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Seismic Fragility Curves for RC Flat Slab Buildings with and Without Infill

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ABSTRACT: Rapid urbanization leads to more demand for construction of commercial buildings in Indian cities. The ease construction and more space demand of buildings are constrained in conventional buildings. To overcome constrained, the flat slab buildings evolved and practiced recent time in urban cities. It is becoming more popular for multistoried commercial buildings but experiences larger displacements under lateral load effect caused by earthquakes. These buildings need urgent to assess the vulnerability of buildings. In this fragility analysis is carried out, and it is useful for the evaluation of the probability of structural damage due to earthquakes as a function of ground motion indices. This paper is an attempt made to develop the fragility curves for seven-storey RC commercial buildings and a comparison made between the bare frame, flat slab, flat slab with drop, flat slab with drop and perimeter beam buildings without and with exterior infill walls. The building models are analyzed using ETABS software and designed as per IS 456. In this, infills are considered along the perimeter of the plan of the building and no infill in ground storey. The infill wall is modelled as equivalent diagonal strut model. The Auto hinges are assigned for both beam and column members. Pushover analysis has been performed on the building models using ETABS software. Yield and ultimate spectral displacement and spectral acceleration are obtained from capacity curves. For the development of fragility curves, HAZUS methodology has been used. Fragility curves are developed for all the eight building models and compared the probability of damage of structures for bare frames and open ground storey buildings. In this assumed, the expected intensity ground motion is considered as seismic zone PGA values. It is observed that in considered flat slab models, flat slab with drop and perimeter beam building is showing minimum probability of damage results in both with and without infill for given intensities.

Keywords: Bare frame, Capacity curves, Equivalent diagonal strut, Flat slab buildings, Fragility curves, PGA, Pushover analysis.

I. INTRODUCTION

The flat slab buildings mainly consist of a reinforced concrete slab supported directly by columns without the presence of beams. The loads are directly transferred from slabs to columns. Sometimes, flat slab also consists of two way reinforced slab with drop panels, column heads or both are provided around the top of columns and perimeter beams.

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This type of slabs is very satisfactory for heavy loads. A flat slab can result in accommodation of more stories in restricted building height. Due to the absence of beams in these buildings, partition walls can be located anywhere in a particular storey to meet the economic and architectural flexibility. The importance of commercial buildings increased day by day in urban cities for commercial uses. In all commercial buildings, the ground storey is used for parking purpose. This type of buildings is designed for gravity loads alone not for earthquake loads. In 2001 Bhuj earthquake shows a number of conventional buildings were collapsed even providing the beams between the columns whereas the flat slab is constructed without beams. It can create more flexible building for lateral loads. These buildings are very highly vulnerable to future earthquakes. The vulnerability can be assess by the fragility curves. This curve helps to predict the vulnerability of the buildings during its service life. The curve is a graph plotted between peak ground responses on X-axis versus probability of damage on Y-axis. Past literature shows that comparison was made on flat slab building with conventional frame building, flat slab with drop, perimeter beam and shear wall. The different types of seismic analyses have done on flat slab buildings. Pane (2008) studied the contribution of masonry infill effect towards the lateral response of the flat slab building. Pushover analysis of 10 storey building was done by SAP 2000. In infilled frames, the infill tends to strengthen the frame and increase the load to the slab and column. Full infill structure increases the capacity to almost three times the capacity of the bare frame [7]. M. Altug Erberik, et al. (2004) focused on the derivation of fragility curves using medium-rise flat slab buildings with masonry infill walls. ZEUS-NL is the software used to model five-storey structures and the inelastic response-history analysis to analyze the flat slab structures. The fragility curves developed from the study were compared with moment-resisting RC frames and concluded that earthquake losses for flat-slab structures are in the same range as for moment-resisting frame structures [5]. Megha Vasavada et al. (2016) explained about the development of fragility curves for 10 storey RC building structures with and without infill walls by HAZUS methodology and compared. The specified level of spectral displacement of the bare frame at the performance point has more probability of damage compared to the infilled frame. Despite high load withstanding value, infill building frame is not considered as effective because it fails soon without intimation [6].

II. OBJECTIVE

The main objective of this work is to develop the fragility curves for seven-storey RC flat slab buildings and comparison of the probability of damage of bare frame, flat slab, flat slab with drop and flat slab with drop and perimeter beam buildings with and without infill effects in different intensity values.

III. METHODOLOGY

Fragility curves are developed by HAZUS methodology. The conditional probability of a particular damage state (ds) for given the spectral acceleration (S_a) is defined by equation (1).

$$P\left[\frac{ds}{Sa}\right] = \phi\left[\frac{1}{\beta ds}\ln\left(\frac{Sa}{Sa,ds}\right)\right] \quad (1)$$

Where,
$S_{a,ds}$ is the value of spectral acceleration at damage state (ds).
S_a is the spectral acceleration of the structure.
ϕ is the standard normal cumulative distribution function.
β_{ds} is the standard deviation for damage state (ds).
At any point in the curve normally represents the exceedance probability of the damage parameter, which can be lateral drift, base shear etc. over the limiting value mentioned at any given ground motion.

IV. MODELLING OF THE STRUCTURE

In this study, the seven-storey RC flat slab building models are considered and model details are given in table-I. The infill walls are only considered along the perimeter of the plan of the building and no infill is placed in ground storey of building.

Table-I: Model details

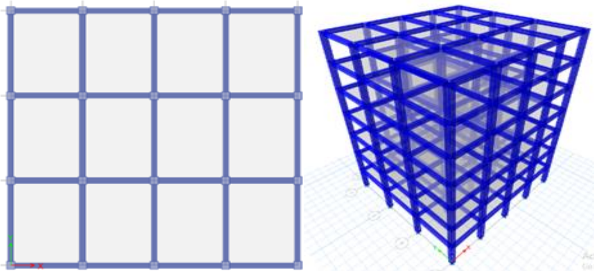
Building Models	Without infill	With infill
Bare frame building	BF	BFI
Flat slab building	FS	FSI
Flat slab with drop building	FSD	FSDI
Flat slab with drop and perimeter beam building	FSDB	FSDBI

Building models consists of 4 bays along X-axis and 3 bays along Y-axis with 4m and 5m width respectively. Storey height is considered as 3m and constant along with the building height. The building models are designed according to IS 456-2000[4] for gravity loads. The ETABS software is used for modelling and analysis of building models. The geometry of building models is mentioned in table-II.

Table-II: Building details

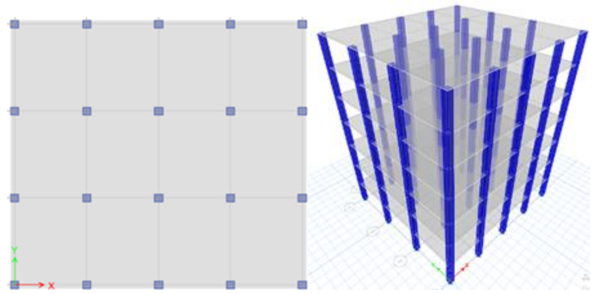
1	Grade of concrete	M30
2	Grade of steel	Fe415
3	Plan dimensions	16m x 15m
4	Slab thickness	200mm
5	Column dimensions	450mm x 450mm
6	Beam dimensions	350mm x 300mm
7	Drop thickness	300mm
8	Drop size	1.8m x 1.8m
9	Live load	3 kN/m^2
10	Wall load	13.56 kN/m
11	Parapet wall load	4.56 kN/m
12	Floor finish load	1 kN/m^2

The fig.1 to 4 shows the plan and 3D view of bare frame, flat slab, flat slab with drop and flat slab with drop and perimeter beam buildings respectively.



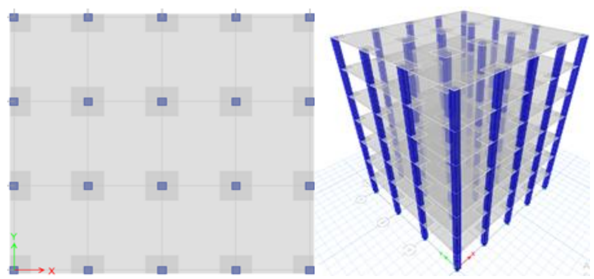
(a) (b)

Fig. 1. (a) Plan and (b) 3D view of bare frame building.



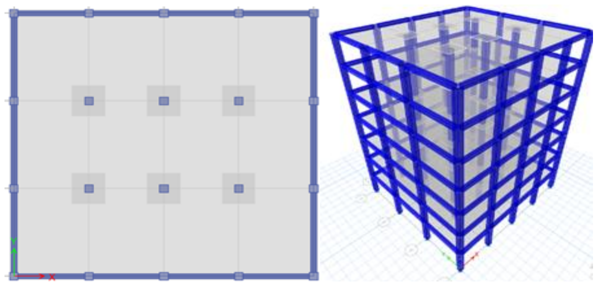
(a) (b)

Fig. 2. (a) Plan and (b) 3D view of flat slab building.



(a) (b)

Fig. 3. (a) Plan and (b) 3D view of the flat slab with drop building.



(a) (b)

Fig. 4. (a) Plan and (b) 3D view of the flat slab with drop and perimeter beam building.

The above building models of bare frame, flat slab, flat slab with drop, flat slab with drop and perimeter beam are also considered with exterior infill walls.

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The infill walls are modelled as equivalent diagonal strut as per IS 1893-2016 [3] and struts are arranged along the exterior periphery face in all the storeys except in ground storey as open ground storey buildings, which are used for the parking purpose in commercial buildings. The width of the strut can be calculated by equation (2).

Width of diagonal strut (W_{ds}) = $0.175\alpha_h^{-0.4} L_{ds}$ (2)

$$\alpha_h = h\left[\sqrt[4]{\frac{E_m t \sin 2\theta}{4E_f I_c h}}\right] \quad (3)$$

$$L_{ds} = \sqrt{l^2 + h^2} \quad (4)$$

Thickness of strut is taken as thickness of infill (t) = 228 mm
Elasticity of masonry (E_m) = 2953 N/mm^2

Elasticity of frame material (E_f) =27386.12 N/mm^2

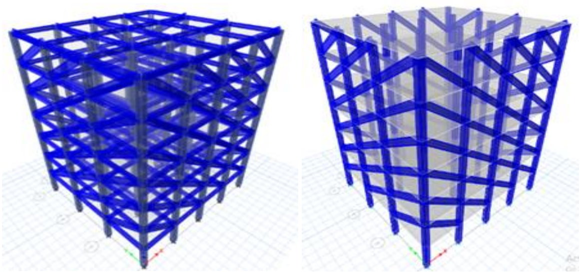
Moment of inertia of column (I_c)= 3.4 x10^9 mm^4

The width of diagonal struts is calculated by using equation (2) and shown in table-III for all the building models in both X and Y directions and width of strut increase due to absence of beams for both FSI and FSDI buildings.

Table-III: Dimensions of the strut

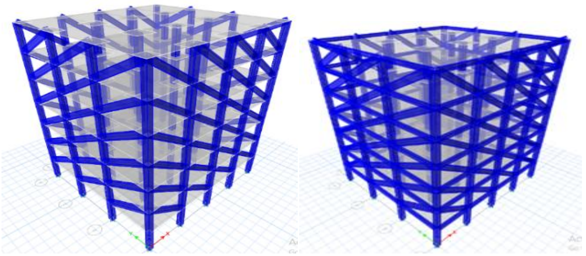
Model	Storey height in mm (h)	Length (*l*)			
		X-direction - 3550mm		Y-direction - 4550mm	
		Angle (Θ)	W_{ds} (mm)	Angle (Θ)	W_{ds} (mm)
BFI	2650	36.74	548	30.21	658
FSI	3000	40.21	552	33.39	652
FSDI	3000	40.21	552	33.39	652
FSDBI	2650	36.74	548	30.21	658

The fig.5 and fig.6 show the 3D views of all the building model with exterior infills and no strut in the ground storey.



(a) (b)

Fig. 5. 3D view of (a) BFI and (b) FSI buildings with exterior infills.



(a) (b)

Fig. 6. 3D view of (a) FSDI and (b) FSDBI buildings with exterior infills.

V. RESULTS AND DISCUSSION

(a) Pushover Curves

The analysis and design is carryout for the gravity loads of all building models. The auto hinges are assigned M3 for beam and P-M2-M3 for column members as per ASCE 41-13. For flat slab building, hinges are assigned for column member as P-M2-M3. The user-defined axial hinges assigned for strut model. Pushover analysis has been performed on all the building models considering 100% of dead load and 25% of live load and displacement control is applied. The fig.7 and fig.8 shows the pushover curves for the considered building models without and with exterior infill respectively. The structure is pushed in a lateral direction until collapse behaviour is achieved. From the fig.7, it is observed that FS will have a maximum displacement of 372.85 mm and minimum base shear of 5794.59 kN compared to all other building models. The BF will have minimum displacement with 274.23 mm and maximum base shear of 7792.43 kN than all other building models. FSD will have a displacement of 288.78 mm and a base shear of 6121.93 kN. The FSDB will have a maximum base shear of 6744.283 kN and a minimum displacement of 281.32 mm when compared with flat slab building models. It was found that less stiffness and strength in flat slab building as compared to other building model and the stiffness is same for the bare frame, flat slab with drop and flat slab with drop and perimeter beam up to the elastic stage. After the elastic stage, stiffness has been changed and providing drop and perimeter beam, the stiffness and strength of flat slab building have been increased. From fig. 8, it is observed that the BFI is minimum displacement with 124.75 mm and maximum base shear of 8137.39 kN to all other building models. The FSI has a maximum displacement of 138.28 mm and minimum base shear of 6325.43 kN compared to all other building models. FSDI will have a displacement of 129.1 mm and a base shear of 6514.41 kN. The FSDBI is maximum base shear of 7160.61 kN and a minimum displacement of 127.79 mm when compared with flat slab building models. It observed that roof displacement decreased by 24% while adding a drop and perimeter beam for flat slab building and slightly varying base shear values. The adding infill wall in perimeter plan, the roof displacements are reduced by 54.5%, 62.9%, 55.32% and 54.5% for the bare frame, flat slab, flat slab with drop and flat slab with drop and perimeter beam buildings respectively and base shear is slightly varying with and without infill walls.

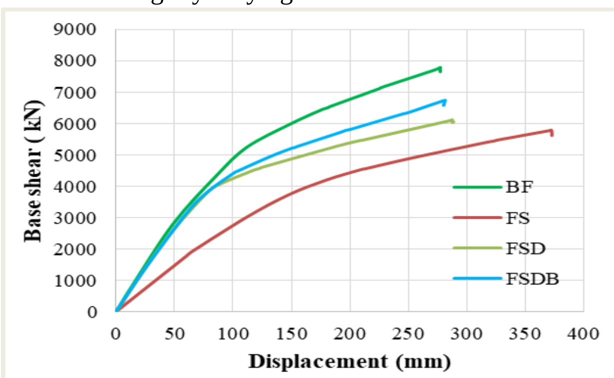


Fig. 7. Pushover curves for building models without infills.

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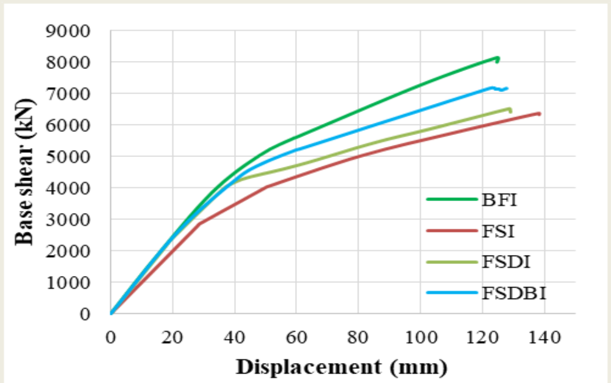

Fig. 8. Pushover curves for building models with infills.

(b) Capacity curve:

The fig.9 shows typical capacity curve and plot is drawn between spectral acceleration on X-axis and spectral displacement on Y-axis. These curves generated through pushover curves using ETABS software and shown in fig.10 and fig.11.

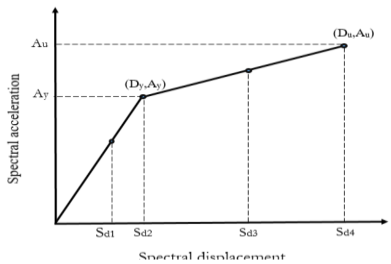

Fig. 9. Capacity curve.

Table-IV: Threshold damage states

Damage states	Condition ($S_{d,ds}$)
Slight	$Sd_1 = 0.7D_y$
Moderate	$Sd_2 = D_y$
Extensive	$Sd_3 = D_y+0.25(D_u- D_y)$
Collapse	$Sd_4 = D_u$

For the respective spectral displacement (mm) values for different damage states, the spectral acceleration (g) values are noted from the capacity curves as shown in table-IV. With the help of capacity points, fragility curves are derived for the buildings based on equation (1). The yield and ultimate capacity points are obtained from the capacity curves for the considered building models generated through ETABS software by pushover analysis.

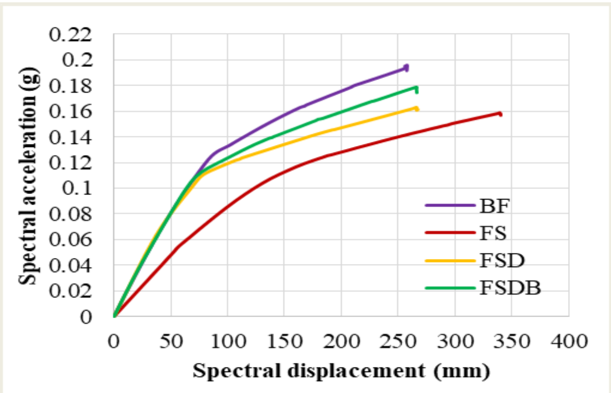

Fig. 10. Capacity curves for building models without infills.

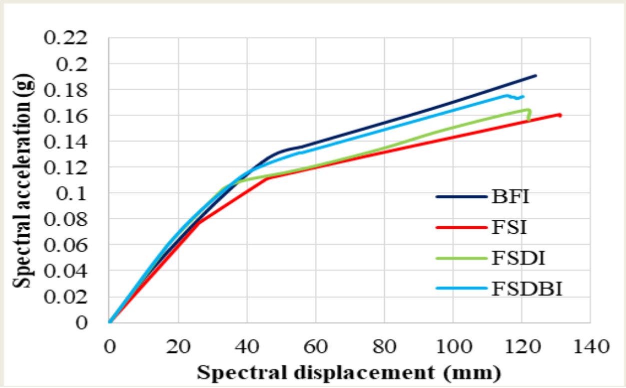

Fig. 11. Capacity curves for building models with infills.

These points are useful for the generation of fragility curves for the building models. The spectral displacements and spectral accelerations for all the building models for various damage states are obtained from capacity curves and shown in Table V.

Table-V: Yield and ultimate points of capacity curves

Model	Slight		Moderate		Extensive		Collapse	
	$S_{d,ds}$	$S_{a,ds}$	$S_{d,ds}$	$S_{a,ds}$	$S_{d,ds}$	$S_{a,ds}$	$S_{d,ds}$	$S_{a,ds}$
BF	58.2	0.092	83.2	0.12	126.9	0.15	257.9	0.19
FS	69.1	0.057	98.7	0.08	158.8	0.11	339.3	0.15
FSD	48.2	0.078	68.9	0.10	118.2	0.12	266.1	0.16
FSDB	50.3	0.084	71.9	0.11	120.4	0.13	265.9	0.18
BFI	32.3	0.096	46.2	0.12	65.66	0.14	123.9	0.19
FSI	18.1	0.058	25.9	0.07	52.25	0.11	131.1	0.15
FSDI	24.6	0.078	35.2	0.10	56.85	0.12	121.7	0.16
FSDBI	31.2	0.089	44.6	0.12	62.6	0.13	116.4	0.17

(c) Fragility curve:

The fragility curves for different building models for various damage states are generated using equation (1). The curve represents the cumulative distribution of damage state conditional exceedance probability from 0 to 1 given the spectral acceleration from 0 to 0.6. This set of curves helps to predict the vulnerability of buildings during its service life. The fragility curve for building models without infill and with infill of β_{ds} values are shown in table VI and VII for 7 storeys (mid-rise) concrete frame building without and with infill are obtained from HAZUS MH MR-5 technical manual [2] for all damage states.

Table-VI: β_{ds} values

Slight(β_S)	Moderate(β_M)	Extensive(β_E)	Collapse(β_C)
0.66	0.65	0.63	0.63

Fragility curves for building models with infill, the β_{ds} values are obtained from equation (5) and as shown in Table VII for seven-storey (mid-rise) concrete frame building with masonry infills are obtained from HAZUS MH technical manual [2] for all damage states.

$$\beta_{ds} = \sqrt{[CONV[\beta_c X \beta_d]]^2 + [\beta_M]^2} \quad (5)$$

Table-VII: β_{ds} values

β_c	β_d	β_M	β_{ds}
0.25	0.45	0.5	0.5124

By substituting β_{ds} values in equation (1), the fragility curves are developed for all the building models without and with infill wall for various damage states like slight, moderate, extensive and collapse as shown in fig 12-19 respectively. From fig.12-19, it is observed that flat slab building with and without infill wall have the highest probability of damage for all damage states, i.e. slight, moderate, extensive and collapse for any spectral acceleration. The bare frame building will have less probability of damage for any spectral acceleration. It is observed, the infill wall placed perimeter plan and above ground storey, the probability damage is slightly higher than the without infill flat slab and bare frame buildings. The results reveal that probability damage more in open ground storey with infill above ground floor flat slab and bare frame building as compared to without infill model. The adding drop and perimeter beam in flat slab building, the probability of damage is reduced as compared to flat slab building. Even though flat slab buildings models with infill wall and the open ground storey also fails as soft storey mechanism.

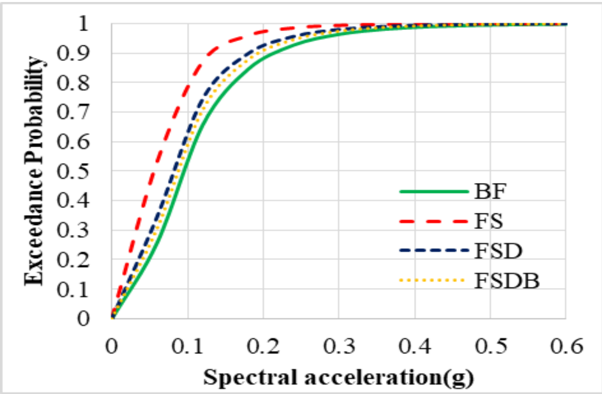

Fig. 12. Fragility curves for building models without infill for slight damage.

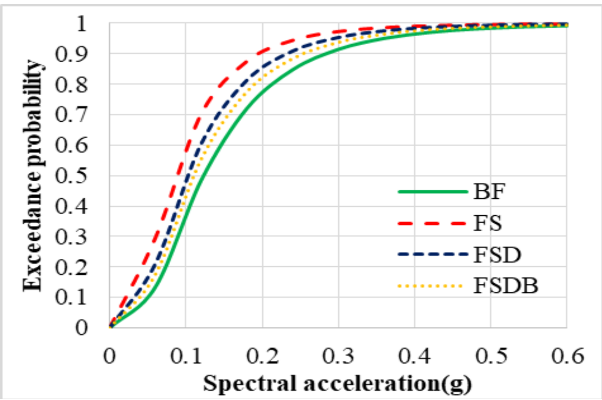

Fig. 13. Fragility curves for building models without infill for moderate damage.

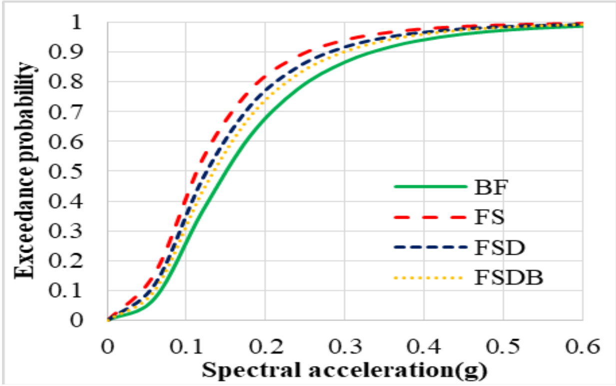

Fig. 14. Fragility curves for building models without infill for extensive damage.

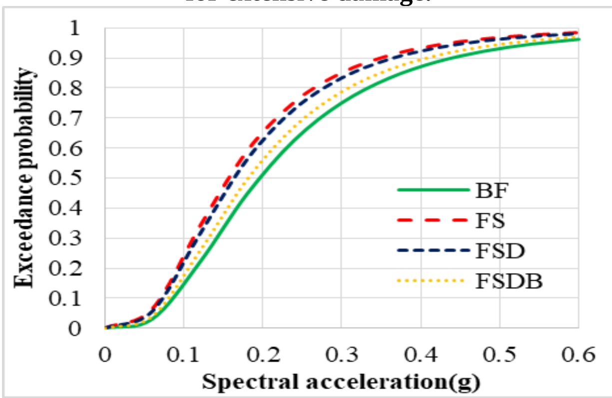

Fig. 15. Fragility curves for building models without infill for collapse damage.

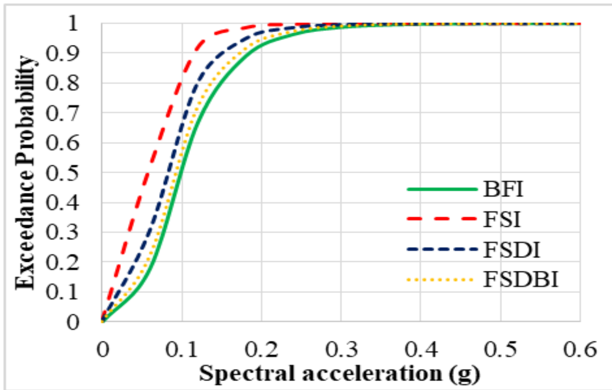

Fig. 16. Fragility curves for building models with infill for slight damage.

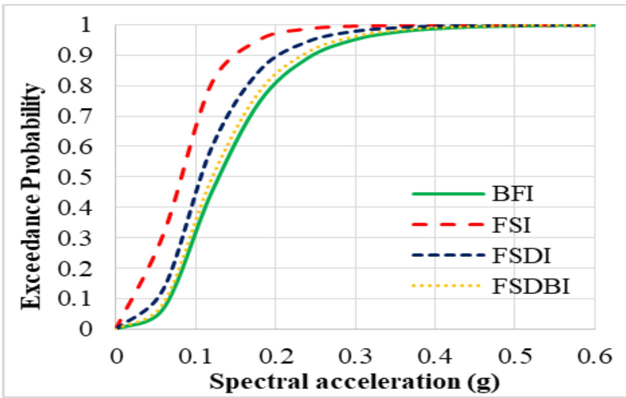

Fig. 17. Fragility curves for building models with infill for moderate damage.

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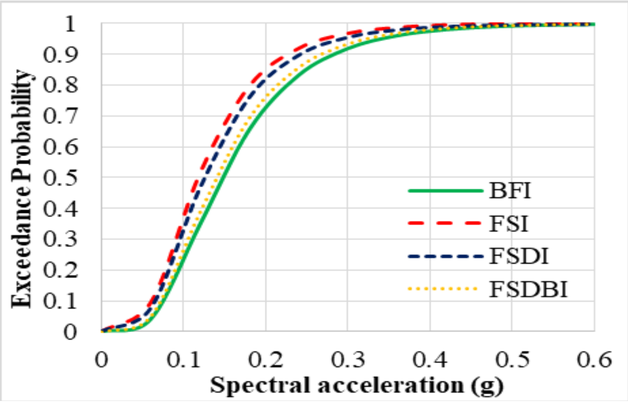

Fig. 18. Fragility curves for building models with infill for extensive damage.

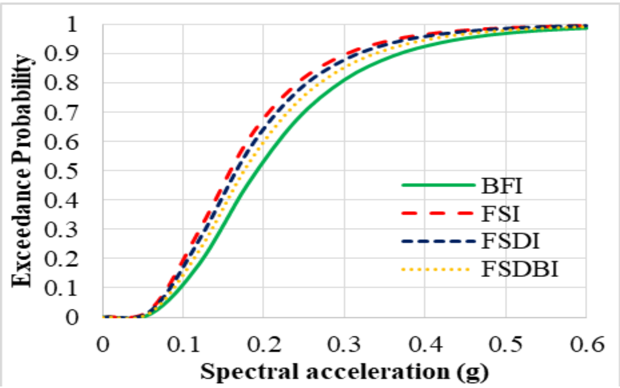

Fig. 19. Fragility curves for building models with infill for collapse damage.

For understanding the vulnerability of buildings, in this study, we assume the expected PGA values as 0.24g and 0.36g as per IS 1893-2016 [3]. The percentage of structural damages for all building models for various damage states in different PGA values are shown in Table VIII and IX. For PGA 0.24g and 0.36g values, the open ground storey with exterior infill above ground floor buildings will have more percentage of damage compared to buildings without infill for various damage states because the columns in ground storey mainly fails in open ground storey buildings. As PGA values increases, the probability of damage to building increases. In all building models, the buildings with exterior infill walls with open ground storey is the maximum probability of damage when compared to buildings without infill for PGA 0.24g and 0.36g respectively for all damage states.

Table-VIII: Percentage of damage for buildings in seismic zone IV (0.24g)

Models	Slight	Moderate	Extensive	Collapse
BF	92.7	84.8	77.2	62.64
FS	98.54	94.52	88.62	75.29
FSD	95.57	90.8	85.12	72.9
FSDB	94.4	88.52	82.48	67.6
BFI	96.3	89.1	83.16	67.2
FSI	99.7	98.6	91.7	79.65
FSDI	98.5	94.4	89.8	76.7
FSDBI	97.36	90.93	85.77	73.2

Table-IX: Percentage of damage for buildings in seismic zone V (0.36g)

Models	Slight	Moderate	Extensive	Collapse
BF	98.1	95.1	91.7	83.3
FS	99.74	98.69	96.7	90.7
FSD	98.9	97.45	95.40	89.55
FSDB	98.6	96.6	94.27	86.43
BFI	99.5	97.8	96	89.23
FSI	99.9	99.7	98.5	94.74
FSDI	99.8	99.1	98.05	93.6
FSDBI	99.7	98.33	96.8	92.72

VI. CONCLUSIONS

- From pushover analysis, it is concluded that flat slab building without drop will undergo larger displacements and have less base shear compared to other building models.
- It is concluded from the pushover results that flat slab building with drop and perimeter beam will have lesser displacements in flat slab building models and maximum base shear due to the presence of both perimeter beam and drops.
- The results of fragility curve reveals that probability of damage is more in open ground storey with infill above ground floor for flat slab, flat slab with drop, flat slab with drop and perimeter beam and bare frame buildings as compared to without infill model. The adding drop and perimeter beam in flat slab building, the probability of damage is reduced as compared to flat slab building. Even though flat slab building models with infill wall is also have more probability of damage as the open ground storey also fails as soft storey mechanism.
- It is concluded that for the same expected earthquake intensity, flat slab with drop and perimeter beam building would have better earthquake performance with lower probability of damage than other considered flat slab buildings. Flat slab buildings will have a high probability of damage for all the damage states in considered building models.
- All flat slab building models with the open ground storey with infill is more vulnerable than bare frame open ground storey building.

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