FRAGILITY ANALYSIS OF HIGH-RISE BUILDING STRUCTURE

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Abstract: In general the most suitable choice in improvement of high-rise building structure against lateral loding is used steel bracing system. The use of steel bracing was potential advantage over other scheme like higher strength and stiffness, economical, occupies less space, add much less weight to existing structure. The use of steel bracing systems for strengthening seismically inadequate high-rise building was a viable solution for enhancing earthquake resistance. Almost all the software like ETABS linear or Nonlinear static analysis presented by RC structure. Main parameter consider fragility curves etc. It was found that all bracing system the lateral displacement of building very effectively. The fragility curves developed in terms of PGA for Limit state: slight, Moderate, major and collapse in lognormal distribution.
The aim of study is development of analytical fragility curves for High-Rise Building structure. Exact analysis using ETABS software* (ETBS'09, a 30 days trial version 2015) is carried out for G+9 , G+14, G+19 building using X-bracing, V-bracing fragility analysis of high-rise structure.

1.1 INTRODUCTION

Developing mega cities leads to increase population in the city and there are not sufficient spaces provided by large number of buildings to accommodate the increasing population. High-rise buildings address this challenge as one of the solutions for the developing countries and mega cities. In addition, high-rise buildings give aesthetic to cities and they are signs of modern development. Comparatively, lower high-rise buildings (approximately 8~20 stories) are more common than super high-rise buildings (usually more than 30 stories) over the worlds. Although it is imperative to know structural behavior of both buildings including their seismic performances. High-rise buildings exhibit far more complex dynamic properties that require careful study and a complete understanding before they can be confidently resided in.

In this study the development fragility functions for Reinforced Concrete (RC) building is presented. Fragility functions provide probability of exceeding a prescribed level of damage for wide range ground motion intensities. Vulnerability analysis can be carried out for buildings, essential facilities, lifelines etc. Fragility functions (or curves) are extremely important for estimating the overall risk to the civil infrastructure from potential earthquakes and for predicting the economic impact of future earthquakes. They can also be very useful for emergency response and disaster planning by a national authority, as well as insurance companies that wish to estimate the overall loss after a scenario earthquake. Furthermore, fragility functions can be used to design retrofitting schemes by carrying out cost/benefit studies for different types of structural intervention schemes.

Seismic vulnerability and effectiveness of strengthening techniques different types of structure (e.g., bridges, buildings etc.) are usually investigated via seismic probabilistic analysis through development of fragility curves. As a short definition, seismic fragility gives probability a structure or structural component reach or exceeds specific level of damage during earthquakes of certain intensity. Therefore, fragility curves may be used to make probabilistic estimates of different damages during ground motion.

1.2 METHODOLOGY

The construction of fragility curves, there is no definitive method or strategy. A great degree of uncertainty in each step of the procedure. This ground motion characteristics, analytical modeling, materials used and definition of limit states. Detailed account is given of the various steps Figure. 1

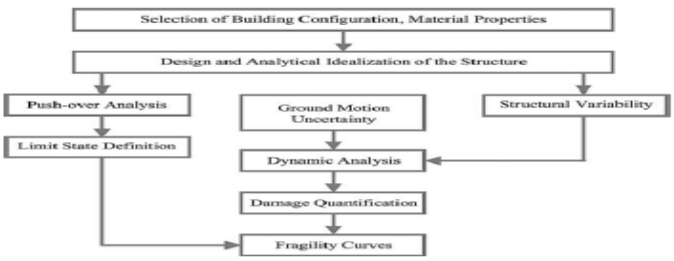


Figure 1 the methodology used in the derivation of fragility curves

1.3 FRAGILITY CURVES

In earthquake, vulnerability evaluations of buildings are normally carried out for judging requirement for strengthening vital facilities and buildings later earthquakes. Fragility curves – show the probability of failure verse us peak ground acceleration. Fig. 2 shows a typical fragility curve with PGA along the x-axis and probability of failure along y-axis. Points in the curve represent the probability of exceedance of the damage parameter, lateral drift, storey drift, base shear etc.

For a PGA of say 'x', the fragility curve gives the corresponding probability of exceedance of limiting damage parameter 'p%'. If 100 earthquake of PGA 'x' occur'p' time the damage parameter exceed limiting value for plot fragility curve.

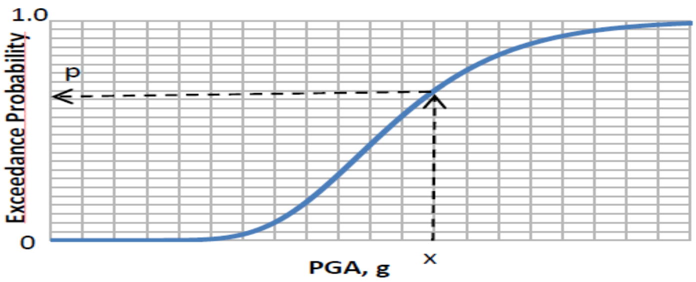


Figure 2: Fragility Curves PGA vs. Probability exceedance

Fig 3 shows typical fragility curves for different limiting values for damage parameter. The intensity measure here is the spectral displacement of the earthquake. Limiting value increases the curves shifts right and more flat. The figure weak shaking the probability of exceedance for the limit state corresponding to slight damage is high. The strong earthquakes probability of exceedance is 100% for first curve, means slight damage is sure, moderate and exceedance damages likely occur. Regions of various damage states such as slight, moderate, Extensive and complete damages are marked between each fragility curves. With the severity of damage, the parameter defining the limit state of damage increases, and the exceedance probability decreases.

For an earthquake with spectral intensity corresponding to weak shaking, the exceedance probability for the slight damage is quite high and the levels defined by higher damage states such as moderate, Extensive, complete are very negligible. Whereas if there is an earthquake of strong intensity the building is more likely to be crossed the damage states of slight and moderate. The exccedance probability for the extensive damage state more than that of complete damage state.

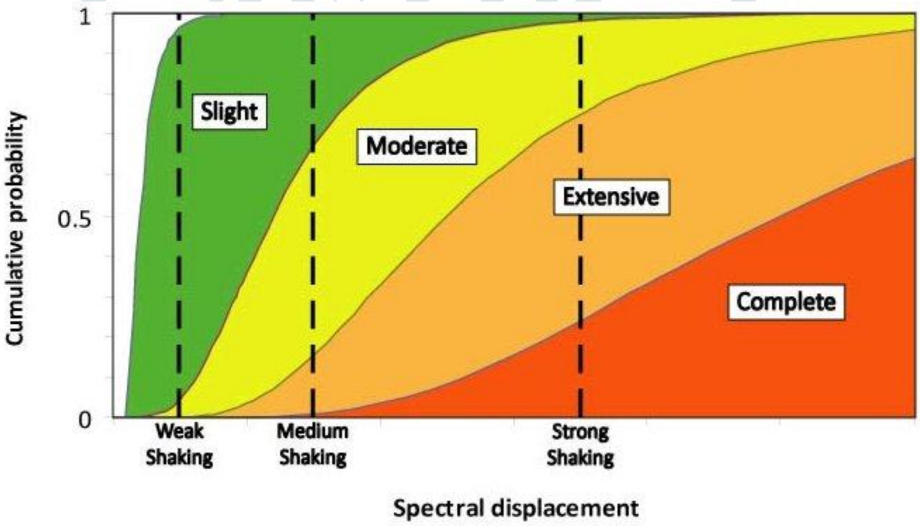


Figure 3: Fragility curves for 4 different limit states (Tobas and Lobo 2008)

1.4 FRAGILITY ANALYSIS, A SHORT DESCRIPTION

In our study, fragility curves are derived using analytical method. Analytical fragility curves are derived in three main steps:

A fragility function represents the probability of exceedance of the selected Engineering Demand Parameter (EDP) for a selected structural limit state (LS) for a specific ground motion intensity measure (IM). These curves are cumulative probability distributions that indicate the probability that a component/system will be damaged to a given damage state or a more severe one, as a function of a particular demand.

The PGA is chosen as a parameter to represent the ground shaking intensity. The number of ground motions required for an unbiased estimate of the structural response is 3 or 7 as per ASCE 7-05.The 10 selected earthquake events are normalized to 0.lg and then scaled to 10 PGA levels of 0.1–1.0 g. For each PGA level, the performance points of the structure due to the selected earthquake events are calculated. Collecting all the roof displacements of the 10 selected events, each with ten PGA levels, produces a 10 X 10 response matrix. For each column in the matrix (i.e., being at the same PGA level), the displacement responses can be further assumed to be a lognormal distribution with the probability density function (PDF) as follows:

$$f(x) = \frac{1}{(\sqrt{2\pi})\varsigma x} \exp\left[-\frac{1}{2}\left(\frac{\ln x - \lambda}{\varsigma}\right)\right]^2 \quad ,0 \leq x < \propto \qquad (1)$$

where, λ and ζ are the two parameters of the lognormal distribution of the random displacement variable x.
They can be calculated from the information on the two parameters of the normal distribution: the mean (μ) and the standard deviation (σ) of the sample population as shown below:

$$\lambda = \ln\mu - \frac{1}{2}\zeta^2 \qquad (2)$$

$$\zeta^2 = \ln[1 + \delta^2] \qquad (3)$$

1.5 FRAGILITY CALCULATIONS

According to the displacement bound of each defined damage state, the fragility curve for the damage state Si is the conditional probability that the building has a state of damage exceeding the damage state Si at a specific PGA level, as shown below:

$$P[S > s|PGA] = P[X > x_i|PGA] = 1 - \emptyset\left[\frac{\ln(x_i) - \lambda}{\zeta}\right] \quad (4)$$

Where, Φ (.) is the standard normal cumulative distribution function, xi is the upper bound for Si(i = I, II,III), and λ and ζ are as defined above in section 4.2.2.1 and are dependent on the PGA level. Sample of calculated spreadsheet to find the fragility curve is shown in next page. In the same manner fragility curve for RC Framed Buildings for seismic force in x direction are obtained using the displacement bounds as per hinge formation as well as using the values as per .

In probability theory and statistics, the cumulative distribution function (CDF), or just distribution function, describes the probability that a real valued random variable X with a given probability distribution will be found to have a value less than or equal to x. CDF can be obtained mathematically with the help of TAYLOR'S SERIES. In the case of a continuous distribution, it gives the area under the probability density function from minus infinity to x. Cumulative distribution functions are also used to specify the distribution of multivariate random variables. Every cumulative distribution function F is non-decreasing and right-continuous. Furthermore,

$$\lim_{X\to-\infty} F(x) = 0 \qquad \lim_{X\to+\infty} F(x) = 1 \quad (5)$$

Suppose X is uniformly distributed on the unit interval [0, 1]. Then the CDF of X is given by:

$$F(X) = \begin{cases} 0 & X < 0 \\ X.,\leq & X < 1 \\ 1 & X \geq 1 \end{cases} \quad (6)$$

1.6 OBJECTIVE

- Deriving fragility curves for high-rise buildings in Zone III as per IS 1893 (Part 1):2002.

1.7 SCOPE OF WORK

- The scope of present work is as follows:-
- Preparation of the 3D physical model of structure, its design and analytical idealization as per IS1893 using ETABS V 15.1.0.
- Performing Static Pushover analysis and obtaining important parameters to define damage states.
- Carry out fragility curve developed based on Analytical method.
- Carry out different bracing (X-bracing and V-bracing) in fragility curves for G+9, G+14, G+19 storey high-rise building

1.8 PLASTIC DEFORMATION CURVES

In (SAP2000, ETABS, etc.) a frame element is modeled as a line element having linearly elastic properties and nonlinear force-displacement characteristics of individual frame elements are modeled as hinges represented by a series of straight line segments. A generalized force-displacement characteristic of a non-degrading frame element (or hinge properties) in ETABS.

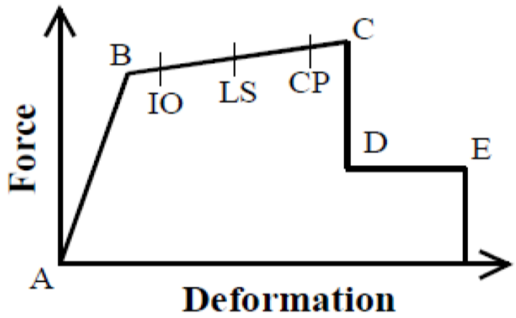


Figure 4: Force-Deformation for Pushover Hinge (Habibullah.et al., 1998)

Point A corresponds to unloaded condition and point B represents yielding of the element. The ordinate at C corresponds to nominal strength and abscissa at C corresponds to the deformation at which significant strength degradation begins. The drop from C to D represents the initial failure of the element and resistance to lateral loads beyond point C is usually unreliable. The residual resistance from D to E allows the frame elements to sustain gravity loads. Beyond point E, the maximum deformation capacity, gravity load can no longer be sustained. Hinges can be assigned at any number of locations (potential yielding points) along the span of the frame element as well as element ends. Uncoupled moment (M2 andM3), torsion (T), axial force (P) and shear (V2 and V3) force-displacement relations can be defined. As the column axial load changes under lateral loading, there is also a coupledP-M2-M3 (PMM) hinge which yields based on the interaction of axial force and bending moments at the hinge location. Also, more than one type of hinge can be assigned at the same location of a frame element. There are three types of hinge properties in ETABS. They are default hinge properties, user-defined hinge properties and generated hinge properties. Only default hinge properties and user-defined hinge properties can be assigned to frame elements.

When these hinge properties (default and user-defined) are assigned to a frame element, the program automatically creates a new generated hinge property for each and every hinge.

Default hinge properties could not be modified and they are section dependent. When default hinge properties are used, the program combines its built-in default criteria with the defined section properties for each element to generate the final hinge properties. The built-in default hinge properties for steel and concrete members are based on ATC-40 and FEMA-273 criteria.

User-defined hinge properties can be based on default properties or they can be fully user-defined. When user-defined properties are not based on default properties, then the properties can be viewed and modified. The generated hinge properties are used in the analysis. They could be viewed, but they could not be modified.

1.9 DESIGN AND MODELING

Selection of Building:

For the purpose of our study, we have finalized high-rise buildings as:

High-rise Building: 10 stories (i.e. G +9)
High-rise Building: 15 stories (i.e. G +14)
High-rise Building: 20 stories (i.e. G +19)

Geometry of Building:

Plan and Elevation details for the Hypothetical buildings [High-rise (G + 9), High-rise (G + 14), High-rise (G + 19)] are shown respectively,

The same geometry are been used for all the above three buildings in medium soil respectively. Thus, in total we have nine models for zone III constituting of high-rise for medium soil respectively.

Specifications used for the models are assumed as: G+9 stories

Design Data:

- No. of story = 10
- Total height of building = 30 m
- Typical Floor height = 3 m
- Beam Size(B) = 230 x 450 mm
- Column Size(C) = 300 x 600 mm
- Slab Thickness = 125 mm
- Grade of Steel = Fe415
- Grade of Concrete = M25
- Density of Concrete = 25 kN/m^3
- Density of Brick = 20 kN/m^3
- Support Condition = Fixed
- X-Bracing Steel Rectangular Section = 120x120x18
- V-Bracing Steel Rectangular Section = 120x120x18
- No. of story = 15, Beam Size(B) = 300 x 450 mm, Column Size(C) = 450 x 750 mm, X-Bracing Steel Rectangular Section = 125x125x10, V-Bracing Steel Rectangular Section = 125x125x10
- No. of story = 20, Beam Size(B) = 300 x 450 mm, Column Size(C) = 450 x 750 mm, X-Bracing Steel Rectangular Section = 150x150x8, V-Bracing Steel Rectangular Section = 150x150x8

Loading Data:

Following loadings are considered for the analysis and design of structure;

Live Load: 3 kN/m^2

Floor Finish Load: 1 kN/m^2

Earthquake Load:

- Location : Ahmedabad
- Zone factor : III
- Importance factor : 1
- Response reduction factor : 5
- Soil condition : Medium

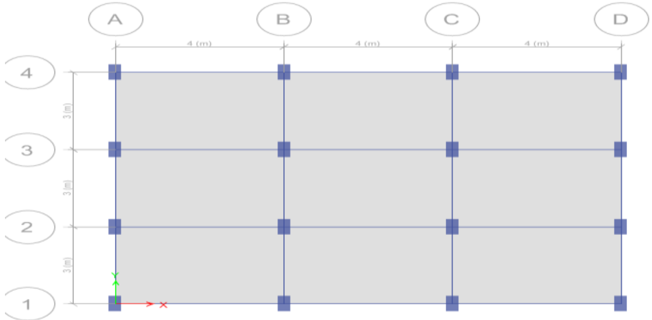


Figure 5: G+9 Building Plan

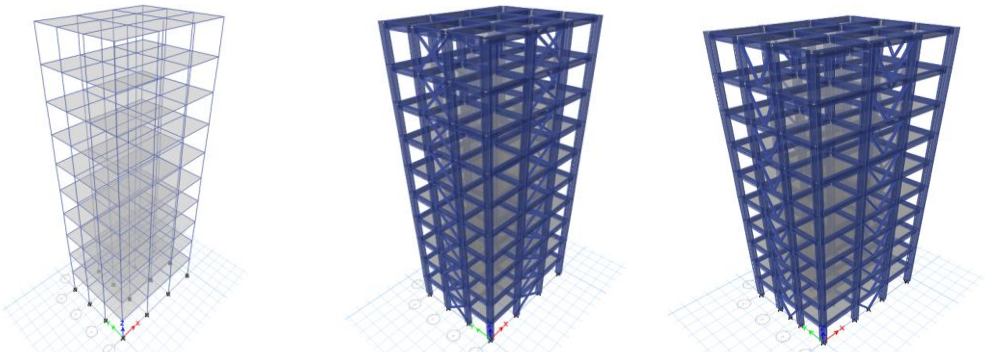
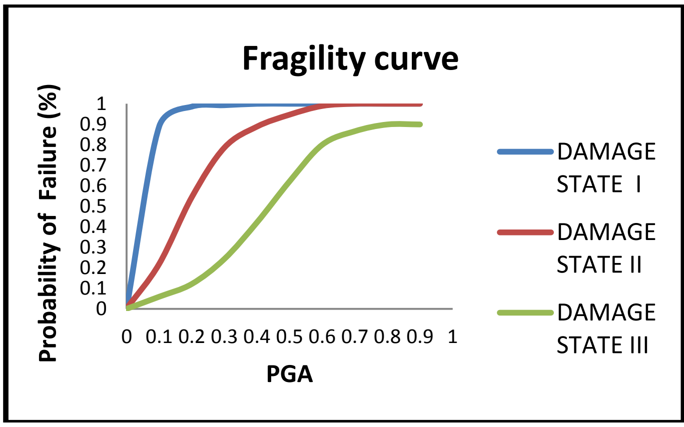
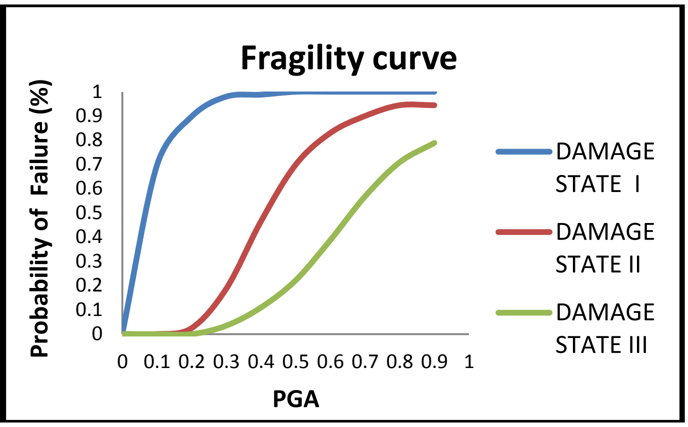


Figure 6: G+9 Building Elevation Bare, X-Bracing, V-Bracing

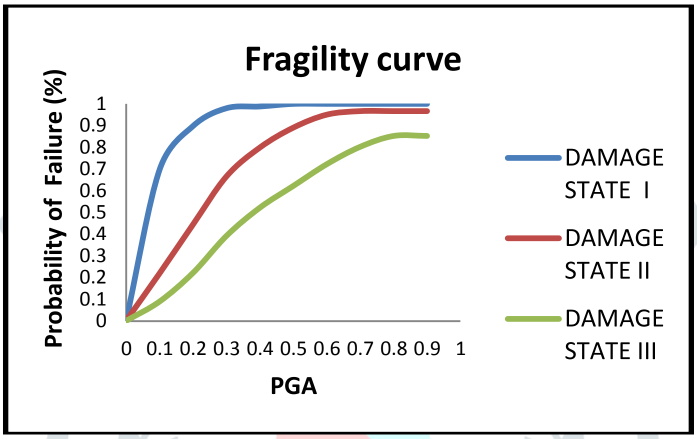
1.10 FRAGILITY CURVES RESULTS:-



(a) G+9 Bare Fragility Curves

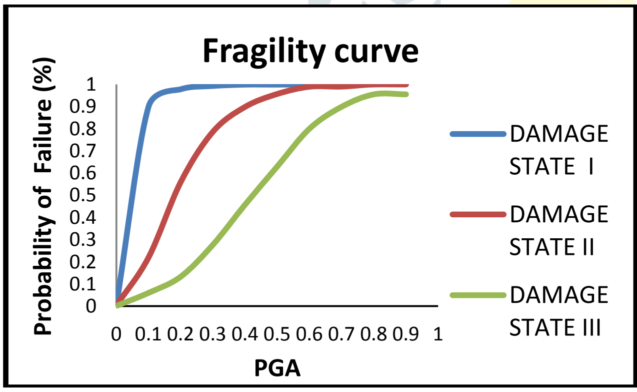


(b) G+9 X-Bracing Fragility Curve

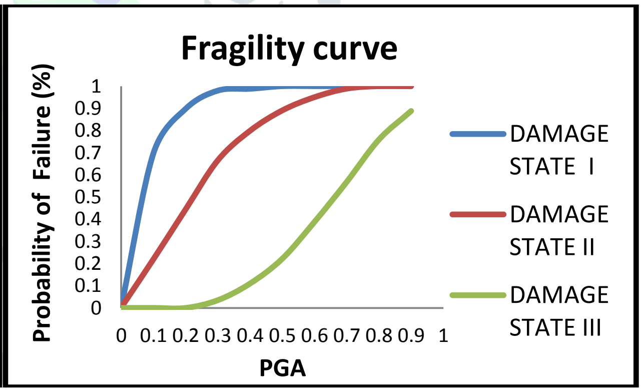


(c) G+9 V-Bracing Fragility Curves

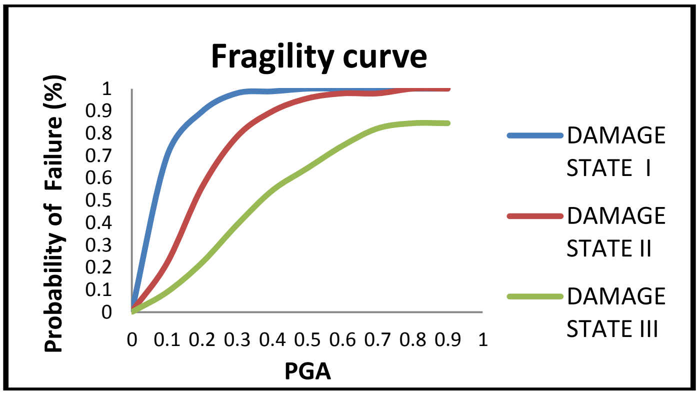
Graph 1: Fragility Curves of G+9 for (a) Bare (b) X-bracing (c) V-bracing



(a) G+14 Bare Fragility Curves

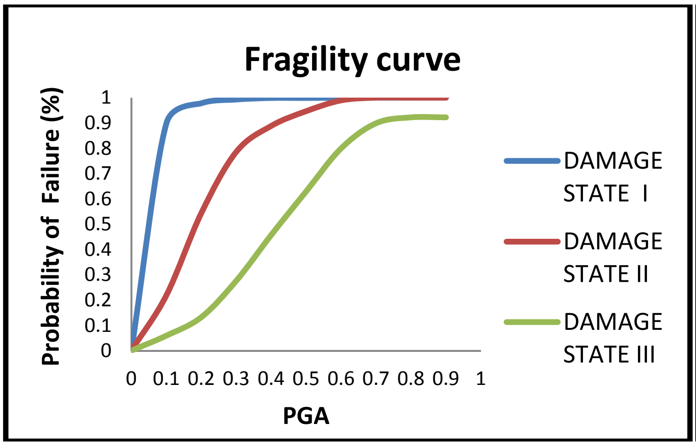


(b)G+14 X-Bracing Fragility Curve

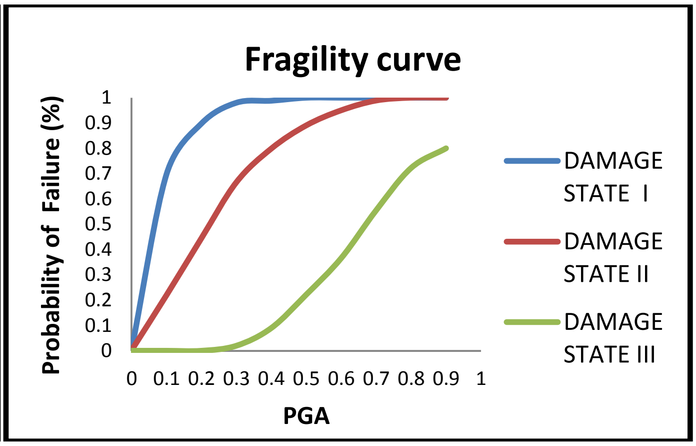


(c) G+14 V-Bracing Fragility Curves

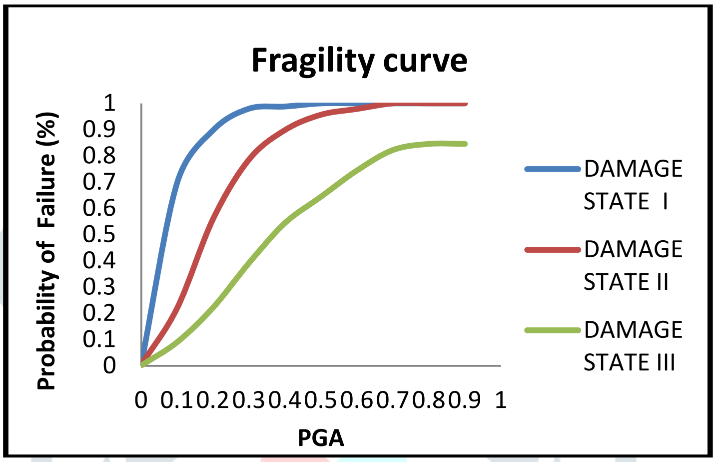
Graph 2: Fragility Curves of G+14 for (a) Bare (b) X-bracing (c) V-bracing



(a) G+19 Bare Fragility Curves



(b)G+19 X-Bracing Fragility Curve



(c) G+19 V-Bracing Fragility Curves

Graph 3: Fragility Curves of G+19 for (a) Bare (b) X-bracing (c) V-bracing

1.11 CONCLUSION

From the parametric study and above fragility curves, it has been conclude that the :

- As per study, time period found from the model analysis is different with time period calculated using the empirical formula as stated in IS 1893(Part 1) : 2002. So, time period is not only dependent on the geometry of the structure but it also depends on soil condition, structural member size and mass of the structure.
- Results show that the probabilities of damage of structure for repairable (II), damage state in medium soil consider decreases as we shift from the Bare to X-bracing structure and further increase from X-bracing to V-bracing structure in G+9, G+14 and G+19 stories.
- Results show that the probability of damage of structure for near collapse (III) damage states in medium soil consider Bare, X-bracing, V-bracing decreases as we shift from the G+9, G+14 and G+19 stories.
- Results shows that the probability of damage of structure for collapse (IV) damage states is increasing as we shift from the medium soil consider. Hence repairing cost and damage to structure is highest in structure situated on G+19 stories, following G+9 to G+14 stories.
- Displacement for G+9 storey bare, X braced and V braced structure are 0.240, 0.042 and 0.052.So, X bracing is better than bare and V braced structure.
- Displacement for G+14 storey bare, X braced and V braced structure are 0.394, 0.074 and 0.091.So, X bracing is better than bare and V braced structure.
- Displacement for G+19 storey bare, X braced and V braced structure are 0.482, 0.141 and 0.156.So, X bracing is better than bare and V braced structure.
- From Non-linear static analysis, generations of hinges in X-bracing are less than V-bracing and Bare structure. So, X- bracing works very effectively in earthquake loading.

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