PAPER • OPEN ACCESS

Fragility Comparison for Soft Storey Infill Reduced Structures by Incremental Dynamic Analysis

To cite this article: B. Vamsi Krishna *et al* 2023 *IOP Conf. Ser.: Earth Environ. Sci.* **1130** 012029

Fragility Comparison for Soft Storey Infill Reduced Structures by Incremental Dynamic Analysis

B. Vamsi Krishna[1], M. Veera Reddy [2], Vasari Naresh[3], D. V. Tanuja[4], T. Sai Bharat[5]

[1]Associate Professor, Department of Civil Engineering, Malla Reddy Engineering College, Secunderabad-500100, India

[2]Professor, Department of Civil Engineering, Kakatiya Institute of Technology and science Warangal, Hanamkonda-506015, India

[3]Assistant Professor, Department of Civil Engineering, Malla Reddy Engineering College, Secunderabad-500100, India

[4]Assistant Professor, Department of Civil Engineering, Malla Reddy Engineering College, Secunderabad-500100, India

[5]PG-Research Scholar, Structural Engineering, Malla Reddy Engineering College,Secunderabad-500100, India

Abstract – A keen understanding of how a structure behaves when it is exposed to earthquake scenarios is required in order to foresee and avert the adverse effects and consequences when such a incident occurs, with the current rate of development in our country the construction of mid and high rise residential apartments are rapidly increasing but the data to understand such structures is insufficient, this data includes seismic vulnerability of structures, hazard maps of earthquake prone areas, seismic risks involved for a structure, this data provides the insight of what magnitude of risks are at hand when a earthquake scenario occurs and how to avert or minimize the losses with those risks [1]. In the present study, an effort is made to determine the behavior of soft Storey structures for various parameters when it is exposed to an earthquake ground motion; this includes the development of models analytically with the existence of soft Storey in them with different infill reductions and analyzing them, two models with varying heights and plot areas are considered for this study, this four models are modeled in such a way that different variations of soft Storey existence depending on the location of walls , percentage of infill reductions among different walls are done, a total of eight variety of models are been analyzed in both the X and Y directions. It is concluded that in all the models the fragility is higher in the models with lower lateral dimensions, as the length of the side decreases the fragility of that side is increasing. The Model without reduction performed efficiently showing less probability to collapse and that height and plan dimensions of the model are dependent on each other for the increase or decrease of fragility in a structure. If the height increases with the same model plan dimensions, the fragility of the structure also increases, if the plan dimension increases the fragility of the structure decreases.

Keywords – Dynamic Analysis, Infill Walls, MDOF, SDOF, Time history analysis.

1. Introduction

Open ground storey (OGS) structures are regularly given in India since they give genuinely necessary parking spot in a metropolitan climate. These structures are seen to be the weakest sort of upward sporadic structures [1]. Large numbers of the structures that bombed in ongoing seismic tremors in India were of this kind. Breakdown of these structures is overwhelmingly because of development of delicate Storey component, joined with P-impact, in the ground Storey segments. The between Storey float is generally extremely huge in the ground Storey contrasted with the narratives above, bringing about enormous arches and twisting snapshots of the ground Storey sections.

This prompts convergence of harm in the ground Storey segments, because of plastic pivot arrangement at the top and base. In traditional plan practice OGS structures are generally dissected as exposed outlines (displayed pillars and sections as casing components) by dismissing the solidness of infill walls. The ongoing Indian plan code, IS 1893 (2002), allows such worked on investigation, yet requires the originator to plan the ground Storey sections for twisting minutes and shear powers, improved by an element as high as 2.5. Practical way of behaving of OGS outlined structures, in any case, can be caught simply by demonstrating the firmness and strength of the infill walls in the upper stories in the examination [2].

Run of the mill private and business apartment complexes in India are constantly developed with brace or open stories at the base for the convenience or leaving of vehicles, this accounts are not given walls because of which this accounts solidness is diminished in bigger greatness than that of the narratives which are above them having a tendency to frame delicate Storey impact in them, because of this presence of delicate Storey in the construction the design is inclined when it is presented to quake situations, when this kind of construction containing delicate Storey at is presented to seismic tremor situations falling flat of sections in the delicate Storey is noticed bringing about underlying disappointment and breakdown of the construction displayed in the Figure 1, India has experienced a couple decimating seismic quakes in the past achieving a tremendous number of misfortunes and outrageous property harm [3].

Figure 1: Soft Storey failures

1.1 Incremental Dynamic Analysis for the development of Fragility Curves

Incremental Dynamic Analysis is a method of dynamic analysis where time history is performed on the structure with a gradual increase in the intensity measure of earthquake ground motion which we use for the analysis, Fragility curves are employed to determine probability of a structure to collapse or generally known as vulnerability of the structure, this graphs are plotted between the peak ground acceleration to the probability of exceedance of the damage, this determines the expected life time of a structure before it reaches the damage state [4].

However, causes of failures and extent of damage depend to a great extent on the type of constructions and the density of population in the area. There are various methods to determine the fragility of a structure among them the following methods is well known

- Empherical methods
- Expert opinion methods
- Analytical methods
- Hybrid methods

For the current study analytical method using the time history analysis fragility has been developed, this method of development of fragility curves gives more accurate behavior than the other methods because of the numerus parameters of the structure are taken into account while performing the analysis [4].

2. Literature Review

This discusses about the effects of soft storey in buildings, N2 methodology, and Development of Fragility through IDA curves. Soft storey is nothing but the deficiency of lateral stiffness in a Storey up to 70% than the above Storey this usually occurs when there is a stilt floor. The existence of soft storey in a structure makes it vulnerable when exposed to earthquakes, on many occasions' buildings with soft storey located at ground floor started to collapse when they are hit with an earthquake.

2.1 Soft storey effects

Dr. Saraswati Setia et al. (2016): In this paper the author explains Seismic response of a RCC building with soft Storey effect, a typical 6 storied RC frame building is being modeled using the computer software STAAD.Pro this model is initially analyzed as bare frame model and then modeled again as a structure having infill walls on all the storey's except at the ground storey making a soft storey effect, Pushover analysis has been done on both the models and from its results it has been concluded that The lateral displacements of the bare frame are larger when compared to the lateral displacements in the structure with the infill walls Building with masonry infill in upper floors only shows a sudden change in slope of displacement This is because of abrupt change in storey Stiffness, the storey shear is maximum in structure with infill walls while compared to the bare frame [3].

2.2 N2 methodology

Arton Dautaj et al.(2017): In this method the author explains that N2 method can be used both for the seismic performance evaluation of newly designed or existing structures. Furthermore, by reversing the analysis process, the method can be used as a tool for the implementation of direct displacement-based design approach, in which design starts from a predetermined target displacement, he has also explained that how N2 method provides results with sufficient accuracy and can be used for systems where seismic response is dominated by the contribution of the first form of vibration [4].

2.3 Incremental Dynamic Analysis

Lucia Tirca et al.(2017): In this paper the author has modeled two structures and conducted Incremental Dynamic Analysis on each structure with ten ground motions one of the structure is a three storey structure and the second is of six storey this two models are designed as steel structures and through IDA different types of failure conditions for the elements in the structure has been studied this involves connection failures brace buckling failure and building failure The summary of IDA curves are transposed into the fragility curves that emphasize the probability of collapse to the spectral intensity of considered ground motions, The conclusions from this study are, As illustrated from IDA curves in Fig2.4, all support to approach connections have inadequate strength and show failure before the connected support individuals arrive at the plausible compressive strength. Due to the short period characteristic of seismic ground motions (high frequency), low-rise buildings show a maximum inter storey-drift of 0.6%, while middle-rise buildings may experience 0.8%. [5]

2.4 Fragility

Linda Astriana et al.(2016): In this paper the author uses the HAZUS-MH MR5 and ATC-40 methodology to estimate the different damage states of a structure, Fragility curve is a probabilistic function relating damage level of a structure to the intensity measure of spectral acceleration, the seismic performance of a moment resisting frame as compared to frame wall system of structure has been compared using pushover analysis yielding capacity spectrums, damage states for each capacity spectrum has been defined using the HAZUS MH methodology, the profile of the building is explained in the Fig2.7 and the fragilities for different damage states are shown in Fig2.8 from the results it is been concluded that building with shear wall are capable to resist the lateral forces and have better earthquake performances with damage probability lower than resisting moment frame. This study on Incremental Dynamic Analysis of a three Storey building and six storey building constructed in the Hyderabad region modeled as a bare frame, soft Storey at ground floor, soft Storey and with interior walls and without any reductions has not beendone until now [6].

3. Objective of Current Study

The main objective of the project is

- To develop fragility curves through incremental dynamic analysis for a 3-Storey and 5-Storey structure on the bases of a bare frame existence of soft Storey with exterior walls, combined exterior and interior walls and without reduction
- Comparison of fragilities for bare frame models with soft Storey models having exterior walls with and without interior walls and without reduction
- Comparison of models fragilities in both the X and Y directions

4. Methodology

A Soft storey is created when stories stiffness is generally less than the 80% of the immediate above storey or if it is less than 70% of the average of above three stories, in order to impart the properties of a soft Storey to a structure while modeling in any software it is necessary to increase the stiffness of the above stories, this can be done by adding few types of structural elements to the model which is created this involves elements such as Showed in the Figure 1, 2, 3 & 4.

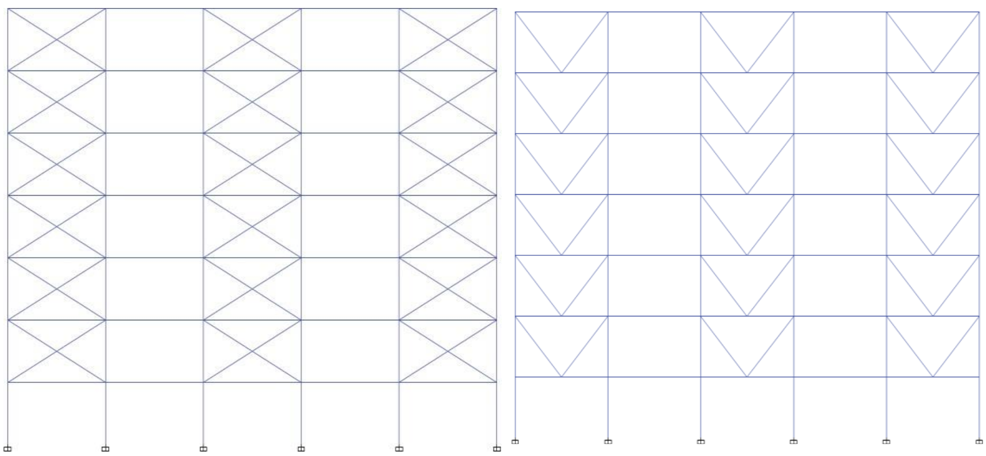

Figure 2: A.X-bracing B.V-bracing

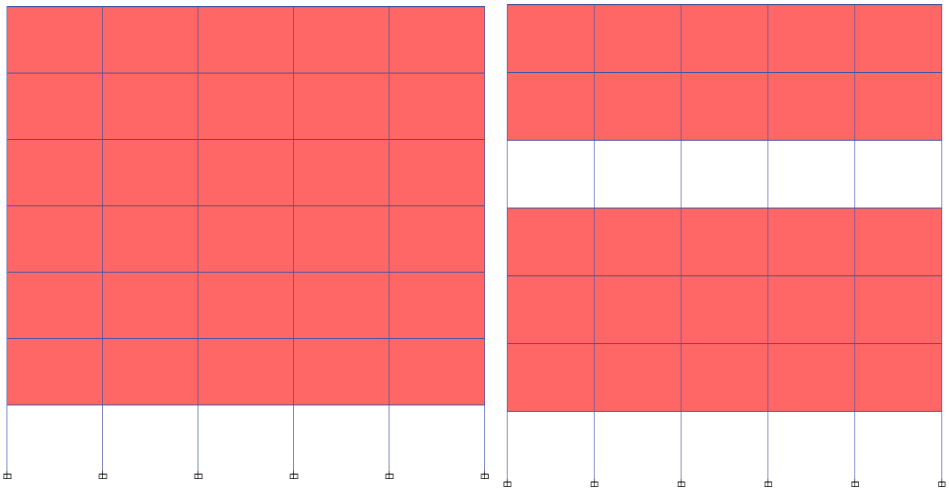

Figure 3: Infill walls

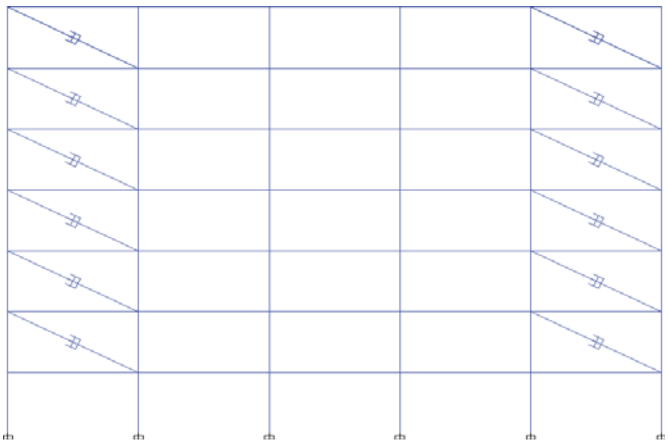

Figure 4: Dampers

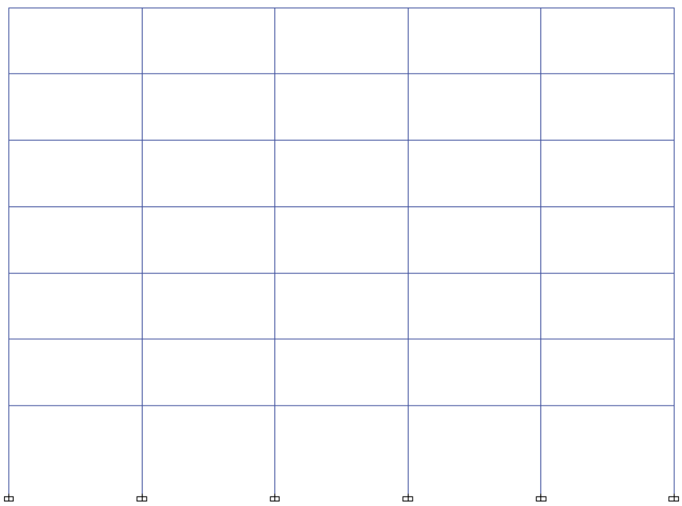

Figure 5: Increased length of bottom storey column

4.1 Pushover analysis
Pushover analysis is a static nonlinear analysis of a structure where the parameters such as structural behavior after the yield, capacity of structure, maximum displacements, progression of hinge formations, and base shears can be calculated using this analysis, for the analysis of structure in this study SAP2000 has been utilized, the procedure of analysis can be done in two ways the first one is by using auto hinge assignment the second one is by using user define hinges.

4.2 N2 Method
N2 method is used to convert a MDOF system into an equivalent SDOF system; this is done by a step by step procedure.

4.3 Ground motion scaling
In order to perform the incremental dynamic analysis scaling of the ground motion is required, to scale a ground motion

4.4 IDA curves development
Incremental dynamic analysis curves are plotted with intensity measure against the displacement of the structure in order to develop these curves we need a set of scaled ground motions the IDA is performed as a response history analysis the following are the steps which are to be followed while performing the incremental dynamic analysis of ground motion showed in figure 6.

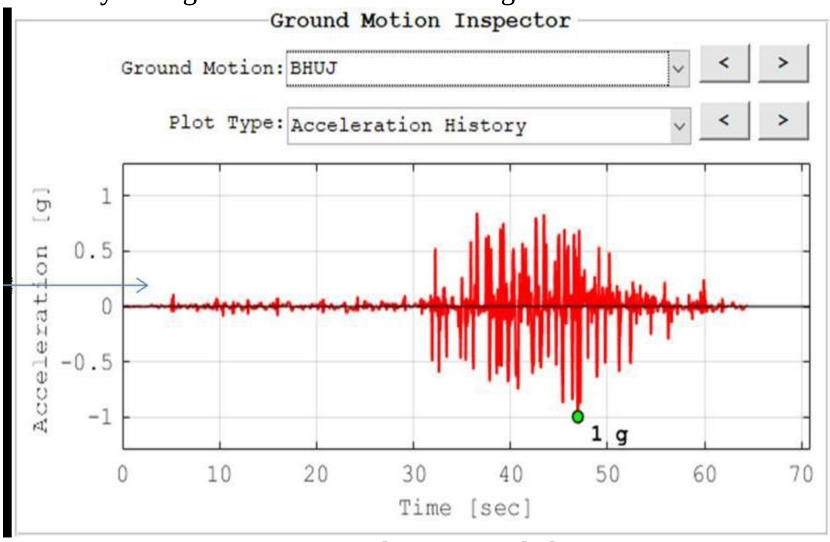

Figure 6: Ground motion scaled to 1.0g

4.5 Fragility curves development
Fragility curves are the probability of damage estimation curves of a structure against increasing intensity measures there are different methods for the development of fragility curves such as the HAZUS MH5 method, Empirical methods, Expert opinion methods, Analytical method, and Hybrid method, in this study Analytical method using the Response history analysis was done in order to get the fragility curves, this analysis is performed using the II-DAP software.

The development of soft Storey from different modeling methods, Pushover analysis procedures, conversion of MDOF to SDOF system using the N2 method, scaling of ground motions for IDA analysis, Procedure for performing Incremental Dynamic Analysis and Development of IDA curves Fragility curves have been Discussed.

IOP Conf. Series: Earth and Environmental Science 1130 (2023) 012029 doi:10.1088/1755-1315/1130/1/012029

5. Structure Modeling and Model Analysis

For this study a 3 Storey and 5 Storey models are selected and they are categorised into four models corresponding to existence of walls, the first models are bare frames without any walls second models are soft Storey models with exterior perimeter walls third model type are soft Storey with exterior and interior walls and fourth without any reductions showed in flowchart Figure 7.

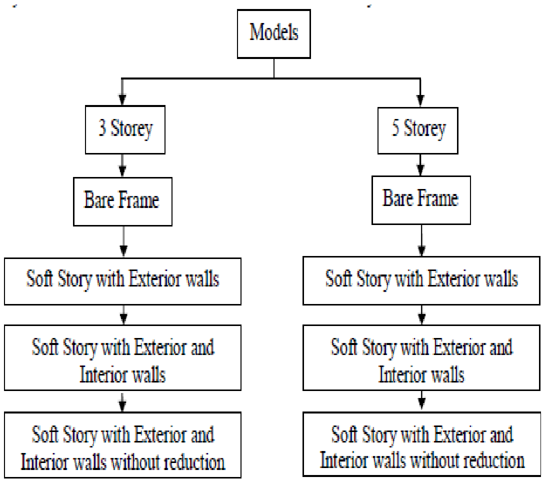

Figure 7: Flow chart of modelling

5.1 Structure Details

Two structures which are of 3 stories and 5 stories and with plot dimensions of 195sqy and 693sqy respectively are taken the following are the plan and Storey configuration of buildings showed in Table 1.

Table 1: Structure details

	Building-1	**Building-2**
Plot Dimensions	12.19m X 12.80m (40'0'' X 42'0'')	36.85m X 16.0m (120'9'' X 52'6'')
Built Up Dimensions	10.97m X 10.36m (36'0' X 34'0'')	32.27m X 13.56m (105'9'' X 44'6'')
Plot Area	156.03Sqm(195Sqy)	589.6Sqm(693Sqy)
Built Up Area	113Sqm (136Sqy)	437.58Sqm(522.87Sqy)
No of stories	3	5
Ground Storey height	3m (9'11'')	3m (9'11'')
Typical Storey height	3m (9'11'')	3m (9'11'')

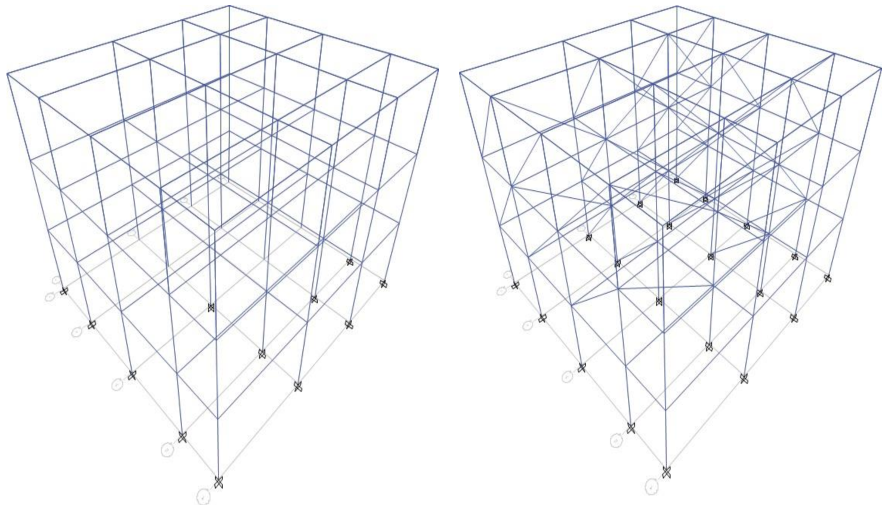

Figure 8: Bare frame & Soft Storey 3D view with strutsBuilding 1

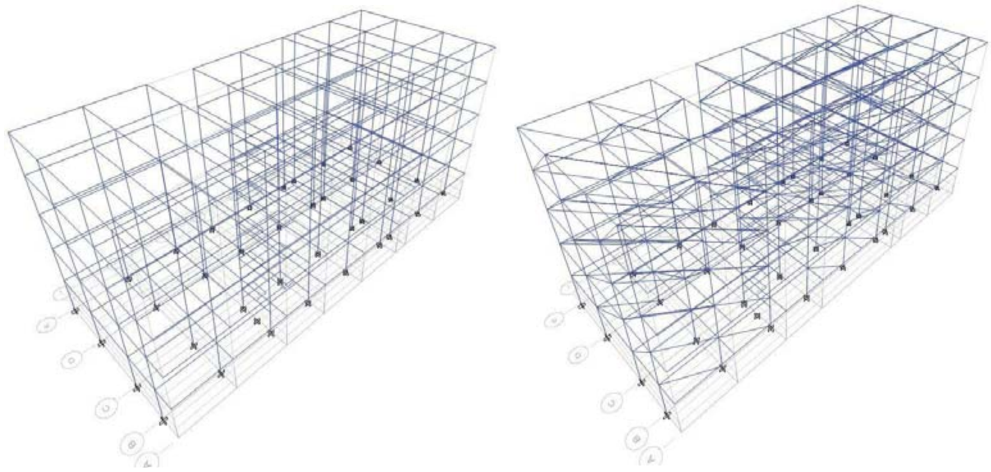

Figure 9: Bare frame & Soft Storey 3D view with strutsBuilding 2

5.2 Loadings

All the loads are calculated and taken from the IS 875, for the dead loads densities of material are taken from the part I of the code and For the imposed load on the residential buildings are taken from the part II, the structure is further analysed for the pushover load which will be discussed in the pushover analysis chapter, the dead load of walls having thickness of nine inches and six inches are calculated for external and internal walls respectively and assigned on corresponding beams the loadings are same for the 3 Storey and 5 Storey buildings, the following table 2 shows all the loads applied on the structure.

Table 2: Loadings

S.No	Load Case	Component	Load Type	Application	Intensity
1	Dead Load	External Walls	Uniformly distributed load	External Beams	13kN/m
2		Internal Walls	Uniformly distributed load	Internal Beams	9kN/m
3		Parapet Walls	Uniformly distributed load	Roof beams	6kN/m
4		Floors-Floor finish	Uniform Pressure	All slabs	1.5kN/m2
5	Live Load	Hall, kitchen, bedroom, toiletfloors	Uniform Pressure	Slabs	2kN/m2
6		Corridors, balconies	Uniform Pressure	Slabs	3kN/m2

5.3 Material and Section Properties

All the materials used for modelling the structure are based on the Indian standards, for the beams and columns defined properties are considered, whereas for the modelling of strut a masonry material has been created, for both the building 1 and building 2.

5.4 Pushover Analysis

Pushover analysis is a static nonlinear analysis of a structure where the parameters such as structural behavior after the yield, capacity of structure, maximum displacements, sequence of hinge formations, and base shears can be calculated using this analysis, for the analysis of structure in this study SAP2000 has been utilized, the procedure of analysis can be done by using auto hinge assignment showed in table 3.

Table 3: Storey Bare frame displacement and shear values

	X-values	
Parameters	Displacement	Base Shear
Yield	0.0092	749
Maximum	0.22	1142
Ultimate	0.36	1019
	Y-values	
Yield	0.0084	729.27
Maximum	0.209	1159
Ultimate	0.29	1073.89

Table 4:-3- Storey soft Storey with exterior walls Storey masses Storey displacements

Storey. No	Mass(Kgs)	Mass m (tonnes)	Storey disp-X (m)	Storey disp-Y (m)
Storey 3	34915.55	34.92	0.5	0.49
Storey 2	51855.07	51.86	0.48	0.49
Storey 1	51855.07	51.86	0.41	0.49

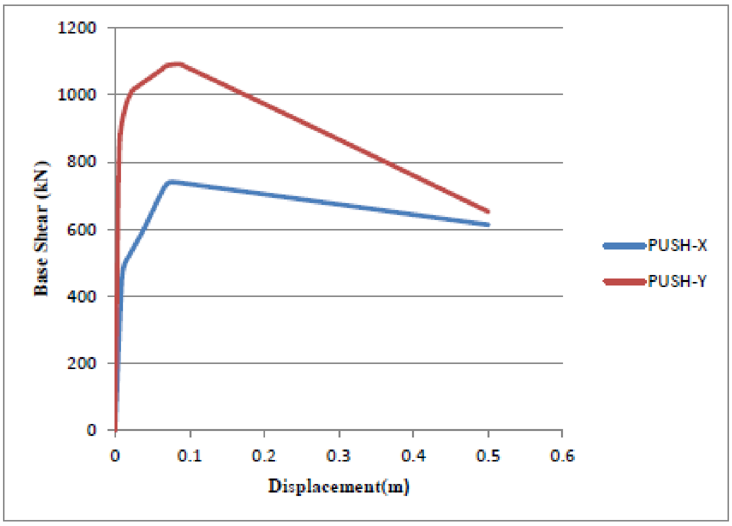

Figure 10:-3- Storey soft Storey with exterior walls pushover curves

Table 5: 5-Storey Soft Storey with exterior walls Storey masses Storey displacements

Storey. No	Mass(Kgs)	Mass m (tonnes)	Storey disp-X (m)	Storey disp-Y (m)
Storey 5	87821.86	87.82	0.18	0.14
Storey 4	128263.78	128.26	0.18	0.14
Storey 3	128263.78	128.26	0.18	0.14
Storey 2	128263.78	128.26	0.15	0.11
Storey 1	128263.78	128.26	0.13	0.11

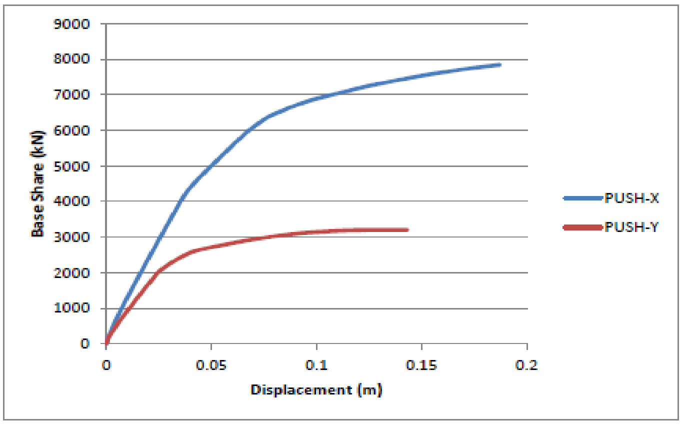

Figure 11: 5- Storey soft Storey with exterior walls pushover curves

5.5 Incremental Dynamic Analysis

Incremental Dynamic Analysis is a method of dynamic analysis where time history is performed on the structure with a gradual increase in the intensity measure of earthquake ground motion which we use for the analysis, through this incremental dynamic analysis the behavior of the structure when it is subjected to an earthquake of certain magnitude and intensity measure, the capacity of the structure to which it can withstand without collapse.

The N2 technique is a quick nonlinear static strategy for the seismic plan of structures. Nonlinear dynamical analysis of the system with many degrees of freedom is relatively complicated and, as such, is not very suitable for everyday design. This is a simple nonlinear method for the seismic analysis of structures. It combines the pushover analysis of a multi-degree-freedom (MDOF) with the response spectrum analysis of equivalent single-degree-of-freedom (SDOF) system In order to overcome these difficulties. By following the steps mentioned in methodology for the data obtained from the pushover analysis has been converted into SDOF system, the following are the calculations and results for each model in x and y directions in table 6,7 & 8

Table 6: 3-Storey Bare Frame X-direction

Storey. No	Mass(Kgs)	Mass m (tonnes)	Storey disp (m)	Relative displacements (d)	d*d	m*d	m*(d*d)
Storey 3	25934.00	25.93	0.36	1.00	1.00	25.93	25.93
Storey 2	33891.00	33.89	0.28	0.78	0.60	26.36	20.50
Storey 1	33891.00	33.89	0.04	0.11	0.01	3.86	0.44
					∑	56.15	46.88

Table 7: 3-Storey Bare Frame Y-direction

Storey. No	Mass(Kgs)	Mass m (tonnes)	Storey disp (m)	Relative displacements (d)	d*d	m*d	m*(d*d)
Storey 3	25934	25.93	0.2931	1.00	1.00	25.93	25.93
Storey 2	33891	33.89	0.215	0.73	0.54	24.86	18.24
Storey 1	33891	33.89	0.0034	0.01	0.00	0.39	0.00
					∑	51.19	44.17

Table 8: Equivalent SDOF Parameters

S. no	Building type	Direction	Equivalent Mass	Yield Disp	Max Disp	Ultimate Disp	Yield Base Shear	Max Base Shear	Ultimate Base shear
1	3-Storey Bare frame	X	56.15	0.008	0.184	0.301	625.247	953.314	850.636
		Y	56.15	0.007	0.180	0.250	629.357	1000.21	926.76
2	3-Storey Soft Exterior walls	X	127.22	0.008	0.064	0.458	435.291	68.352	567.449
		Y	127.22	0.007	0.085	0.496	883.000	1091.00	652.00
3	3-Storey Soft Storey exterior and interior walls	X	175.94	0.007	0.069	0.495	470.1	715.09	590.53
		Y	175.94	0.005	0.067	0.49	941.85	1125.625	663.01
4	3-Storey soft Storey without reduction	X	185.23	0.007	0.069	0.495	517.11	786.59	649.583
		Y	185.23	0.005	0.067	0.49	1036.03	1238.182	729.311
5	5-Storey Bare frame	X	201.72	0.009	0.245	0.706	471.671	2230.554	1549.504
		Y	201.72	0.008	0.267	0.691	348.828	1402.197	1029.559
	5-Storey Soft	X	543.87	0.031	0.166	--	3609.81	7215.95	--

6	Exterior walls	Y	543.87	0.021	0.132	--	1809.50	2942.864	--
7	5-Storey Soft Storey exterior and interior walls	X	679.18	0.031	0.087	--	6258.36	8875.09	--
		Y	679.18	0.024	0.102	--	2511.45	3107.335	--
8	3-Storey soft Storey without reduction	X	691.35	0.031	0.087	--	6884.19	9762.5	--
		Y	691.35	0.024	0.102	--	2762.35	3418.063	--

5.6 Incremental dynamic analysis
The following are the incremental dynamic curves and fragility curves which are obtained for all the eight models in both X and Y directions of 3-storey and 5-storey was presented in Figure 11-14.

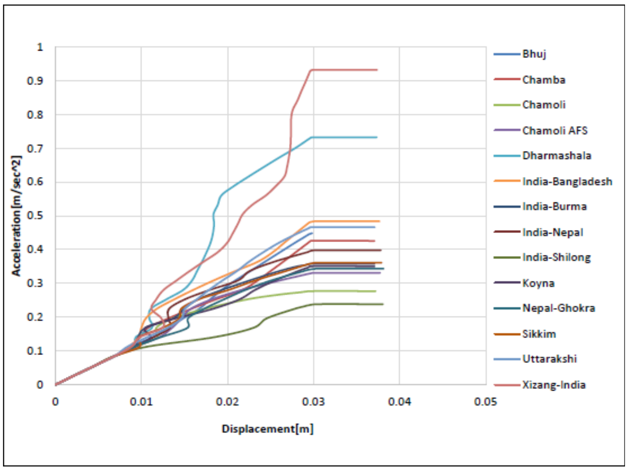

Figure 12: 3-storey soft storey with exterior walls X-direction

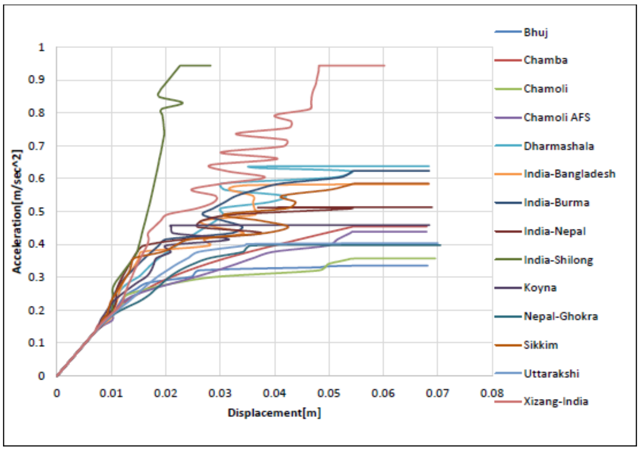

Figure 13: 3-storey soft storey with exterior walls Y-direction

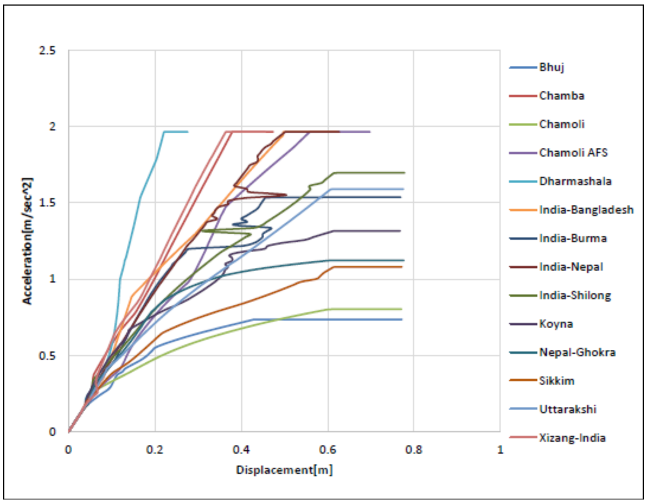

Figure 14: 5-storey soft storey with exterior walls X-direction

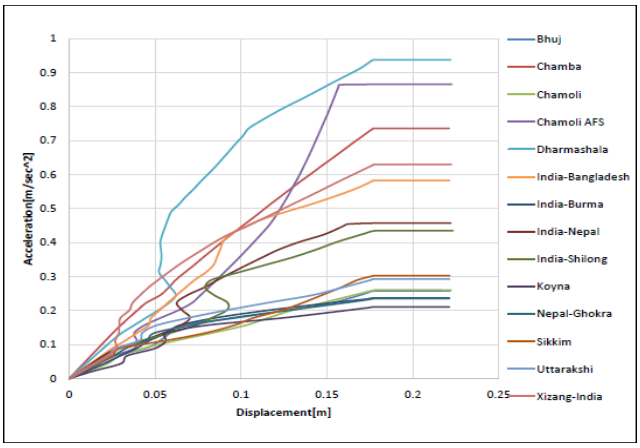

Figure 15: 5-storey soft storey with exterior walls Y-direction

5.7 Fragility Curves

The following are the combined fragility curves in X &Y Directions which are obtained individually from each IDA curve obtained for all the eight models showed in Figure 15-18

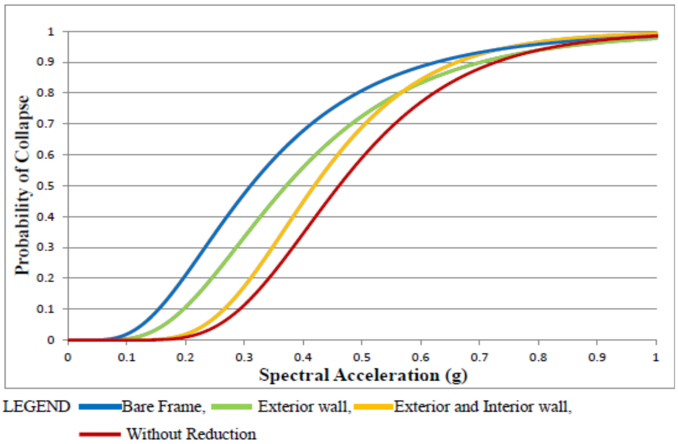

Figure 16: 3-Storey X-Direction Fragility curves

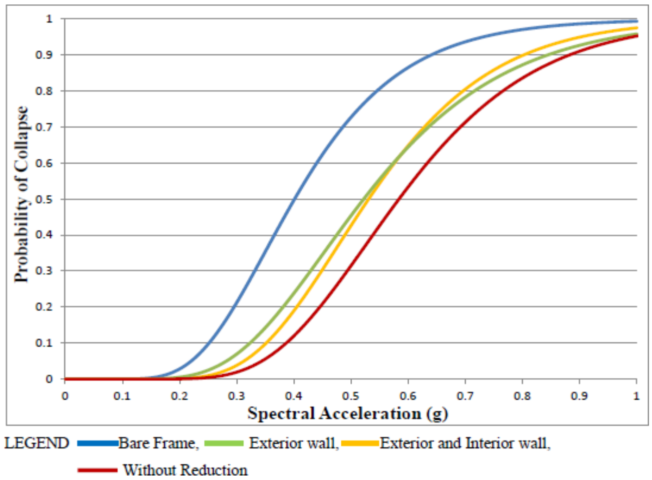

Figure 17: 3-Storey Y-Direction Fragility curves

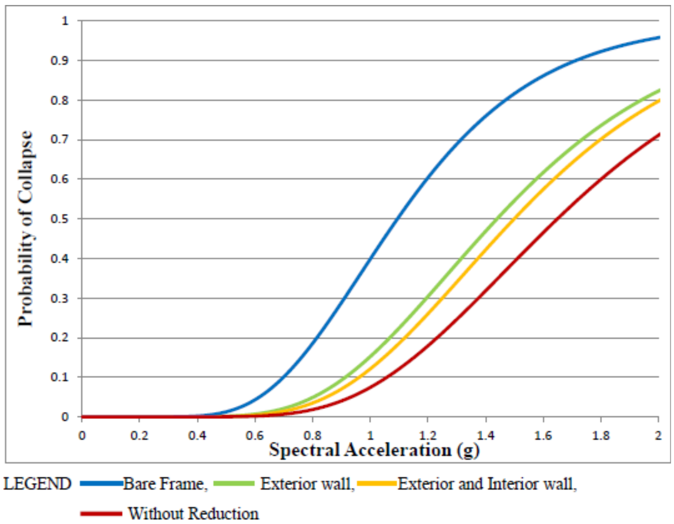

Figure 18: 5-Storey X-Direction Fragility curves

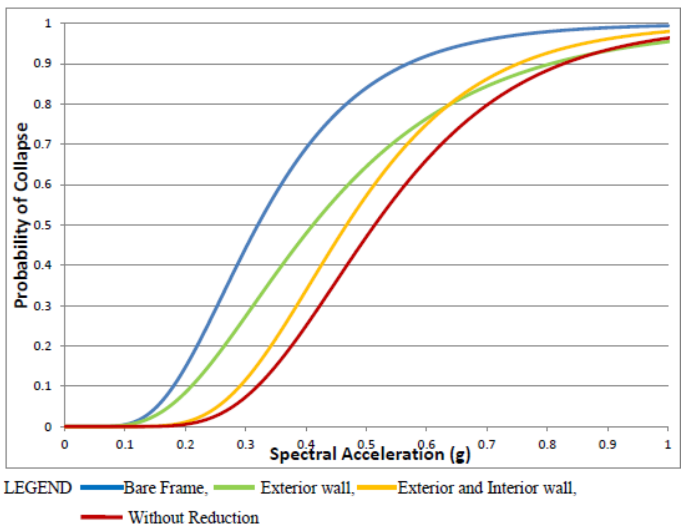

Figure 19: 5-Storey Y-Direction Fragility curves

6. Conclusions:

In this project work, two building models of 3-Storey and 5-Storey having a plot area of 195sqy and 693sqy respectively are considered and analyzed in four different model types as bare frame, soft Storey with exterior walls, soft Storey with interior and exterior walls, and without any reduction. Two types of analysis are performed on the structures, initially static nonlinear pushover analysis and then incremental dynamic analysis, in order to perform the incremental dynamic analysis the MDOF system models are converted into equivalent SDOF models using the N2 method, 12 ground motions are scaled to the required intensities and they are used for the development of IDA curves, from the developed IDA curves fragility of the model is extracted in X and Y directions for each model.

- The time period of the structure increases with increase in height of the structure and decrease with increase in the mass of the structure, from the model analysis it is observed that the time period of the structure in the first mode for a 3-Storey bare frame is 0.31 seconds and that of a 5-Storey bare frame is 0.56 seconds
- The time period of the structure decrease with increase in mass and stiffness of structure, the bare frame model has higher time period when compared to the model without reduction, 3-Storey bare frame time period for first mode is 0.31 seconds where as for model without reduction is 0.25 seconds similarly for 5-Storey structure 0.56seconds for bare frame and 0.39secconds for model without reduction
- From the IDA and Fragility curves in the 3-Storey models it is concluded that the probability of collapse in X-direction is higher in the models having soft Storey in them.
- It is concluded from observing the above results that in all the models the fragility is higher in the models with lower lateral dimensions, as the length of the side decreases the fragility of that side is increasing.
- It is concluded that Model without reduction performed efficiently showing less probability to collapse
- It is concluded that height and plan dimensions of the model are dependent on each other for the increase or decrease of fragility in a structure, if the height increases with the same model plan dimensions the fragility of the structure also increases, if the plan dimension increases the fragility of the structure decreases.

References:

[1] Christine A. Goulet, UCLA, Jennie Watson-Lamprey, Watson-Lamprey Consulting,Jack Baker (2018). Assessment of Ground Motion Selection and Modification (GMSM) methods for non-linear dynamic analyses of structures. Geotechnical Earthquake Engineering and Soil Dynamics IV
[2] Linda Astrian , Senot Sangadji , Edy Purwanto , S.A. Kristiawan (2016). Assessing sesmic performance of moment resisting frame and frame- shear using fragility curve. Sustainable Civil Engineering Structures and Construction Materuals, SCESCM 2016. Procedia engineering 171 (2017) , 1069-1076.
[3] Dr. Saraswati Setia et al. (2016). A Very Efficient Solution for Performing Incremental Dynamic Analysis. Cloud to IDA , part of Springer Nature 2018. M. di Prisco and M. Menegotto (Eds.): ICD 2016, LNCE 10, pp. 355–368, 2018
[4] Arton Dautaj et al.(2017): Earthquake Vulnerability Assessment for RCC Buildings of Guwahati City using Rapid Visual Screening. Procedia Engineering 212 (2018) 214–221.
[5] Lucia Tirca et al.(2017): Fragility curves for RC frames under multiple earthquakes. Soil Dynamics and Earthquake Engineering 98 (2017) 222-234.
[6] Linda Astriana et al.(2016), Fragility Assessment for Vertically Irregular Buildings with Soft Storey. World Academy of Science, Engineering and Technology, International Journal of Civil Environmental Engineering, Vol:10, No:10.
[7] Seong-Hoon Jeong and Amr S. Elnashai. (2006). Fragility Analysis of Buildings with Plan Irregularities. 4th International Conference on Earthquake Engineering.
[8] F.Hejazi S. Jilani, J. Noorzaei, C. Y. Chieng, M. S. Jaafar.(2011). Effect of Soft Storey on Structural Response of High Rise Buildings. IOP Conf. Series: Materials Science and Engineering 17 (2011)