Seismic Fragility And Relationships Of High-Rise Reinforced Concrete Buildings

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ABSTRACT: Fragility is conditional probability of attainment or exceedance of multiple damage states for given intensity of ground excitation. This study focuses on the development of fragility curves for high-rise building in Pakistan subjected to earthquake loadings. Sample buildings 15,20 and 25 storey were design according to ACI 318-02 (new version) and U.B.C 1997 building design code using SAP 2000, incremental dynamic analysis were perform for these sample buildings using eleven ground motions of Kashmir earth quake 2005 to have IDA curves plotted between PGA and Displacement. From these IDA curves PGAs corresponding to yielding and collapse limit states for each sample building were observed. Lognormal distribution function was then applied to find out probability of failure with respect to PGAs in term of fragility curves. To investigate the effect of no. of stories of the buildings on fragility curve parameters, regression analysis has been carried out between fragility curve parameters and no. of stories.

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KEYWORDS: Yielding, Collapse, Performance levels, Fragility Curves, Building Frames

1. INTRODUCTION

The tallness of a building is relative and cannot be defined in absolute terms either in relation to height or the number of stories. But, from a structural engineer's point of view the tall building or multi-storied building can be defined as one that, by virtue of its height, is affected by lateral forces due to wind or earthquake or both to an extent that they play an important role in the structural design. Tall structures have fascinated mankind from the beginning of civilization. The Egyptian Pyramids, one among the seven wonders of world, constructed in 2600 B.C. are among such ancient tall structures. Such structures were constructed for defense and to show pride of the population in their civilization. The growth in modern multi-storied building construction, which began in late nineteenth century, is intended largely for commercial and residential purposes.

The development of the high-rise building has followed the growth of the city closely. The process of urbanization that started with the age of industrialization is still in Progress in developing countries like Pakistan. Industrialization causes migration of people to urban centers where job opportunities are significant. The land available for buildings to accommodate this migration is becoming scarce, resulting in rapid increase in the cost of land. Thus, developers have looked to the sky to make their profits. The result is multistoried buildings, as they provide a large floor area in a relatively small area of land in urban centers.

Performance-Based Seismic Design

Earthquake engineering is based on the fact that real structures yield when subjected to design level ground acceleration. The post yield structural response is one of the major parameters that the structural designer is interested in. The level of performance expected from a structure is determined by various factors like its significance, economics, and various social and political issues. This led to the development of Performance Based Earthquake Engineering (PBEE). PBEE ensures that the design meets a set of performance objectives expected from a given building. The prediction of a unique collapse load is not easily available.

Performance based design is a relatively new concept in structural engineering and is rapidly becoming widely accepted. The growing acceptability of the performance-based design approach is reflected by a number of documents regarding seismic rehabilitation of existing buildings that have been published by Federal Emergency Management Agency (FEMA), the Structural Engineering Association of California (SEAOC), and Applied Technology Council (ATC).

This design method involves a set of procedures by which a building structure is designed in a controlled manner such that its behavior is ensured at predefined performance levels under earthquake loading. A non-linear analysis tool is required to evaluate earthquake demands at the various performance levels. Pushover analysis (FEMA-273, 1997) is widely adopted as the primary tool for such non-linear analysis because of its simplicity compared with dynamic procedures. A design performance level is a statement of the desired behavior of the building, should it experience an earthquake of specified severity (called the earthquake design level).

Building performance is a combination of both structural and non-structural components, and is expressed in terms of building performance levels. These building performance levels are "discrete damage states" selected from among the infinite spectrum of possible damage states that buildings could experience as a result of earthquake response. There is a number of building performance levels or particular damage states defined in codes (FEMA-273, 1997) like:

Operational (OP)
Immediate Occupancy (IO)
Life Safety (LS)
Collapse Prevention (CP)

2. METHODOLOGY OF RESEARCH

The methodology that will be adopted to develop fragility curve for model building is analytical. For purpose model buildings of different heights are selected. These structures will then be designed using commercially available software SAP 2000. After designing, these buildings will be dynamically analyzed by using non-linear dynamic analysis. Incremental dynamic analysis will be used to analyze the structures. Under the effect of different ground motions, the yielding and collapse capacity of the buildings will be find out. These capacities will be then evaluated by statistical methods to develop the fragility curves.

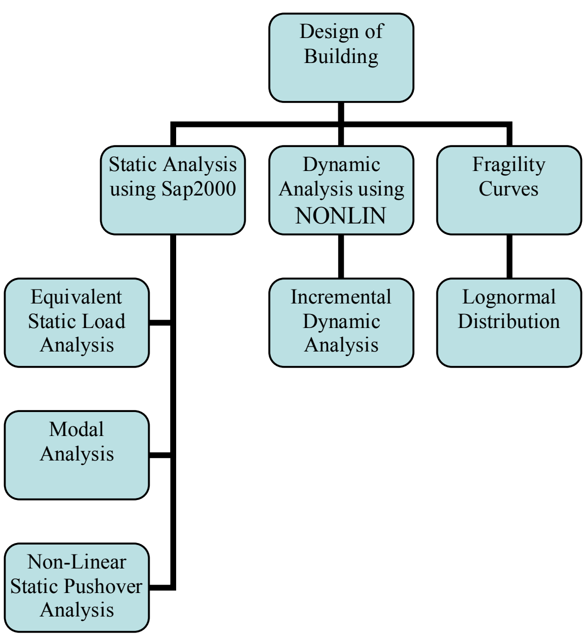


Figure-1: Flow chart diagram.

3. SAMPLE BUILDINGS

Three 2-D frames i.e., 15, 20, and 25-story frames, which represent high-rise concrete moment resisting frames, were considered for this study. These frames are considered to be interior bay of buildings. Typical story height for each frame is 12ft. Figures 7.2 to 7.5 shows the structural configuration of model frames. Member sizes and gravity loads considered for these frames are given in Table .

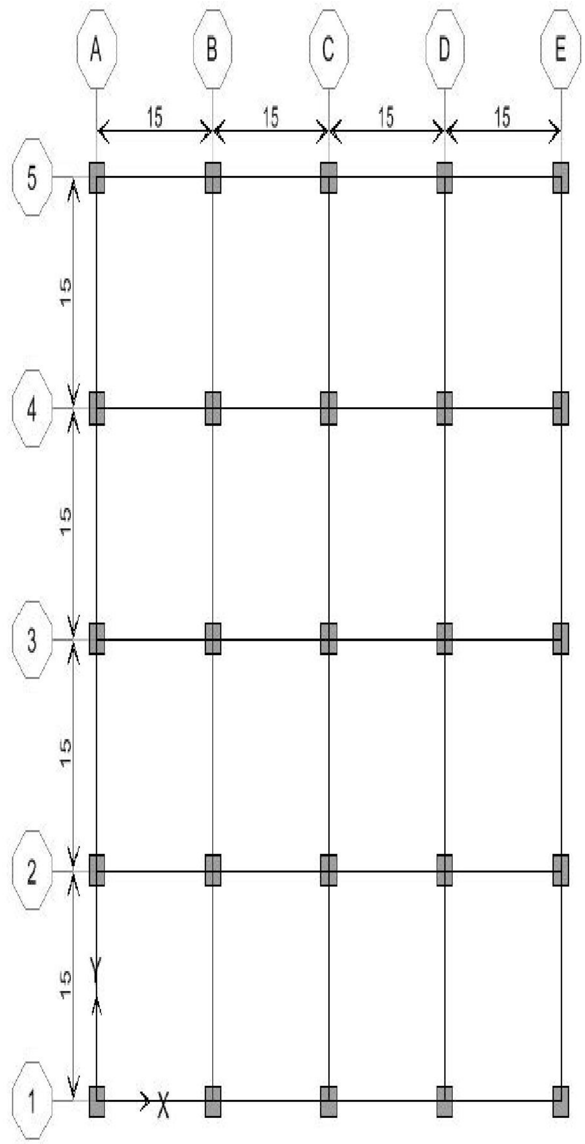


Figure-2: Framing plan of sample building.

Table 1: Member Sizes and Gravity Loads for Model frames

15-Story Reinforced Concrete Moment Resisting Frame						
Story Level	Beam Dimension		Column Dimension		Super Imposed DL (psf)	Live Load (psf)
	B (in)	H (in)	X (in)	Y(in)		
Roof	12”	21”	24”	24”	55	30
Storey 13-14	12”	21”	24”	24”	40	50
Storey 8-12	12”	21”	27”	27”	40	50
Storey 3-7	12”	21”	30”	30”	40	50
Storey 1-2	12”	21”	33”	33”	40	50
20-Story Reinforced Concrete Moment Resisting Frame						
Story Level	Beam Dimension		Column Dimension		Super Imposed DL (psf)	Live Load (psf)
	B (in)	H (in)	X (in)	Y(in)		
Roof	12”	21”	24”	24”	55	30
Storey 16-19	12”	21”	24”	24”	40	50
Storey 9-15	12”	21”	27”	27”	40	50
Storey 4-8	12”	21”	30”	30”	40	50
Storey 1-3	12”	21”	33”	33”	40	50
25-Story Reinforced Concrete Moment Resisting Frame						
Story Level	Beam Dimension		Column Dimension		Super Imposed DL(psf)	Live Load (psf)
	B (in)	H (in)	X (in)	Y(in)		
Roof	12”	21”	24”	24”	55	30
Storey 21-24	12”	21”	24”	24”	40	50
Storey 16-19	12”	21”	27”	27”	40	50
Storey 9-15	12”	21”	30”	30”	40	50
Storey 4-8	12”	21”	33”	33”	40	50
Storey 1-3	12”	21”	36”	36”	40	50

Material properties and seismic design data for these frames is as follows:
Material properties:
f’c = 3,000 psi
fy = 60,000 psi
fyv = 40,000 psi
Wc = 150 pcf
Seismic Design Data (UBC 97):
Seismic Zone = Zone 3
Soil Type = Sd
Importance Factor = I = 1.0
Over-Strength Factor = R = 8.5 (SMRF)

4. GROUND MOTIONS

The indiscriminate nature of earthquakes makes the damage assessment problem probabilistic. Eleven ground motions of Kashmir earth quake 2005 have been used in this study to take the random nature of earthquakes into Consideration. Fig. 3 shows the acceleration spectra of the ground motions.

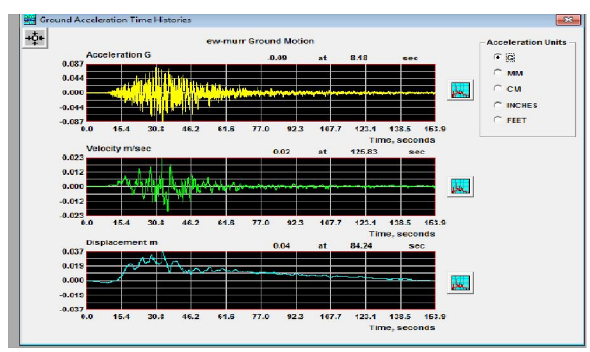


Figure 3. Ground motion time histories

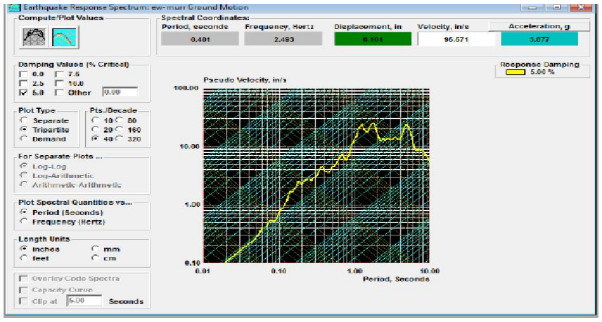


Figure 4. Ground motion response spectrum

5. DAMAGE LEVELS

Yielding and collapse are basic damage levels for this study. Recent studies considered Different damage levels and corresponding limit values in terms of different damage measures. Building types of structure, Kircher et al. [1] and Smyth et al. [2] precise four different damage levels: slight; moderate; major or extensive; and complete or collapse. Maximum inter-story drift ratio was accepted as the damage measure and each damage level has an assumed limit value of inter-story drift ratio. Javanoska [3] used similar damage levels. However, the Park–Ang damage index [4] was employed by them as a damage indicator. For the present study, only yielding and collapse are considered, since they can be determined analytically with reasonable accuracy.

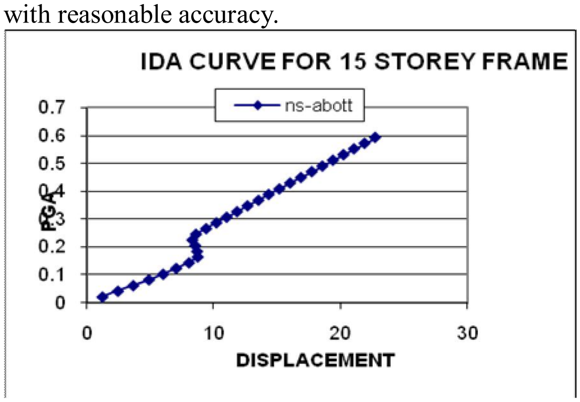


Figure 5. IDA Curve

Incremental Dynamic Analysis.

A plot of Intensity Measure (IM) of ground motion versus Damage Measure (DM) of structural response under scaled ground motion is known as an IDA curve.

Incremental dynamic analysis is carried out on ground motions of Kashmir earth quake 2005 as a result IDA curves between damage measure and intensity measure is produced. In this study peak ground acceleration as considered as intensity measure and displacement is considered as damage measure. Relationship between PGA and displacement is linear up to yield point. Damage measure increases infinitely when structure reaches its collapse capacity. Nonlin software is used to develop IDA curve. The shape of IDA curve is different for each ground motion. From these IDA curves yielding and collapse limit values are obtained in term of PGA as shown in figures.

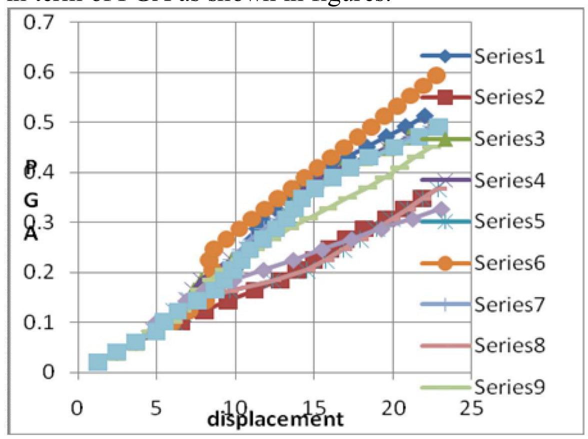


Figure-6. IDA curves for 15storey frame.

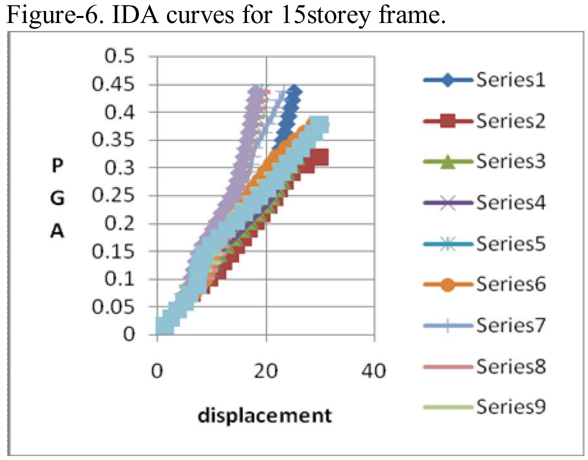


Figure-7. IDA curves for 20 storey frame.

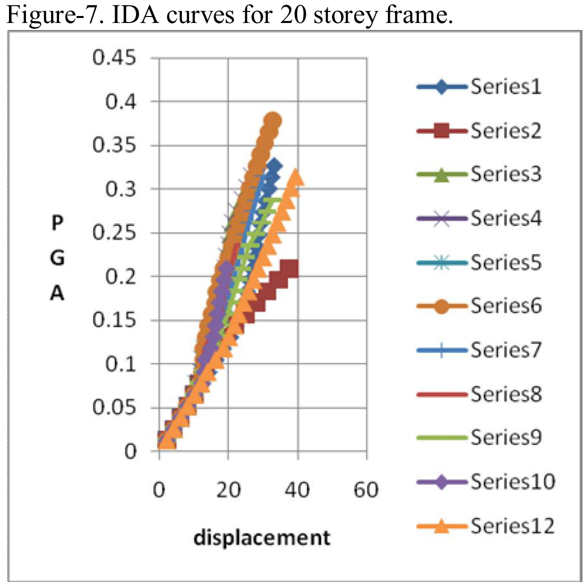


Figure-8: IDA curves for 25storey frame

6. FRAGILITY CURVES.

Fragility curves provide estimates for the probabilities of a population of structures reaching or exceeding various limit states at given levels of ground shaking intensity. A limit state usually represents a damage condition, or a limitation of usage, in the same terms as the response. In recent studies, limit states have been defined in terms of deformation rather than load and multiple limit state satisfaction has been widely accepted.

Fragility curves express the probability of structural damage due to earthquakes as a function of ground motion indices, e.g., PGA, PGV, Sd, Sa. In this study, an analytical approach was adopted to construct fragility curves for a mid-rise building. A typical building structure is considered and designed according to the seismic design codes in Pakistan. Using the strong motion records from Kashmir, non-linear dynamic response analyses are performed, and the ground motion indices for the frame building are obtained. Using the ground motion indices, fragility curves for the frame building are constructed assuming a lognormal distribution

Based on the results of IDA curves cumulative probability of the occurrence of damage, equal to or higher than the damage level D, is determined using equation 7.1.

$$P(\leq D) = \Phi\left(\frac{\ln X - \lambda}{\zeta}\right)$$

where

Φ = Standard normal distribution

X = Lognormal distributed ground motion index (PGA)

λ = Mean deviation

ζ = Standard deviation

Fragility curves for each sample building against yielding and collapse is shown in figures below.

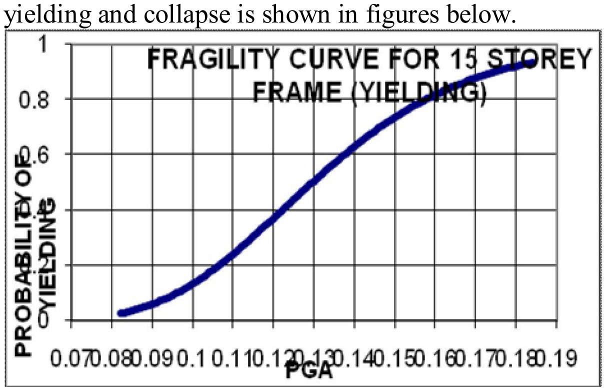


Figure 9: Fragility Curve for 15 Storey Building Frame (Yielding)

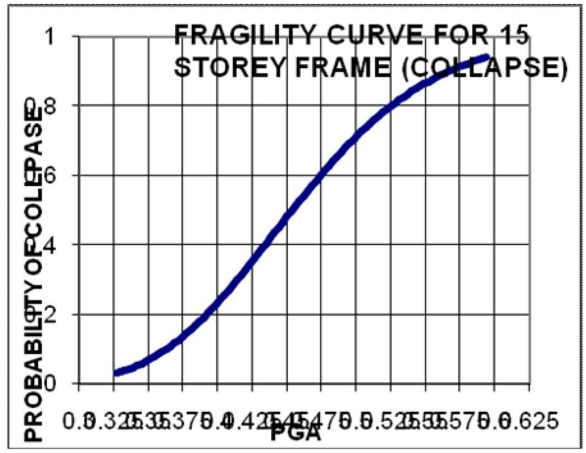


Figure 10: Fragility Curve for 15 Storey Building Frame (Collapse)

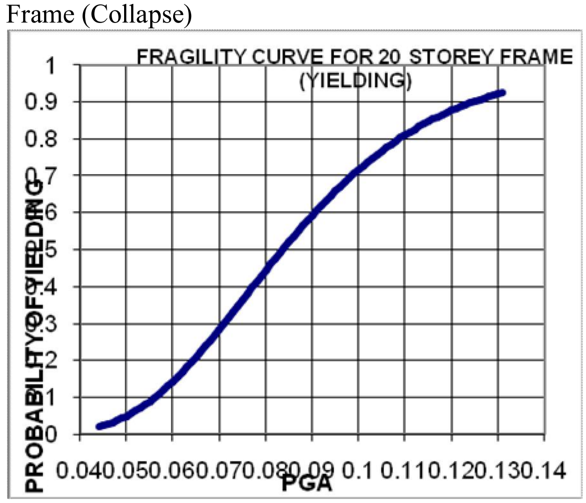


Figure 11: Fragility Curve for 20 Storey Building Frame (Yielding)

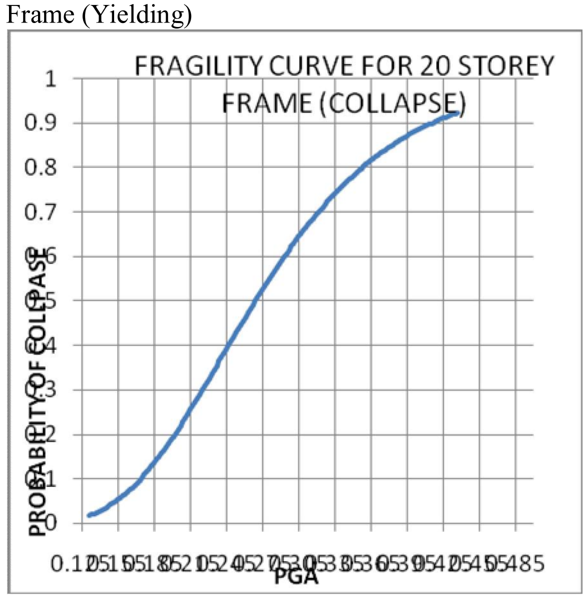


Figure 12: Fragility Curve for 20 Storey Building Frame (Collapse)

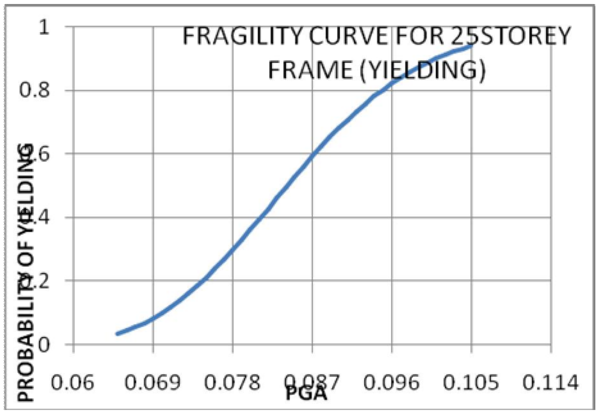


Figure 13: Fragility Curve for 25 Storey Building Frame (Yielding)

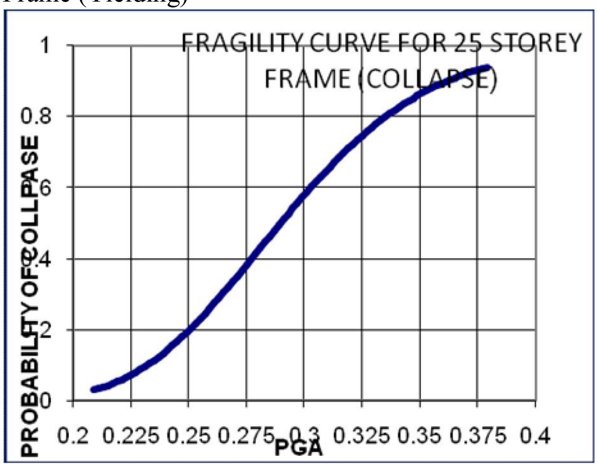


Figure 14: Fragility Curve for 25 Storey Building Frame (Collapse)

7. REGRESSION ANALYSIS

Linear Regression Analysis has been carried out to determine the relationship between fragility curve parameter (PGA for fixed probability) and no of stories of model buildings. The equations have been developed are shown below:

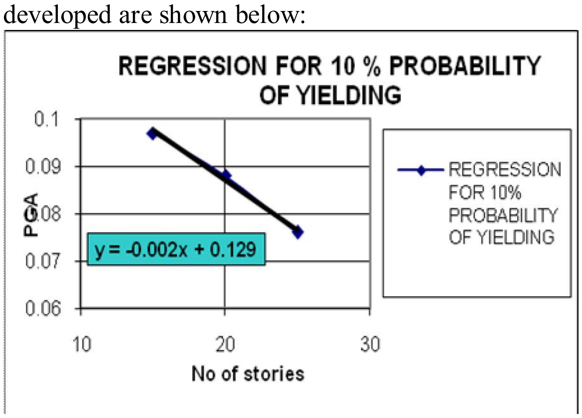


Fig 15: Relationship between PGA and No. of Stories for 10% Probability of Yielding

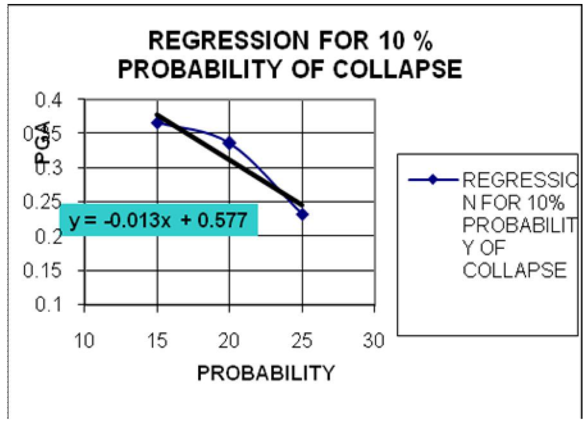


Fig 16: Relationship between PGA and No. of Stories for 10% Probability of Collapse

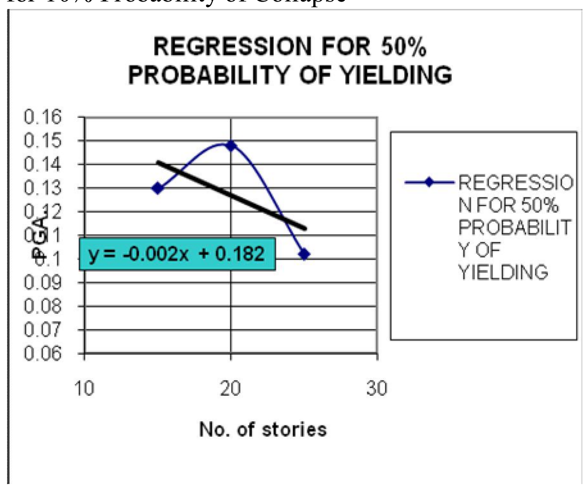


Fig 17: Relationship between PGA and No. of Stories for 50% Probability of Yielding

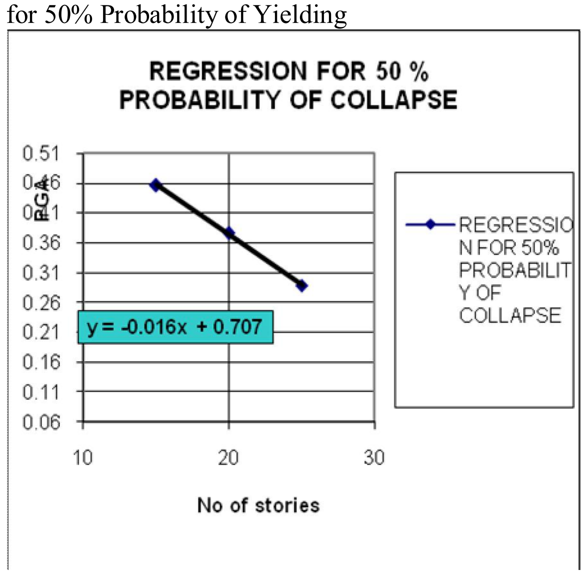


Fig 7.70: Relationship between PGA and No. of Stories for 50% Probability of Collapse

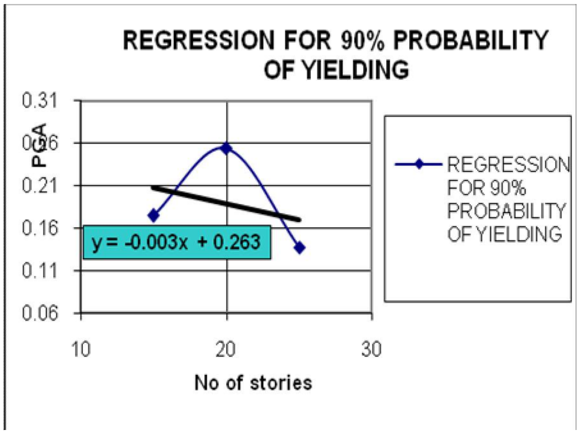


Fig 18: Relationship between PGA and No. of Stories for 90% Probability of Yielding

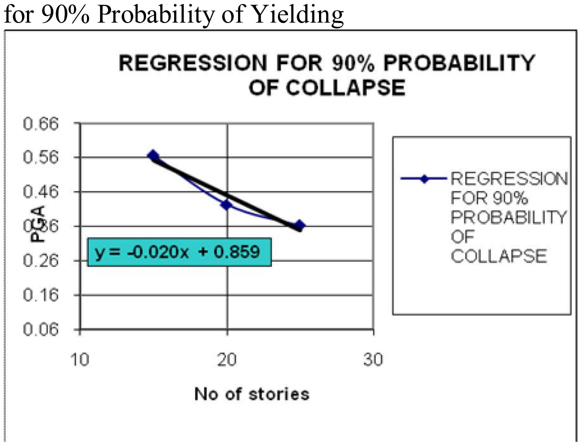


Fig 19: Relationship between PGA and No. of Stories for 90% Probability of Collapse

8. CONCLUSIONS

The past several decades have witnessed a series of costly and damaging earthquakes. In order to be prepared for such natural disasters, it becomes essential to reasonably estimate, predict and mitigate the risks associated with these potential losses. Risk is typically defined by three components: a hazard (the earthquake), the assets (e.g. building infrastructure) and the fragility of those assets with respect to the hazard. Each component of risk is inextricably fraught with uncertainties. To accurately and reliably relate how fragile (or vulnerable) specific types of buildings may be for a given earthquake intensity may only appropriately be expressed by accounting for these uncertainties. The major findings of this study are:

This study is one of the first to relate the vulnerability of tall buildings (a specific class of infrastructure) to different earthquake intensity measures.

The purpose of this study was to introduce a method for the development of fragility curve for high rise buildings under the effect of different earthquake loadings.

Effect of different structural parameter on structural performance due to earthquake loading is observed and a relationship between the fragility curve parameters and no of stories.

It was observed from fragility curve that there is an effect on fragility curve parameters due to no. of stories (height of building), time period, stiffness and weight.

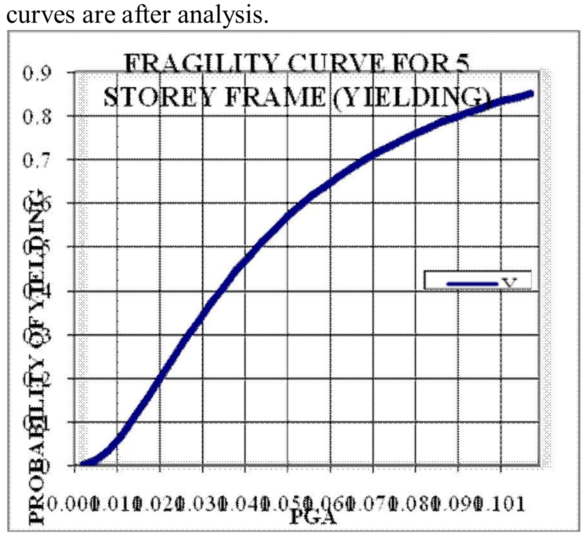
Linear regression analysis has been carried out to determine the relationship between PGA and no of stories. As result equation have been develop to determine the seismic force for a fixed probability for any height of building.

9. RECOMMENDATIONS

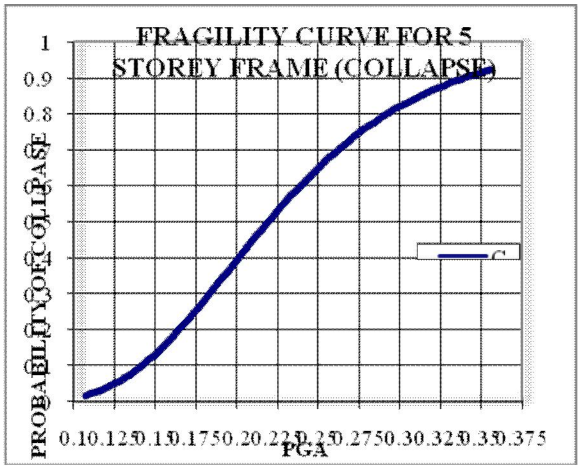
These new vulnerability relationships will be very useful for researchers, emergency management agencies and engineers wishing to better estimate the overall loss after an earthquake for tall buildings (a unique infrastructure which concentrates people and value-at risk). Improved forecasts (accounting for tall building behavior) will provide officials with better tools to more adequately plan and stimulate efforts to reduce risk and to better allocate resources to prepare for emergency response and recovery from an earthquake. Future work is required and may include incorporation of soil-structure interaction, more sophisticated representation of tall building behavior and development of vulnerability relations for other classes of tall buildings.

10. APPLICATION.

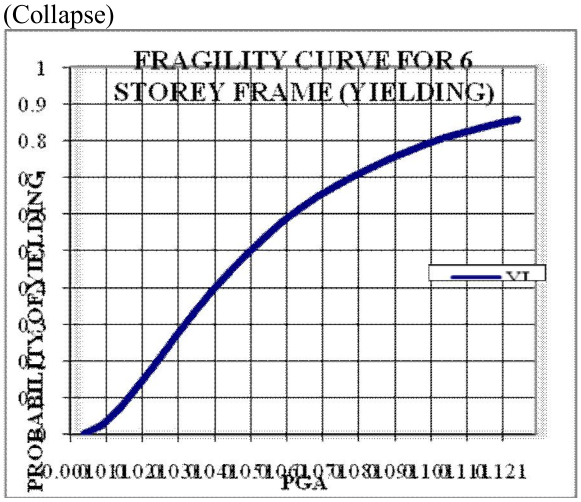
The same study is applied to existing building in Pakistan. Three existing building of 5 , 6 and 7 storey are used and analyzed by above procedure. Following fragility curves and regression analysis curves are after analysis.



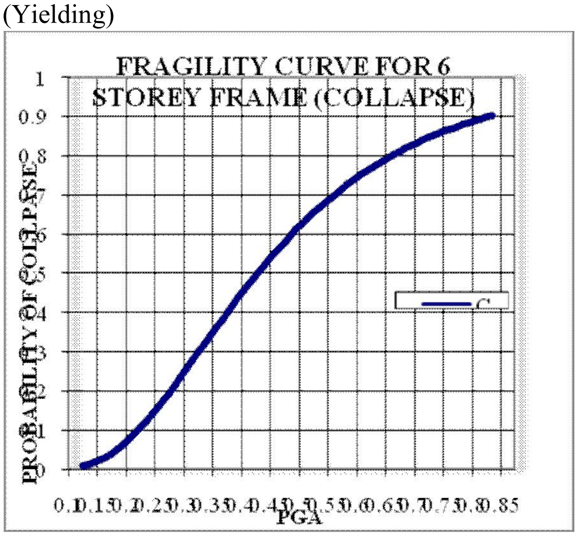
Fragility Curve for 5 Storey Building Frame (Yielding)



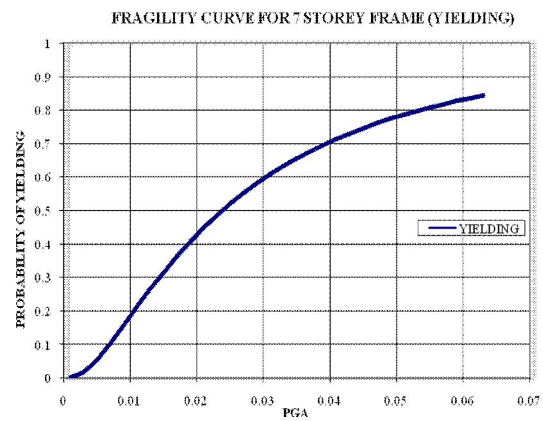
Fragility Curve for 5 Storey Building Frame (Collapse)



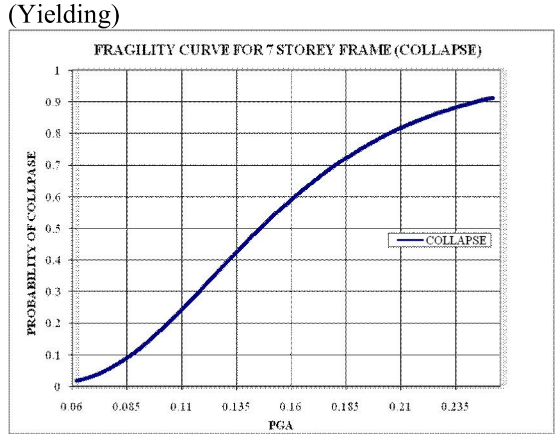
Fragility Curve for 6 Storey Building Frame (Yielding)



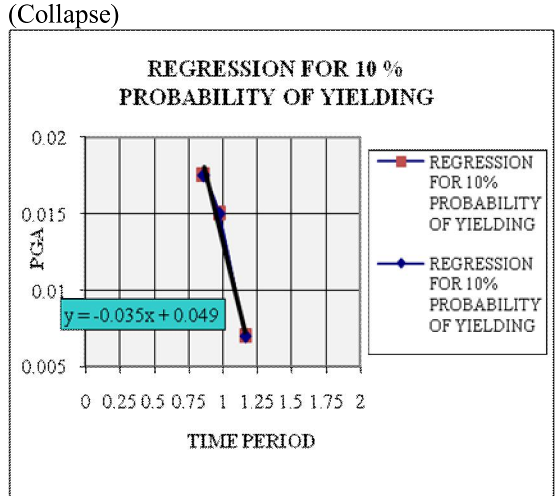
Fragility Curve for 6 Storey Building Frame (Collapse)



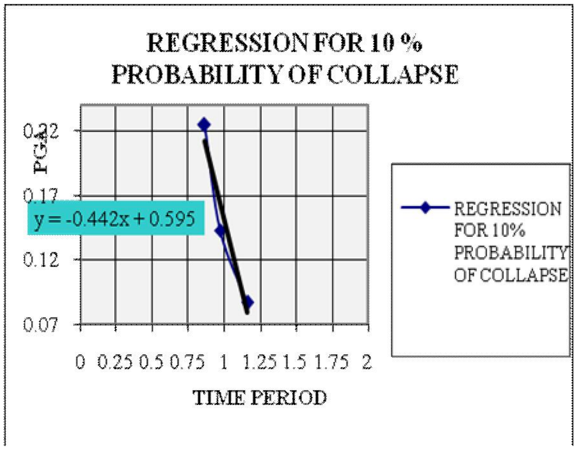
Fragility Curve for 7 Storey Building Frame (Yielding)



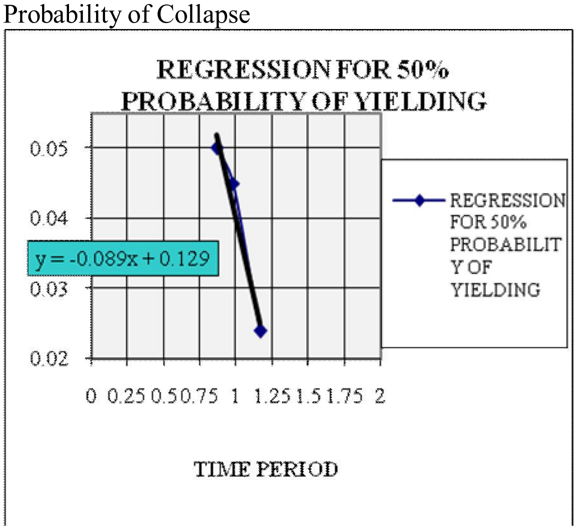
Fragility Curve for 7 Storey Building Frame (Collapse)



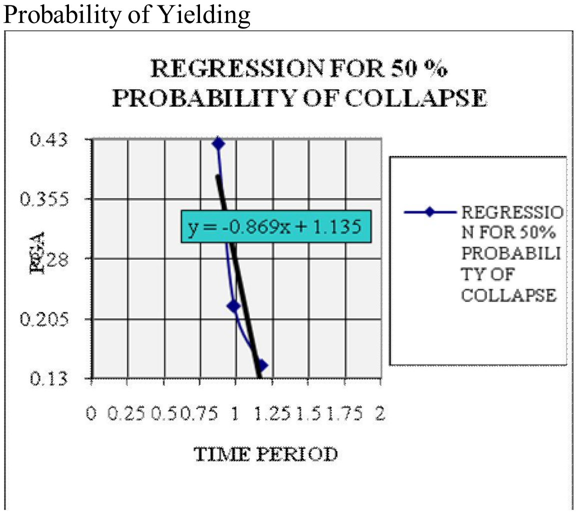
Relationship between PGA and Time Period for 10% Probability of Yielding



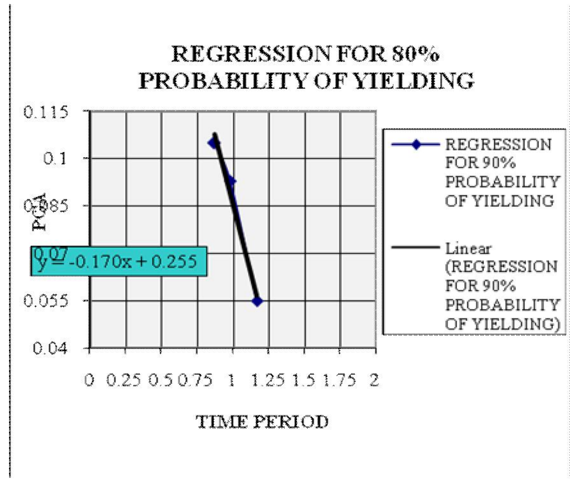
Relationship between PGA and Time Period for 10% Probability of Collapse



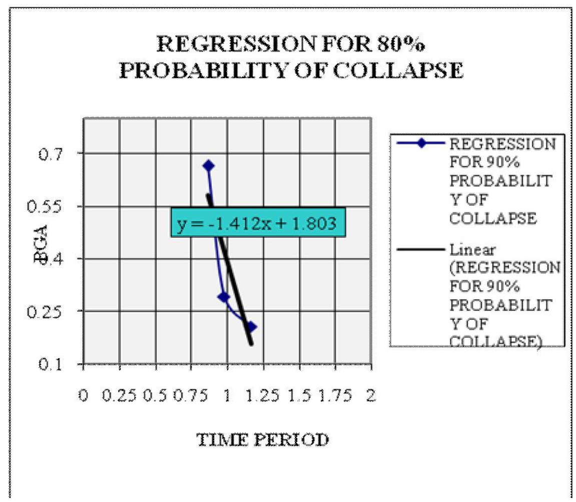
Relationship between PGA and Time Period for 50% Probability of Yielding



Relationship between PGA and Time Period for 50% Probability of Collapse



Relationship between PGA and Time Period for 80% Probability of Yielding



Relationship between PGA and Time Period for 80% Probability of Collapse.

11. CONCLUSIONS & RECOMMENDATIONS

Fragility analysis is a useful approach to access the performance of existing building structures under different seismic loads.

The probability of yielding or collapse increases as the PGA increases.

Regression analysis shows that with the increase in the time period of the building structure, the PGA corresponding to yielding or collapse limit state decreases for a fixed probability of failure.

12. RECOMMENDATIONS

This study focused on 5, 6 and 7 story frame buildings, which represent the typical heights usually found in Islamabad region. Research should be conducted for other heights of buildings and those structures which are having shear walls in them.

The case study frames were subjected only to the Kashmir earthquake histories. Further study should be carried considering the many other famous earthquake histories. The structures can be retrofitted if they are not meeting the latest strength or serviceability requirements.

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