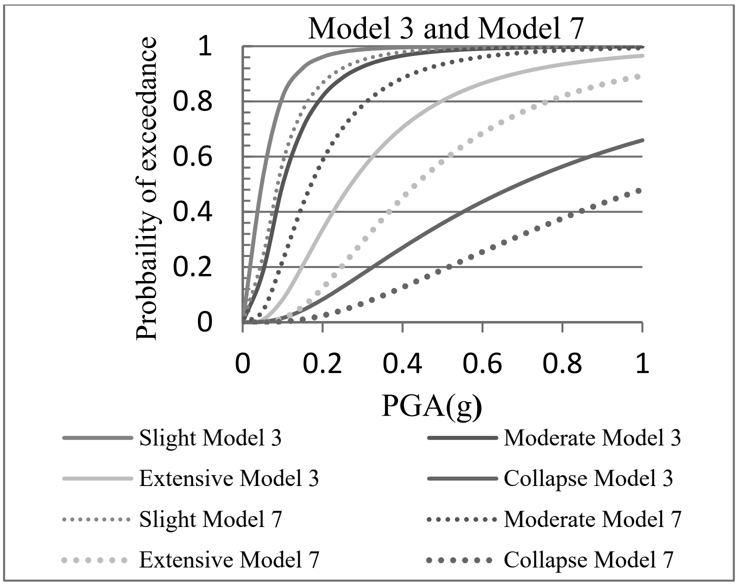

Figure 8: Fragility curves for model 3 and model 7

For the model 3, added shear wall has influence to reduce the fragility 1.67%, 8.43%, 35.95% and 53.16% for slight moderate, extensive and collapse damage states respectively.

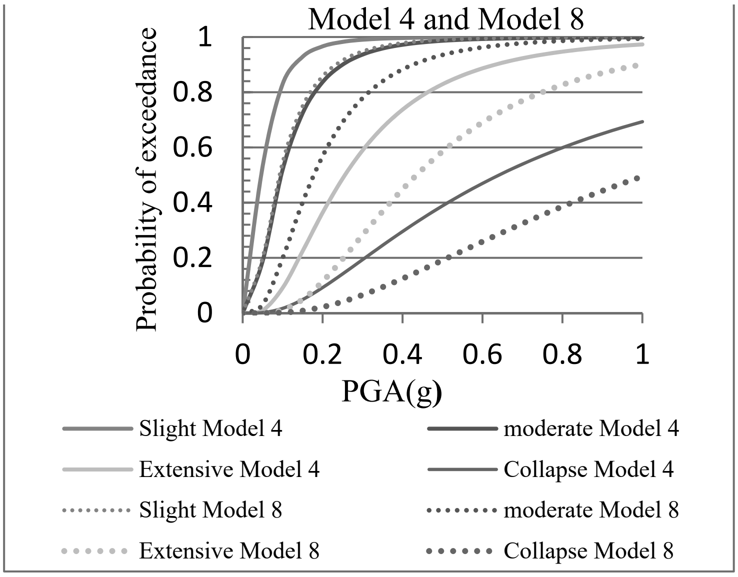

Figure 9: Fragility curves for model 4 and model 8

For the model 4, added shear wall has influenced to reduce the fragility by 1.80%, 9.16%,39.08% and 57.61% for slight moderate, extensive and collapse damage states respectively at 0.4g PGA.

The probabilities of exceeding the limits at damage states were greater when lift core were at corner of the building. The fragility curves of model 5, model 6, model 7 and model 8 as per HAZUS's 4.2 Sp3 are very close to each other. Since the vulnerability were greater when lift core was at corner (model 4), the reduction in vulnerability is greatest after balancing its irregularity. The length of shear wall added to balance the torsional irregularities are greatest for model 4, which increased the lateral stiffness of the building (model 8), hence reduced the displacement responses of the building and has highest reduction in vulnerability.

3. Conclusions:

Shifting the lift core away from the centre increases the lateral displacements, creates torsional irregularities in building. Probabilities of failures at 0.4g PGA for collapse damage states are greater for HAZUS 4.2 SP3 than FEMA 356 2000. For the average of all the fragility curves plotted, the probability of collapse at FEMA damage state is 67.78% lower than that at HAZUS for 0.4g PGA. Providing the extra shear wall for balancing the torsional irregularity makes the first two fundamental modes of translation and hence decreases the vulnerability.

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