DERIVATION OF HYBRID VULNERABILITY FUNCTIONS BASED ON OBSERVATIONAL DATA FOR IRAN

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ABSTRACT:

Iran is located on one of the most seismic areas of the world. It is situated over the Himalayan-Alpied seismic belt and is one of those countries which have lost many human lives due to the occurrence of earthquakes. Therefore research studies related to seismic risk assessment is very important in this country. Based on this study, a data bank of post-earthquake damage distributions observed in the earthquake events; and judgmental vulnerability relationship developed for Iran, a hybrid methodology of vulnerability analysis is applied, involving elements from both empirical and judgmental methods to derive new hybrid fragility curves for different building types. Hybrid curves show more better correlation between data in comparison with empirical curves had been derived.

KEYWORDS: index hybrid vulnerability function, MMI to PGA conversion, damage, probability distribution

1. INTRODUCTION

Iran is situated on Himalayan-Alpied seismic belt, and experienced many destructive earthquakes since many years ago. Additionally, in recent years Tabas, Naghan, Manjil, Ghaen and Bam earthquakes caused heavy structural damages and human life lost in Iran. Since many years ago, the seismic assessment of existing structures and developing the strengthening methods of them have been discussed. These researches have been done in two fields of vulnerability assessment and structural strengthening before the earthquake event and structural damage assessment after earthquake event. In Iran, although the first case have been discussed and studied so vast and resulted in "Seismic Rehabilitation Code for Existing Buildings in Iran (IIEES, 2002)", but for the second case that is the subject of this paper, there are not sufficient studies. Seismic risk assessments were carried out on buildings to identify the urban areas to suffer large life and economic losses after an earthquake. The results of such studies are important in decreasing losses under future seismic events as they allow strengthening and disaster management plans to be set down. In Iran, the majority of existing buildings are not designed for meet modern seismic code frameworks. Therefore prediction tools such as vulnerability curves are required that will allow the seismic risk assessment of buildings to be carried out.

Vulnerability curves relate the probability of exceedence of multiple damage states to a parameter of ground motion severity and can thus be referred as a graphical representation of seismic risk. In the case of building population, they predict the proportion of the losses in each damage state after an earthquake.

Loss assessment for seismic risk analysis purposes has traditionally been carried out using empirical (or statistical) methods, which are either categorization methods, or inspection and rating (scoring) methods (UNDP/UNIDO, 1985). On the other hand, in situations where statistical methods cannot be applied (due to lack of data) or some more detailed information is sought, judgmental methods can offer an attractive alternative.

Existing vulnerability curves can be classified into the four generic groups of empirical, judgmental, analytical and hybrid according to whether the damage data used in their generation derives mainly from observed post-earthquake surveys, expert opinion, analytical simulations, or combinations of these, respectively. Each data source has associated advantages and disadvantages.

Empirical curves use the building damage distributions reported in post-earthquake surveys as their statistical basis. The observational source is the most realistic as all practical details of the exposed stock are taken into consideration alongside soil–structure interaction effects, topography, site, path and source characteristics. However, the same aspects that render observational data the most realistic are responsible for the severe limitation in their application potential.

Judgment-based curves are not associated with the same problems regarding the quantity and quality of building damage statistics that typify empirical relationships. Expert panels of civil engineers with experience in the field of earthquake engineering are asked to make estimates of the probable damage distribution within building populations when subjected to earthquakes of different intensities. Probability distribution functions are fit to the expert predictions to represent the range of damage estimates at each intensity level. The probability of a specified damage state is derived from the resulting distributions and plotted against the corresponding ground-motion level to obtain a set of vulnerability curves, and associated uncertainty bounds. Since the experts can be asked to provide damage estimates for any number of structural types, the curves can be easily made to include all the factors affecting the seismic response of different structures. Consequently expert opinion is the predominant source used by most current rehabilitation codes in the United States of America for the generation of damage probability matrices and vulnerability curves (e.g. ATC-13 and ATC-40). The reliability of judgment-based curves is questionable, however, due to their dependence on the individual experience of the experts consulted. It is practically impossible to evaluate of the degree of conservatism associated with the judgment-based source, and inherent in the expert vulnerability predictions is a consideration of local structural types, typical configurations, detailing and materials. Hence if the country of the fragility curve derivation is characterized by construction practices that differ significantly from those used in Iran, their application to the latter may be precluded.

Hybrid vulnerability curves attempt to compensate for the scarcity of observational data, subjectivity of judgmental data and modeling deficiencies of analytical procedures by combining data from the different sources. Existing examples of hybrid curves typically involve the modification of analytical or judgment-based relationships with observational data. In most cases the data deriving from the additional sources are, however, very limited in quantity and scope.

This article is deduced from two studies which have been done lately. The first study is “Derivation of vulnerability functions based on observational data for Iran” and the second one is “Vulnerability assessment of common buildings constructed in Mazandaran province”. The first study is based on empirical method and the second one is based on judgmental method that has used Arya method. Due to lack of observational damage data used for generation of empirical vulnerability functions a judgmental vulnerability data is used to gain more damage data and improve fragility curve fitting to data.

2. DETERMINATION OF THE DAMAGE DATA BANK

In this paper, new hybrid relationships for Iran are derived from a database of observed post-earthquake damage distributions collected from 3 survey reports published by research groups and governmental authorities and one judgmental relationship developed in Iran. The 16 and 6 datasets are forming the statistical basis for the curve derivation that each consists of the damage distribution and earthquake characteristic for masonry building and steel or concrete building respectively.

The judgmental relationships that developed for Mazandaran province of Iran have done by Arya method which has 4 categories of damage states. Although, the empirical relationships applied here have 3 categories of damage states. Thus for combining these relationships, damage states should be calibrated to each other. In this way, 3 damage categories 0-30%, 30-60% and 60-100% was adopted. Thus in case of judgmental relationships, first category was set to 0-30% damage state, second one was set to 30-60% and third & forth one was set to 60-100% damage state. Damage states used in this study are categorized in 3 states, 0-30%, 30-60% and 60-100% damage.

3. GROUND MOTION CHARACTERIZATION

In a vulnerability relationship, the horizontal axis represents the seismic demand. The measure chosen should be capable of representing the influence of source, path and site on the strong ground motion and should be evaluated independently of the seismic vulnerability of the building stock on which it is imposed. In this paper PGA was adopted as the seismic demand.

The Modified Mercalli Intensity (MMI) scale is qualitative, antiquated and may not adequately reflect the seismic performance of many modern building types. Nevertheless, the MMI scale has been used for many decades and a great deal of the historical seismic damage information is formulated in MMI. In particular, the two major sources of damage data for US buildings (ATC-13 and ATC-36), which are used in the benefit-cost model, both formulate building damage data in MMI. Peak ground acceleration (PGA) is a quantitative, modern measure of the level of ground motion. However, PGA does not fully capture the seismic parameters which relate ground motion to building damages In detail, building damages depend not only on the level of ground shaking but also on the duration and frequency content of the ground motions.

As the judgmental relationships applied here, are based on Modified Mercalli Intensity (MMI) scale, some MMI/PGA Relationships are reviewed here to convert MMI to PGA.

1)B.A.Bolt, W.H.Freeman represented:

MMI	VII	VIII	IX
PGA(g)	0.1-0.15	0.25-0.3	0.5-0.55

2) Research with title of “Seismic Rehabilitation of Federal Buildings: A Benefit -Cost Model”:

MMI	VII	VIII	IX
PGA(cm/s2)	2.218	2.556	2.414
PGA(g)	0.225	0.260	0.245

3) Kenneth W. Campbell represented:

$$MMI = 8.76 + 0.637 (\text{In } PGA) - 0.114 (\text{In } PGA)^2$$

4) Wald et al. represented:

$$MMI= 3.66\log(PGA)-1.66$$

5) Research with title of “The Basic of Seismic Risk Analysis”:

MMI	VII	VIII	IX
PGA(g)	0.1	0.2	0.4

Average of converted PGAs are used to data.

4. METHODOLOGY FOR DERIVATION OF VULNERABILITY FUNCTION

Hybrid vulnerability functions for buildings in Iran were derived using the 16 and 6 datasets of observed or predicted damage distributions described in Table 1. Each dataset can be visualized as a bar chart, wherein the number of the surveyed buildings lying within each damage state is plotted side-by-side in order of increasing damage severity.

Table 1. The composition of the damage database

Earthquake	type	Ms	No. of data-sets	No. of buildings
Bam,2003	Empirical	6.7	1	19161
Ghaen,1997	Empirical	7.1	2	52
Manjil,1990	Empirical	7.7	10	667335
Mazandaran	Judgmental	------	3	375

Then continuous probability distribution functions fit to each dataset (e.g. Fig. 1). Many continuous probability distribution functions were considered for the damage frequency representation and Kolmogorov-Smirnov one-sample tests were carried out to assess the goodness of fit to the functions with the data. A bias of the frequency plots towards the low or high damage states was observed in the case of small and severe ground motions respectively, which was seen to be best represented by beta probability distribution function for empirical data and exponential probability distribution function for judgmental data. Therefore cumulative distributions were fitted to each of the 16 damage datasets using the non-linear regression module of the program STATISTICA (StatSoft Inc., 1995), which evaluates the model of function shape parameters through minimization of the square of the residuals. The damage state exceedence probabilities were next determined from the fitted cumulative distributions for the appropriate structural system.

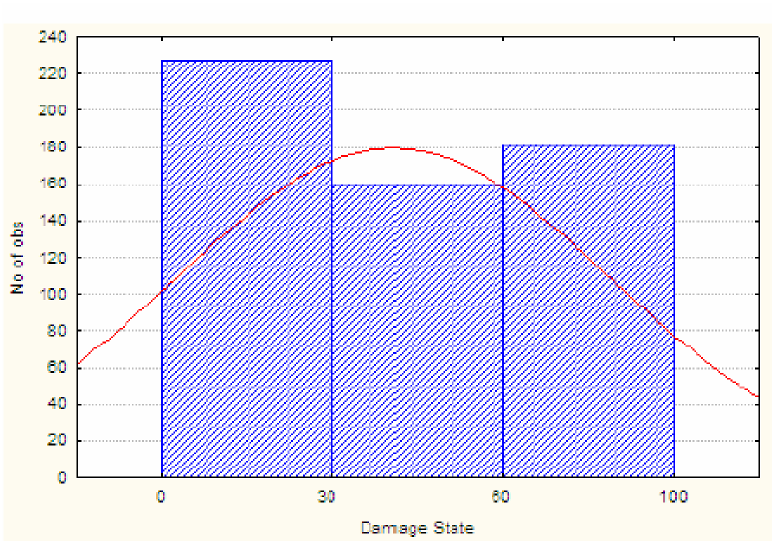

Figure 1. Continuous probability distribution functions fit to each dataset (Bam earthquake, steel frames)

Thus 16 values of exceedence probability for each of the damage limit states are obtained, and when plotted against the related ground motion parameter, forms a vulnerability plot. Various cumulative distribution functions were again assessed to model the vulnerability curve shapes. The functions most commonly used in existing relationships are cumulative normal and lognormal distributions, however following many trials a relationship of the form of Eq. 1 was found to yield the optimum fit for all considered ground motion parameters (GM). This functional form is therefore used to derive the empirical vulnerability curves in this paper, with the parameters α and β being found from non-linear regression on the plotted observational data.

$$P(d \geq D/GM)=1-\exp(-\alpha.GM^{\beta}) \quad (1)$$

Vulnerability curves were derived using peak ground acceleration (PGA).
Hybrid vulnerability relationships for PGA are summarized in Tables 2-4 and Hybrid vulnerability plots for 0-30%, 30-60% and 60-100% damage states are as below shown in Figs. 2 to 13.

Table 2. Summary of the hybrid vulnerability relationships developed for peak ground acceleration and their fit to the observational data for masonry buildings

Curve parameters						Damage state (%)
*L 90%		*U 90%		Mean		
α	β	α	β	α	β	
0.633373	0.147104	6.028153	1.054820	3.33076	0.600962	0-30
-1.079E+09	-4.754E+01	1.1099E+09	7.606E+01	1.53E+07	14.2619	30-60
0.401578	0.626253	1.505313	2.092368	0.953446	1.35931	60-100

Table 3. Summary of the hybrid vulnerability relationships developed for peak ground acceleration and their fit to the observational data for steel buildings

Curve parameters						Damage state (%)
*L 90%		*U 90%		Mean		
α	β	α	β	α	β	
0.057164	-0.674464	2.390320	1.228812	1.22374	0.277174	0-30
-0.54551	-2.84294	1.166989	3.304095	0.310738	0.230579	30-60
-0.26974	-3.35892	0.571364	4.379718	0.150812	0.510401	60-100

Table 4. Summary of the hybrid vulnerability relationships developed for peak ground acceleration and their fit to the observational data for concrete buildings

Curve parameters						Damage state (%)
*L 90%		*U 90%		Mean		
α	β	α	β	α	β	
-0.59613	-1.08323	3.578593	1.110761	1.49123	0.013765	0-30
-0.60914	-1.89399	1.660202	1.328656	0.525532	-0.28267	30-60
-0.43998	-2.30292	0.964201	1.263064	0.26211	-0.51993	60-100

* α and β, the parameters defining the curves for the mean curves, upper and lower 90% confidence bounds (U90% and L90%, respectively)

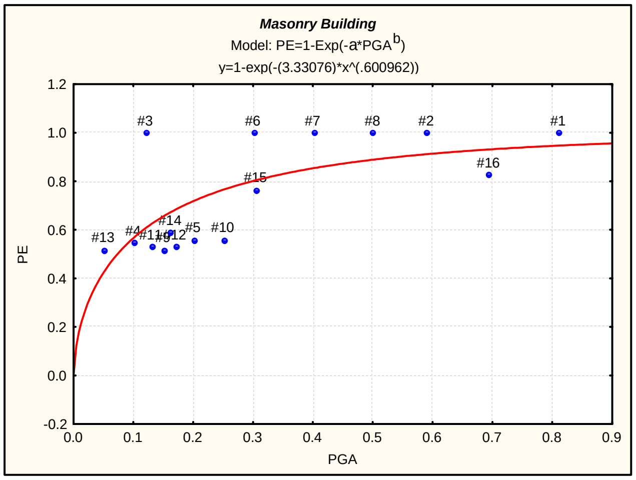

Figure 2. Masonry buildings in 0-30% damage state

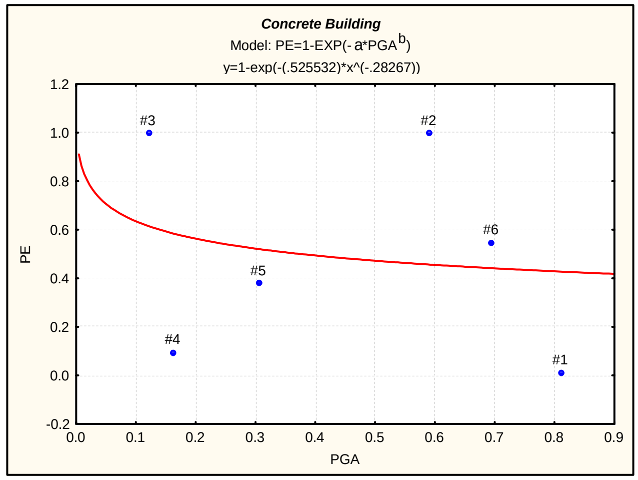

Figure 3. Masonry buildings in 30-60% damage state

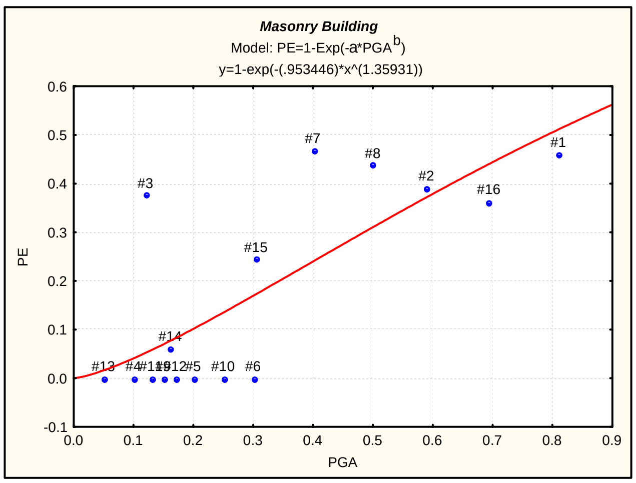

Figure 4. Masonry buildings in 60-100% damage state

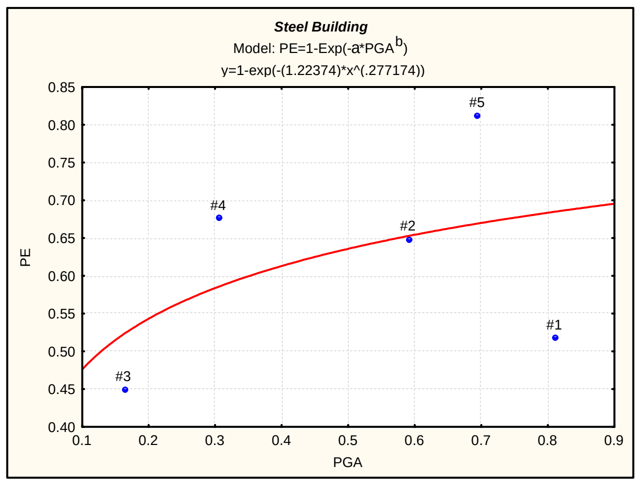

Figure 5. Steel buildings in 0-30% damage state

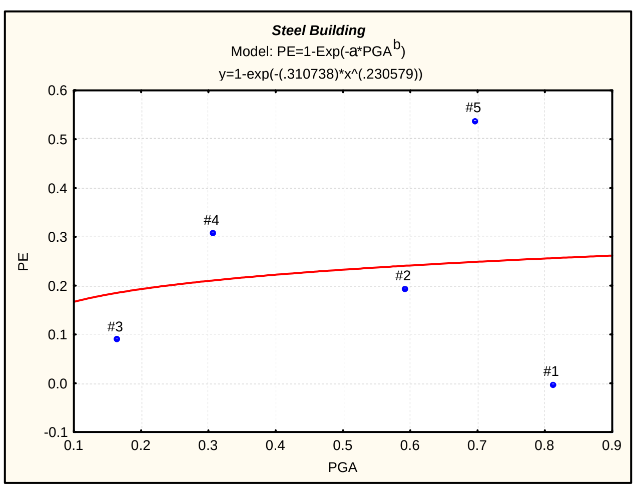

Figure 6. Steel buildings in 30-60% damage state

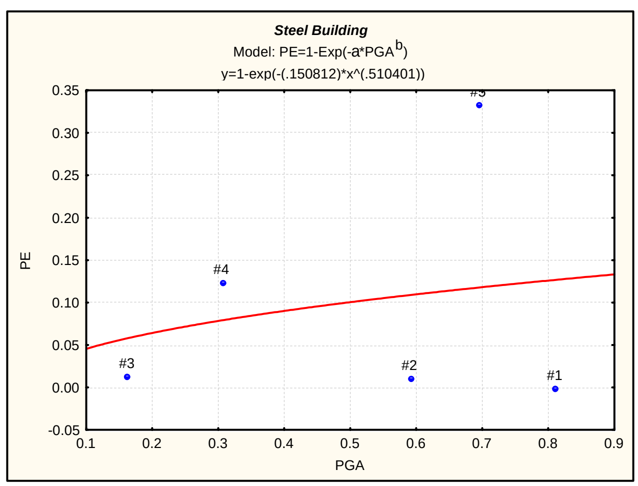

Figure 7. Steel buildings in 60-100% damage state

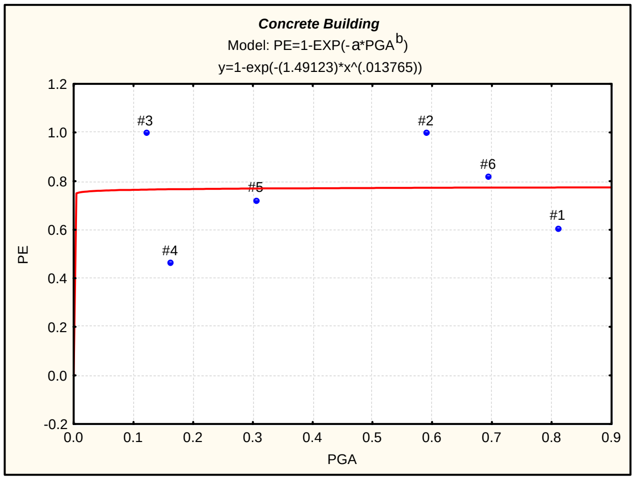

Figure 8. Concrete buildings in 0-30% damage state

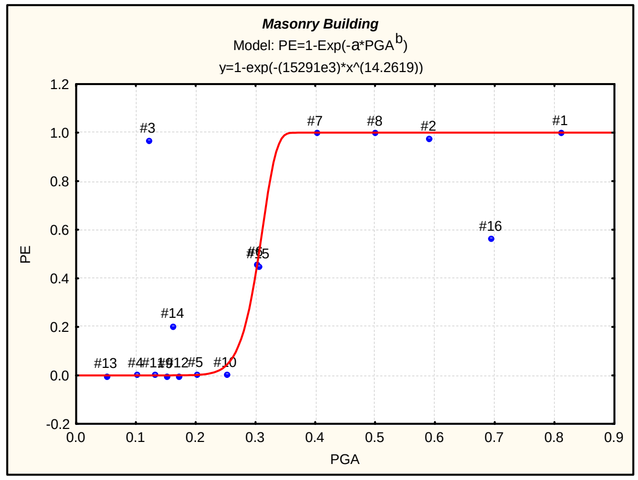

Figure 9. Concrete buildings in 30-60% damage state

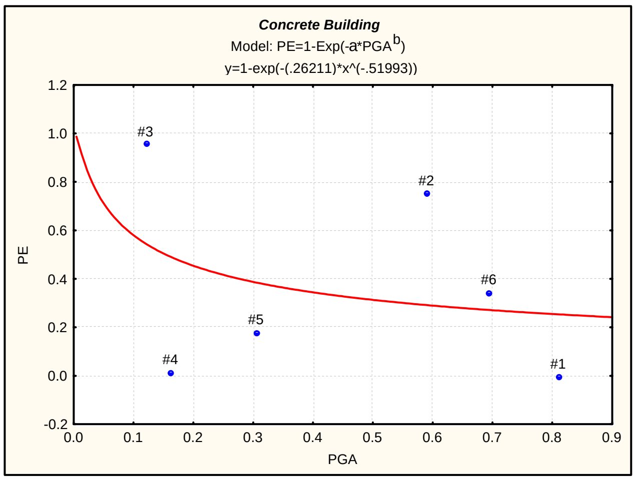

Figure 10. Concrete buildings in 60-100% damage state

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