A Gui Framework For The Development Of Fragility Curves For A Low-Rise & Medium-Rise Buildings

B. Uday Kumar,Gandla Nanabala Sreekanth

Abstract: ***"Earthquake's do kill the people." It is a clear misconception. Earthquakes never kill, but it is always the constructional failure which makes the situation worse and leads to the loss of life. Earthquake's root to a huge economic loss apart from the tortuous pain of loss of lives. This calls for the need of seismic strengthening as the circumgyrations are inevitable. Seismic strengthening improves the structural safety but does not reduce the seismic response. Seismic strengthening is a pre-disaster assessment. But the need to study the observance of the existing buildings against the circumgyrations lead to a stew of post-disaster mitigation with pre-disaster planning known as Fragility analysis. Fragility analysis refers to the partial assessment of vulnerability of the buildings subjected to earthquake motions. In this study, the fragility curves are developed with the aid of Incremental dynamic analysis or Non-linear dynamic analysis conducted on the model. The curves explain the conditional anticipation which outstrip adefinite limit of failure and therefore guesstimate the susceptibility of the structure. Fragility curves are very much useful in seismic loss estimation studies in earth quake prone zones. Two structural models four storey & six storey 3D open frame buildings were considered.The structural models are designed for dead, live and seismic loads according to the Indian Code. A set of 5 Farfield ground motions scaled from 0.1 to 1 with an increment of 0.1 are used in the Incremental dynamic analysis using SAAP2000. Four performance levels, namely Fully Operational (FO), Immediate Occupancy (IO), Life Safety (LS) and Collapse Prevention (CP) were considered and monitored in the analysis using MATLAB. The objective of the study is to develop the fragility curves for a low rise (G+3) and medium rise (G+5) building models using the Graphical User Interface (GUI) in MATLABR2016a considering the four selected performance levels. The study depicts the use of Hybrid method (combination of Expertise & analytical methods) for the development of Fragility Curves.***

Keywords: Seismic strengthening, Pre-disaster assessment, Post-disaster mitigation, Fragility analysis, vulnerability assessment, Fragility curves, Incremental Dynamic Analysis (IDA), Non-linear Dynamic analysis, Graphical User Interface (GUI), SAAP2000, MatlabR2016a.

I. INTRODUCTION

The use of buildings to its complete potential after a rugged earthquake is not clearly inscribed in IS1893-2016.This issue is neither dealt in many of the regional building codes.

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B.Uday Kumar pursuing M.Tech in Structural Engineering from Rajeev Gandhi Memorial College of Engineering and Technology, NANDYAL, A.P

Gandla Nanabala Sreekanth assistant professor in the school of civil engineering at Rajeev Gandhi Memorial College of Engineering and Technology

To overcome this issue the Performance Based Seismic Design (PBSD) is used as a factor to provide a clear and concise idea of structural damage due to potential earthquakes. PBSD deals with design, evaluation and construction of the buildings based on past earthquakes and type of usage. The structural performance level depends on life cycle, Importance factor of the building and in some cases construction cost.The performance level is an epitome of maximum extent of damage to a structure against a definitive earthquake design level.On the whole the building performance is classified in structural and non-structural performance levels as per FEMA 273-1997 and FEMA 356-2000 as Fully Operational, Immediate Occupancy, Life Safety andCollapse Prevention.

The performance levels are described as follows

a) Fully Operational

The building is readily suitable for casual use with a nominal damage or in some cases nil damage to the structural and non-structural components. In the due course of study the term is denoted as FO.

b) Immediate Occupancy

The structural componentsof the building experiences anominal or nil damageand the non-structural components are exposed toa minor damage. The building is to be repaired and restored to some extent before the building can function as before.In the due course of study the term is denoted as IO.

c) Life Safety

The structural and non-structural components of the building are subjected to severe damage and are to be repaired before re-occupancy. Repair is practically possible but it may be economically impractical and not feasible. In the due course of study the term is denoted as LS.

d) Collapse Prevention

The structural and non-structural components are subjected to a humungous damage and are set for collapse. The structural collapse is avoided without considering the Non-structural vulnerabilities. The building forges a fatalhazard to life and repair is treated as a complete economic loss.In the due course of study the term is denoted as CP.

Generally during an earthquake the buildings fail mostly by buckling. The buckling can be assessed by the extent of drift of the components or structures. In this study Drift is used the common parameter to differentiate the performance levels. This criteria roots back to the guidelines inscribed in FEMA 273-1997 and FEMA 356-2000.

Fragility is a tool for the prediction of structural and

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non-structural damage. The fragility curve is described as the probability limit of a structure to exceed or reach a predefined damage state. It provides the feasibility toevaluate the damage against aspecificground motion index. The main objective of the present study is:

i. To evaluate the drift of the buildings with varying height and

ii. To build up the seismic fragility curves for a low-rise (G+3) and medium rise(G+5) buildings having similar geometry and same material and componential properties.

IDA is treated as the first step in the development of Fragility Curves. These curves study the probability of failure of the structure against a specific damage state for different levels of ground motions. These curves are further used to make retrofitting decisions, estimation of economic loses and casualties and also help in disaster response planning which is of a prime importance in case of a havoc.

The IS code provides speculations for the design and construction of the buildings subjected to earthquake, but the code doesn't specify any clause or data to develop fragility curves. This is the main reason for use of Euro code 8 part-1 and Federal Emergency Management Agency (FEMA) 356 and FEMA273 as the base for development of Fragility curves.

II. LITERATURE REVIEW

M. Altug Erberik et.al. (2004)[3]developed Fragility curves for Low-rise, Mid-rise and High-rise buildings. ZEUS-NL software is used to derive fragility curves. The paper Deals with the Comparison between Flat slab structures and Moment resisting frame structures in the ambience of Fragility curves. The Inelastic response history analysis is adopted in the study. It is a treat of Comparison between Low-rise, Mid-rise and High-rise buildings in the context of Fragility curves. The results of the mid-rise buildings are satisfactory compared to that of high-rise and low-rise buildings. This paper aims at the Non proficiency of Flat slab system against earthquake forces for low, mid and high rise buildings.

Kyung Ho Lee et.al. (2006)[4]traced Fragility Curves for the Wood frame structures. Cashew software is used to derive fragility curves. Snow and Earthquake Loading is used in the analysis. Single, Double and Multiple Hazards are considered. Detailed summons regarding the shear walls are taken without any proper solid base. Fragility curves are developed against maximum and minimum shear wall drifts. Nonlinear Dynamic time history analysis is performed to generate fragility curves. This paper suggests a Nonlinear Dynamic Time history analysis against Wood frame structures for seismic vulnerability evaluation.

Jun Ji et.al. (2007)[5]developed a Analytical Framework of Seismic Fragility Analysis for RC High-Rise Buildings. ZEUS-NL software is used in the study. The study deals with the development of an analytical framework to conduct fragility analysis for high-rise buildings. This study treats High rise buildings as a sample lumped parameter model. In this study the High rise buildings are of the only importance. Study of different types of fragility curves is done. First of its kind to evaluate fragility relations of High rise structures.

Joonam Park et.al. (2009)[6]dealt with Seismic Fragility Analysis of Low-Rise Unreinforced Masonry Structures. Only the Unreinforced masonry structures are considered for the analysis. This paper dealt with the evolution of Fragility curves for low rise buildings. Depicts the inexpedient behaviour of unreinforced masonry structures against seismic intensity. Out of plane stiffness is considered for Risk assessment. The study is restricted to 2 storey structures.

Ufuk Hancilar et.al. (2014)[7] considered Earthquake Vulnerability of School Buildings – AProbabilistic Structural Fragility Analysis. Open sees software is used for Model Generation. SAAP 2000 software is used for Linear Elastic Modelling and Analysis. The study deals with the development of fragility curves for a 4 storey Reinforced concrete shear wall building with moment resisting frames. It is the study of Vulnerability of school buildings in Istanbul. Material properties, Geometric properties and Cross sectional dimensions were considered same as the original prototype. Mean damage ratios (MDR) were calculated to the school building considered. Uncertainties were distinguished under 5 cases as per FEMA 356.

TarannumYasmin et.al. (2015)[8]conducted Fragility Analysis for Seismic Vulnerability Assessment of Buildings. The paper suggests a technique for the selection of appropriate assessment method to evaluate the seismic vulnerability of existing buildings. Various methodologies to developfragility curves were listed. It is the Prime step of study of Fragility curves against seismic hazards in INDIA. Several empirical, analytical and hybrid methods were discussed for fragility analysis.

Fadzli Mohamed Nazri et.al. (2016)[9] developed Seismic Fragility Curves for Industrial buildings using Non-linear Analysis. This study look up to fragility curves and performance curves of industrial buildings with distinct geometries. The performance curves are developed based on lateral load, which is affected by the geometry of the building. Farfield ground motions were used in the analysis. The study accounts to the comparison of fragility curves.

III. STRUCTURAL MODELLING

The structures considered in this study illustrate a typical low-rise and mid-rise RC residential frame structures in urban areas of AP. Most of the buildings in Andhra Pradesh are low-rise to medium-rise structures. Reinforced Cement Concrete (RCC) is the most vividly used constructional material in most parts of AP due to its adaptability to local conditions. Two structural models 4 storey and 6 storey open frame buildings were considered.

a) Basic Properties of the Building

The plan of the building's considered for Non-linear Dynamic analysis in show in the figure 1. The Plan is same for both G+3 and G+5 buildings. The plan consists of three bays of 2.5 m along x-axis and two bays of 2.5 m along y-axis. The storey height is 3.0m. Beam sizes are 230 mm x 300 mm, Column sizes are 250mm x 300mm, Slab thickness is 150 mm. Grade of concrete used is M30.

Assumptions:

1. Thecorollaryof the soil structure interaction (SSI) is neglected in the study.
2. Saint Venant's principle is considered.
3. The structure is exposedagainst single horizontal component of earthquake ground motion. (either in X or in Y)
4. The considered horizontal component of earthquake is along x-axis.

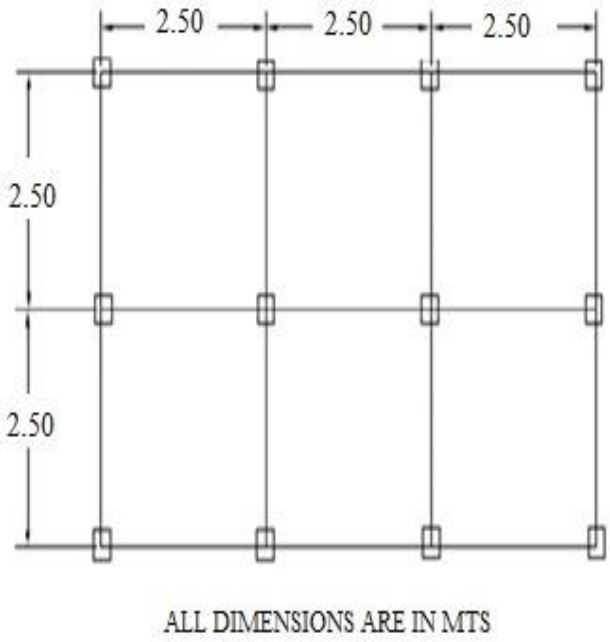

Fig 1: Plan of the building

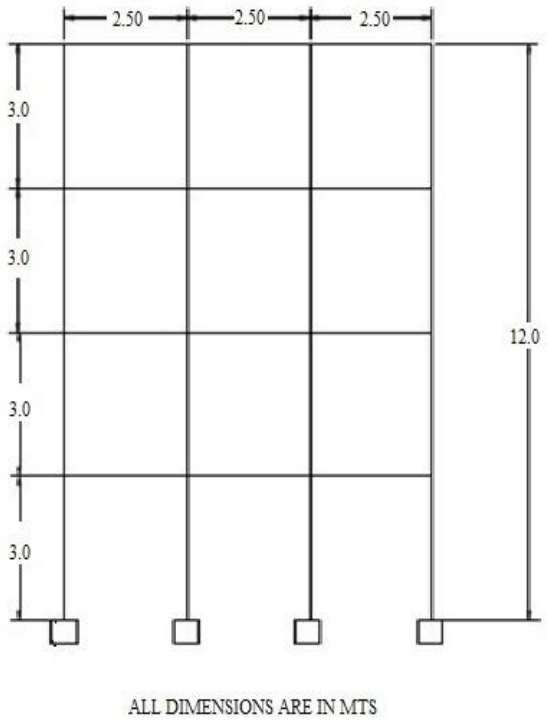

Fig 2: Elevation of a G+3 Building

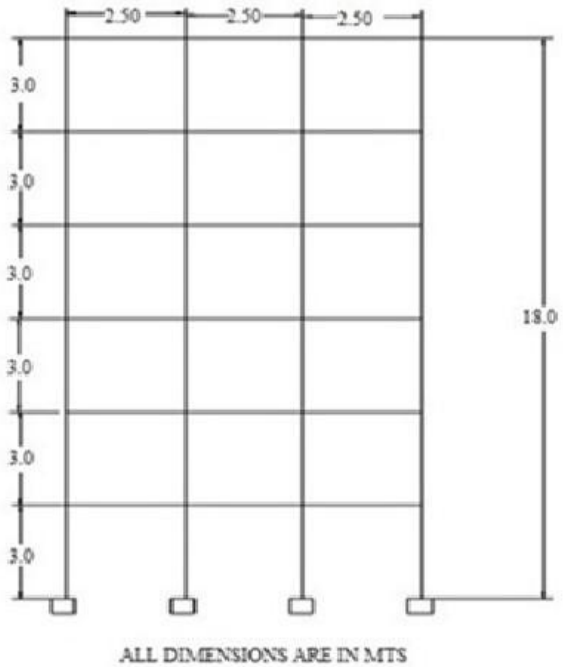

Fig 3: Elevation of a G+5 Building

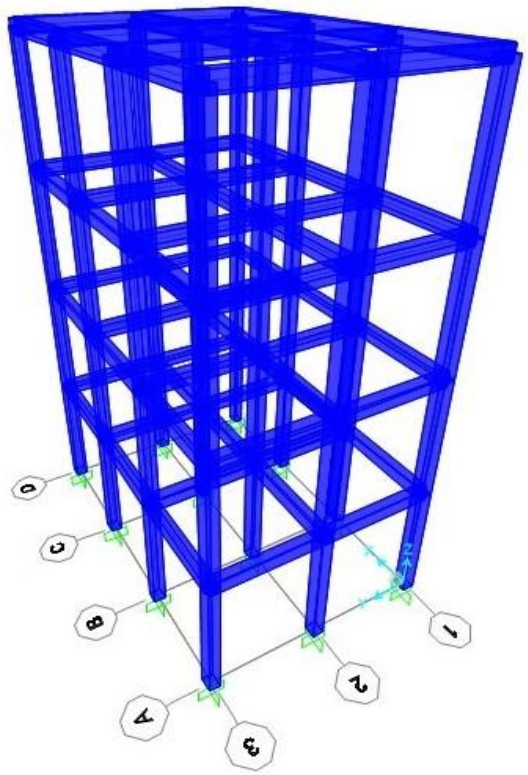

Fig 4: Extrude View of a G+3 Building in SAAP

b) load calculation:

The lateral seismic forces are calculated using the equivalent lateral force. Thecomponents of the structures were designed as per the IS Code for the effect of dead, liveand seismic loads.The live loads are 3 KN/m and dead load factor is 1 along Global Z direction. The models are assumed to be situated ata stable rock foundation to avoid the soil structureinteraction. This property is similar to Soil type A in euro code 8. Soil type A was used in the study.

c) Selection of Ground Motion Data:

This is the most important parameter for IDA and intern development of Fragility Curves. Usage of an appropriate number of ground motion records is of a significant concern. Most codes specify use of three to seven sets of earthquake records to describe the behavior of the building. For this study three sets of earthquake records namely

a) Uttarkashi b) Sikkim and c) Nepal are used in the IDA.

The criteria for the selection of ground motion data is as follows

1. Far field Data (Epicentral distance is more than 70 km)
2. Magnitude Ranges from 6 to 8.

The selected ground motions are tabulated as follows.

Table- 1: Details of Ground Motion Data

S. NO	EARTHQUAKE NAME	YEAR	MAGNITUDE
1	NEPAL	2015	7.9
2	SIKKIM	2011	6.9
3	UTTARAKASHI	1991	6.8

d) Scaling of Ground Motion Data:

After the selection of Ground Motion Data the selected data is scaled from 0.1g to 1.0g at an increment of 0.1. The scaling methodology linearly scales the acceleration domain so as to obtain the target spectrum. The process preserve the inherent uncertainty in the selected recordings.

Scaling = $\frac{x}{y} * acceleration\ records$

Where x= value to be scaled for i.e. 0.1, 0.2, ---------

y= PGA of the respective accelerogram.

IV. INCREMENTAL DYNAMIC ANALYSIS

Incremental Dynamic Analysis is treated as the first step in the development of Fragility Curves. The ground motions selected may be realor simulated. Usage of real records rather than simulated records proves to be more realistic since they include all ground motion characteristics.In this analysis 3 records of far field ground motion are selected to perform IDA in SAAP2000 version 20. The characteristics of the ground motions are stated in the table below.

Table 2: Characteristics of Ground Motion Data

S.NO	GROUND MOTION TYPE	EARTHQUAKE NAME	STATION NAME	PGA	DURATION (SEC)
1	REAL	NEPAL	KTP_EW	2.548	159.96
2	REAL	NEPAL	PTN_NS	1.507	159.96
3	REAL	NEPAL	THM_NS	1.505	159.96
4	REAL	NEPAL	TVU_EW	2.288	159.96
5	REAL	UTTARAKASHI	UTTARAKASHI	2.370	39.92

a) Procedure of IDA in SAAP 2000

The detailed procedure of the incremental dynamic analysis

using SAAP 2000 software in step by step manner is discussed in a detailed manner as below.

1. Selection of model.
2. Fixing number of bays along X and Y directions.
3. Defining material properties.
4. Defining the Section properties.
5. Defining Plastic Hinges.
6. Assigning Plastic Hinges to beams and columns.
7. Defining the Time History Functions.
8. Defining Load patterns.
9. Defining Load cases.
10. Fixing the base of the model.
11. Defining Frame loads.
12. Setting IDA to Run.

After the IDA was completed the displacement results were extracted in tabular form. In this particular study maximum displacement for each Time History Function is derived for usage in Drift Ratio calculation.

b) Drift Ratio calculation

Drift Ratio is illustrated as the ratio of maximum displacement to that of total height of the building.

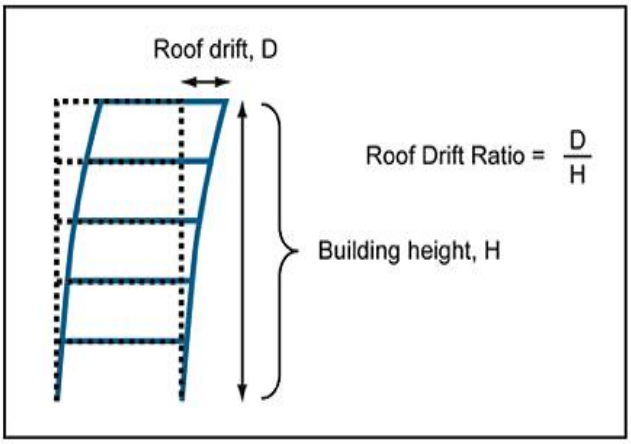

Fig 5: Roof Drift Ratio

V. FRAGILITY CURVES

Fragility curves are log-normal functions which assert the probability of reaching or exceeding aspecific damage state. The curves are developed in terms of spectral acceleration or spectral displacement or peak ground velocity and PGA. As we used PGA in the IDA, same parameter is used to derivethe fragility curves. The Cumulative Distribution Functions (CDF) are calculated by dividing the number of data points which are in the range of predefined damage state with total number of data points. The CDF is calculated in Matlab using a predefined function named as nrmcdf. The conditional probability of a structure if the PGA is known for a particular damage state D, is defined by:

$$P(D/PGA) = \emptyset((\ln(PGA) - \mu)/_{\sigma}$$

Where $\emptyset$ is the standard normal cumulative distributionfunction;

$\mu$is the mean value and

$\sigma$is the standard deviation of the natural logarithm of PGA.

The above mentioned formula is the basic equation for fragility analysis and is also used for the interpretation of the results.Log-normal functions with two parameters (μandσ) were fitted for different performance levels: FO, IO, LS and CP, associated with four and six storey structures which create fragility curves.The parameters are tabulated below as shown in Table 3.

Table 3: parameters of log-normal distribution of the models.

S.NO	BUILDING ID	FO		IO		LS		CP	
		μ	σ	μ	σ	μ	σ	μ	σ
1	G+3	205.132	54.626	407.799	109.106	813.132	218.068	1015.8	272.549
2	G+5	306.466	81.866	610.466	163.587	1218.47	327.031	1522.47	408.753

a) Development of Fragility Curves

There are several procedures such as Cornell method, Monte Carlo simulation method etc., to derive the Fragility curves. But on a whole all those methods are put down under 4 methods. They are as follows

a) Expert based method.
b) Empirical method.
c) Analytical method.
d) Hybrid method.

For the present study Hybrid method is used which involves the expertise of FADZLI et.al. along with the inclusion of analytical method for the development of Fragility curves. A GUI framework for the development of Fragility Curves is developed in Matlab. The GUI framework is tested and proven good for different heights and different soil conditions. The outline of GUI framework is depicted in the figure 6 and figure 7.The whole set of fragility curves are shown in Figure 8 and Figure 9.

Fig 6: GUI framework of Fragility before Analysis

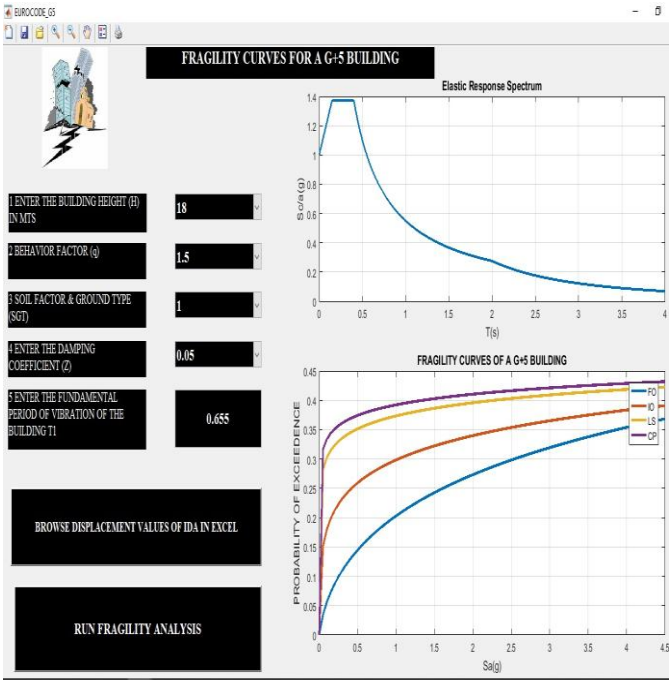

Fig 7: GUI framework of Fragility after Analysis

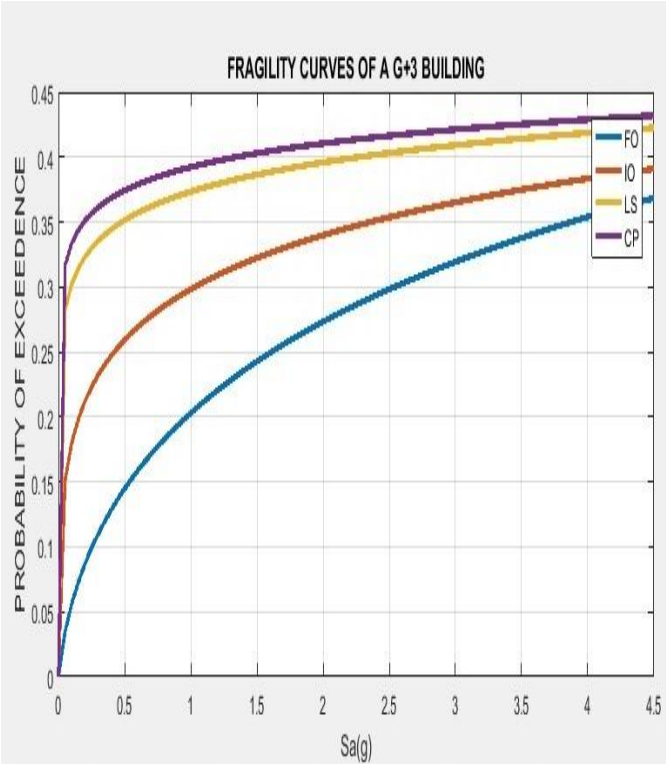

Fig 8: Fragility Curves for a G+3 building

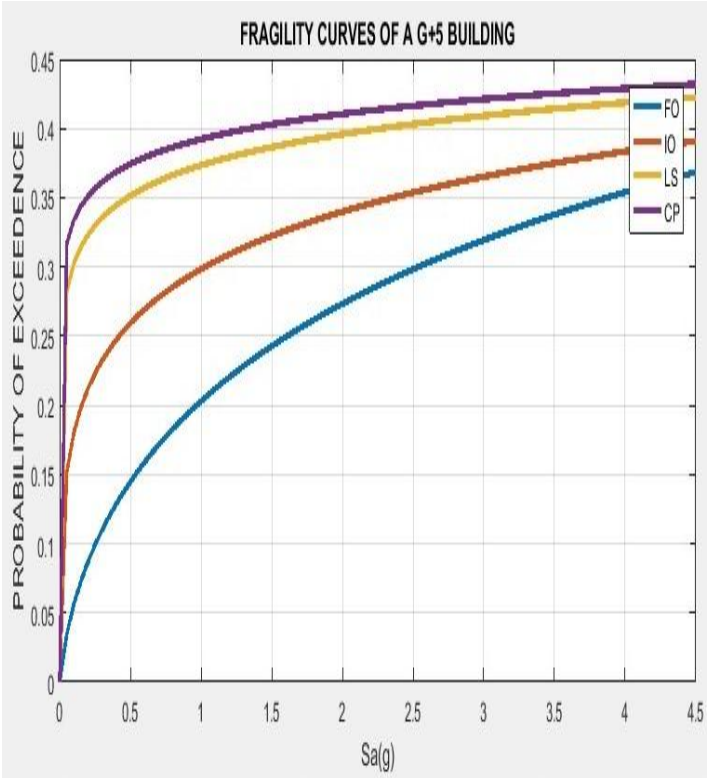

Fig 9: Fragility Curves for a G+5 building

VI. RESULTS & CONCLUSIONS

When exposed to the ground motions, the probability of reaching or exceeding the FO level is approximately 3.77% & 3.75% for four storey structure and six storey structure. The

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probability of reaching or exceeding the IO level is approximately 3.74% & 3.73% for four-storey structure and six storey structure. The probability of reaching or exceeding the LS level is approximately 3.73% & 3.72% for four-storey structure and six storey structure. The probability of reaching or exceeding the CP level is approximately 3.72% & 3.72% for four-storey structure and six storey structure respectively.

The fragility curves were developed for two types of buildings. The fragility curves were analyzed based on four limit states, namely FO, IO, LS, and CP. By considering the limit states, designers can predict the damage level and possible location of hinge deformation. Comparison of the fragility curves of the two models show that the low-rise building (G+3) has the highest probability of reaching FO, IO and LS levels. The probability of reaching CP level is same for both the buildings.

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AUTHORS PROFILE

B.UDAY KUMAR is pursuing M.Tech in Structural Engineering from Rajeev Gandhi Memorial College of Engineering and Technology, NANDYAL, A.P. He completed his B.Tech in Civil Engineering from JNTUA in 2016.

GANDLA NANABALA SREEKANTH is presently working as assistant professor in the school of civil engineering at Rajeev Gandhi Memorial College of Engineering and Technology. He has expertise in the Structural Dynamics.