Six^th International Conference of
Seismology and Earthquake Engineering
16-18 May 2011 Tehran, Iran

Development of Structural Fragility Curves Considering the Site Condition for Tehran

Babak Mansouri[1], Amir Kiani[2]

1- Assistant Professor, Risk Management Research Center,
International Institute of Earthquake Engineering and Seismology, Tehran, Iran
2- PhD Student, International Institute of Earthquake Engineering and Seismology, Tehran, Iran
Email: mansouri@iiees.ac.ir, amirkianii@yahoo.com

ABSTRACT

The development of realistic seismic loss model is essential in devising and implementing large scale urban and risk management procedures. That is such studies are essential to better understand the severity and the extent of the damage and the direct or indirect losses to the built environment and consequently to the human lives. Basic steps in estimating seismic loss include the computation of site specific seismic hazards and to derive proper structural fragility curves in accordance to the actual building taxonomy. These functions are site specific by nature because they are mainly dependent on the design and the local construction method in one hand and on the seismic properties of the site on the other hand.
Using an Interactive tool (ELER) developed for the seismic risk assessment of the region, the spectral demand curve were computed for a central region of Tehran that can easily be expanded for the entire region. The fragility curves were derived according to the Kircher method considering the demand spectrum and the capacity curves for masonry and low quality concrete frame structures. The results were compared with the “Complete” damage state of the empirical functions as surveyed for the Manjil-Rudbar earthquake of 1990, in Iran. The results compare well and the notion for developing low cost and rapid scenario-based urban damage data is supported herein.

Keywords: Risk Management, Seismic Loss Model, Fragility Curves, ELER, GEM, EMME

1. INTRODUCTION

Rapid and accurate urban risk assessment is the necessity for sustainable development. To devise proper foundations for effective disaster and risk management procedure, it is indispensable to understand the severity and the extent of the damage and the direct or indirect losses to the built environment and consequently to the human lives. Basic steps in estimating seismic loss include the computation of site specific seismic hazards and to derive proper structural fragility curves in accordance to the actual building taxonomy. These functions are site specific by nature because they are mainly dependent on the design and the local construction method in one hand and on the seismic properties of the site on the other hand.
Recently, the “GEM - Global Earthquake Model” program has been initiated in order to create a

global loss model for the earthquake prone regions of the world. This program includes the "EMME – Earthquake Model for Middle East" where IIEES is an active contributor. "ELER – Earthquake Loss Estimation Routine" is an interactive tool provided for the project in order to compile the existing/available data and to estimate the loss in various levels. Using ELER, site specific parameters are derived for constructing NEHRP 1997 or IBC 2006 uniform hazard spectra curves for an important site within Tehran. Exploiting these as the "Demand" curve and using the building capacity curves, "Equivalent-PGA" fragility curves are developed for some typical structures of Tehran. The outcome is stored in an integrated system that is capable in producing thematic loss maps. The fragility curves are derived according to the Kircher method considering the demand spectrum and the capacity curves for masonry and low quality concrete frame structures. These rather analytical results are compared for the "Complete" damage state of the empirical functions as surveyed for the Manjil-Rudbar earthquake of 1990, in Iran. The results are in reasonable agreement and the notion for developing low cost and rapid scenario-based urban damage data is supported herein.

2. METHODOLOGY AND RESULTS

For the risk and disaster management point of views, scenario-based risk assessment is of interest. In order to derive proper structural fragility curves, seismic properties of the desired site and the dynamic behaviour of the buildings must be taken into account. For this, a central region of Tehran is selected as it represents the common soil type, the effects of two major active faults (namely the Tehran and the Rey faults) and also two most common structural types. In the following sections, the scenario based hazard mapping of the major aforementioned faults, the derivation of the seismic demand curves, and the PGA-equivalent procedure in creating fragility curves for the area of interest within Tehran are described.

2.1. Earthquake Hazard

A number of known important active faults have been discovered near or within Tehran. The effects of these must be investigated and the contribution of the ones with high destructions must be highlighted. Based on some previous studies (CEST and JICA, 2000, IIEES, ?????), the most probable hazardous faults are:

- Mosha Fault (length ~ 200km & depth~26.9km)
- North Tehran Fault (length ~ 90km & depth~24.4km)
- South Ray Fault (length ~20km & depth~19.1km)

These faults are graphically shown in Figure 1 and the fault model parameters are tabulated in Table 1. The faults' lengths, origins and azimuths were determined from surface fault traces. The faults' widths and magnitudes were calculated from length using an empirical relation for reverse faults according to Wells and Coppersmith (1994).

In the ELER software, the Earthquake Hazard Assessment (EHA) module is used to input the earthquake parameters in order to create rapidly shaking maps. The earthquake epicenter coordinates, depth and magnitude information as well as the line geometry were fed into the program.

Table 1. *Fault Model Parameters [CEST-JICA, 2000]*

		Ray Fault model	NTF (North Tehran Fault) model	Mosha Fault model
Length (km)		26	58	68
Width (km)		16	27	30
Moment Magnitude (Mw)		6.7	7.2	7.2
Origin	N (degrees)	35.8255	35.6815	35.5876
	E (degrees)	51.7392	52.4955	51.5061
Azimuth (Clockwise from North) (degrees)		263	263	283
Dip angle (degrees)		75	75	75
Depth of upper edge (km)		5	0	0

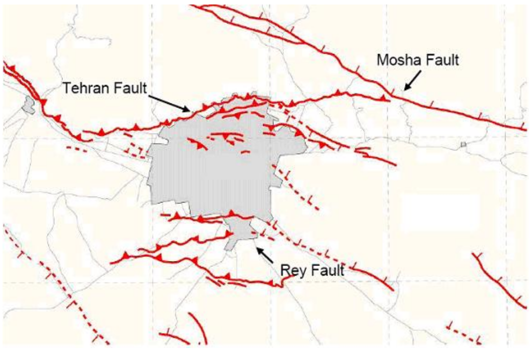

Figure 1*. Tehran and corresponding known active faults*

2.1.1. Site Effect

The assessment of global seismic site conditions provides a valuable tool for predicting the ground-motions at the earth surface where most of the urban elements at seismic risk are found. For a specific area of interest, conventionally, large amount of various data sets (i.e. borehole data) and sophisticated computations are required for understanding and modeling the site effects. For the cases where there is no such detailed information available, or in an attempt to simplify the site effect modeling, Wald et al. (2004), and Wald and Allen (BSSA, 2007) describe a methodology for seismic site condition mapping using topographic slope. The Vs30 measurements, the average shear-velocity down to 30 m, are correlated with topographic slope. In their model, two sets of parameters were derived for active tectonic and for stable continental regions. These findings were compared with actual Vs30 measurements upon availability which concluded in reasonable agreements.

The GTOPO30 is a global digital elevation model (DEM) developed in the late 1996. It was derived from several raster and vector sources of topographic information with a spatial resolution of 30 arc seconds (approximately 1 kilometer). The Gtopo30 enables the user to plot the distribution of ground motions on topographic maps. The upgrade to the latter is the SRTM30 (30 arc second data). The NASA had completed a space mission exploiting the Shuttle spaceship and some advanced Interferometric Radar instruments onboard. The SRTM (Shuttle Radar Topographic Mission) program had surveyed the entire globe in less than 12 days, in February 2000, and created topographic maps with different spatial resolution (or grid spacing). The topography has been processed mainly with two different spatial resolutions, 30m for the US regions and 90m for global coverage, where the data is obtainable from the US Geological Survey (USGS) website. However, the SRTM30 is the coarser data with about 1 kilometers grid spacing as it is used for global Vs30 mapping. Using the global SRTM30 database (30 arc-sec global topography, Farr and Kobrick, 2000), the slope calculations and slope conversion to Vs30 values was carried out and the data has been made available for many regions including Iran. The Vs30 map of Iran and Tehran are provided by the USGS source and the output of the ELER software as shown in Figure 2.

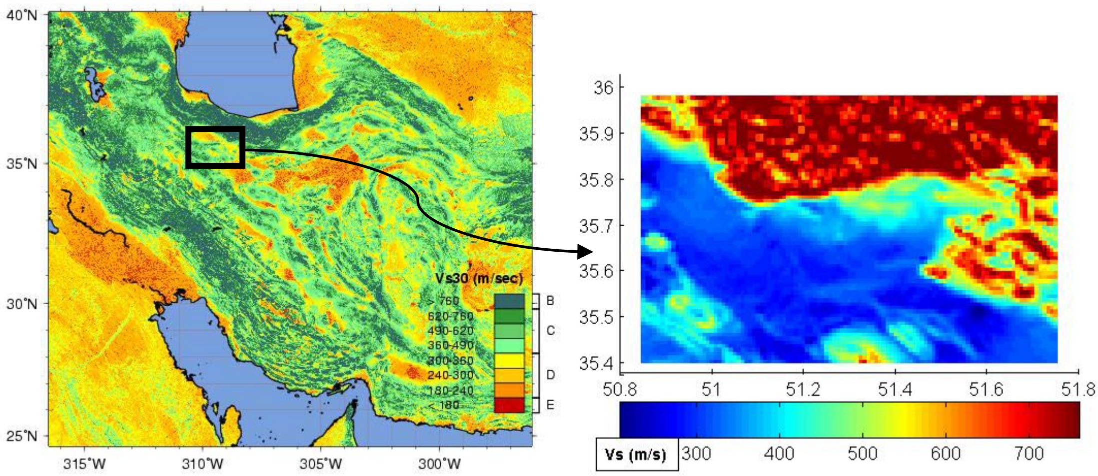

Figure 2. *The upper 30-m average shear wave-velocity (Vs30) for Iran & Tehran (USGS and ELER)*

2.1.2. Ground Motion Prediction Equations (GMPEs)

The Next Generation Attenuation (NGA) relations and Boore et al., 1997 GMPEs provide means in computing the ground motion parameters at the ground surface by taking into account the local site effects (i.e. Vs30 parameter). In this research, three well-known equations namely the Boore and Atkinson, 2008, Boore et al., 1997, and Campbell & Bozorgnia (2008) are selected to produce input data at the ground surface. The desired input data are the Peak Ground Acceleration and the Spectral Acceleration distributions. Figs 3 and Figs 4 depict the distribution of the PGA values for the Tehran Fault and the Rey Fault scenarios for the Boore and Atkinson, 2008 equation. Similar maps were also created for the other two equations as discussed in above. The comparison between the maps that were created by mathematical simulation (Center for Earthquake and Environmental Studies of Tehran - CEST) in 2000 and the maps created by this research shows a good agreement. A major benefit in using such a methodology is the speed and the ease of implementation as appreciated in today's demand of disaster management in line with damage, losses and casualty estimations.

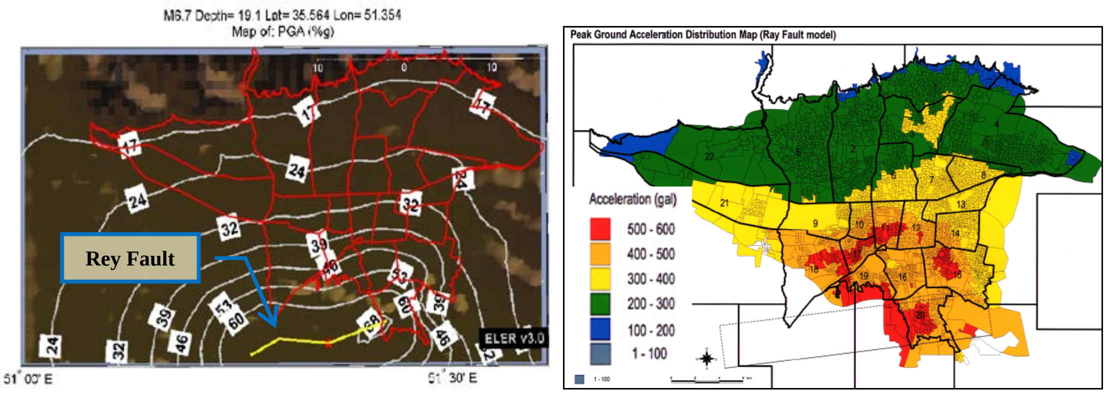

Figure 3. *Peak Ground Acceleration Distribution Maps for the Rey Fault Scenario - Comparison between The results from Boore and Atkinson, 2008 ground motion prediction equation and the CEST maps*

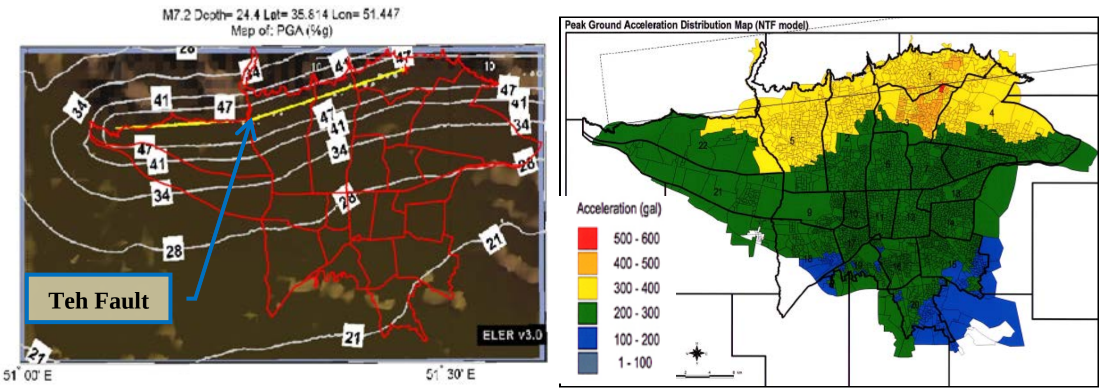

Figure 4. *Peak Ground Acceleration Distribution Maps for Tehran Fault Scenario - Comparison between The results from Boore and Atkinson, 2008 ground motion prediction equation and the CEST maps*

2.2. Development of Structural Fragility Curves

2.2.1. Area of Interest (AOI) and Selected Structural Taxonomy

The geographic central part of Tehran is selected as it represents the stock of older masonry houses in addition to the more recent reinforced concrete moment frame constructions. The area of interrest is centerred around the geographic coordinates of Lat: 35.738 degrees and Lon: 51.426 degrees. This area also represents the common soil type (Type III according to 2800 Iranian Seismic Building Standard) of the city. This soil type is comparable to the "class D" of the NEHRP 97 or the IBC 2006. It should be noted that these building types are very common within the extent of Tehran. The masonry buildings are usually aged more than 30 years old and are categorized as low-rise or mid- rise that are comparable to the URML and URMM according to the HAZUS terminology. The R/C frame constructions have basically started to grow during the 80's and constitute of a major structural taxonomy. Conventional fragility curves (similar to the HAZUS methodology) pronounce the probability of Slight, Moderate, Extensive and Complete damages for the building stock in terms of a parameter describing the severity of the earthquake (i.e. PGA, PGV, Sd, etc…). According to the construction quality and/or the level of implemented seismic design criteria, different levels of seismic performances namely, High-Code, Moderate-Code, Low-Code Pre-Code (not designed for seismic loads) are taken into account. But for this research Low-code and Pre-code categories are emphasized and the related fragility curves are derived.

2.2.2. Demand Spectra and Structural Capacity Curve

The seismic demand spectrum is selected according to NEHRP 97. It is necessary to compute the spectral acceleration for 0.3 sec and 1.0 sec periods (Sa@0.3 sec, Sa@1.0 sec). From the three GMPEs described in the previous section, three different spectral acceleration maps were created and the average value of the spectral accelerations were calculated for each earthquake scenario. Then, based on the severity of the averaged seismic input, the most destructive scenario was determined. Figure 5 and Figure 6 show the spectral acceleration maps, in terms of %g, at two periods, T=0.3 sec & T=1.0 sec, using the Boore and Atkinson, 2008, ground motion prediction equation for the Tehran and Rey scenarios.

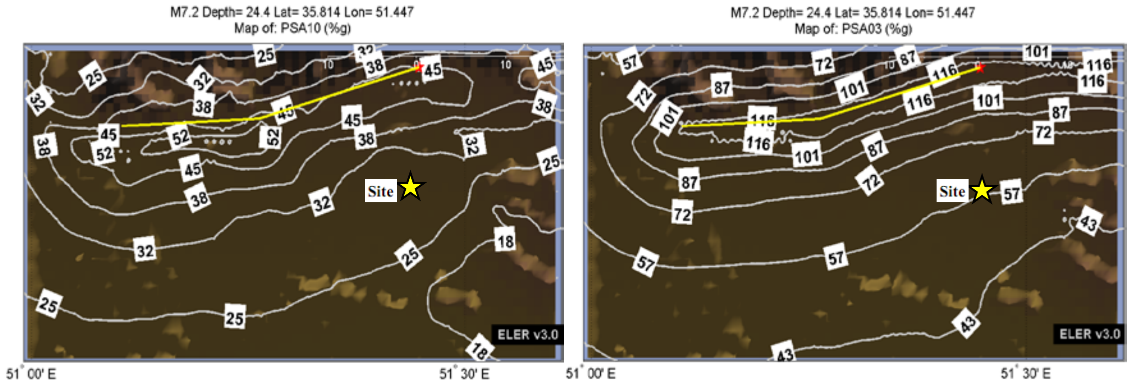

Figure 5. *Spectral accelerations (%g) at T=0.3 sec & T=1.0 sec obtained from the Boore and Atkinson, 2008 ground motion prediction equation (Teh fault)*

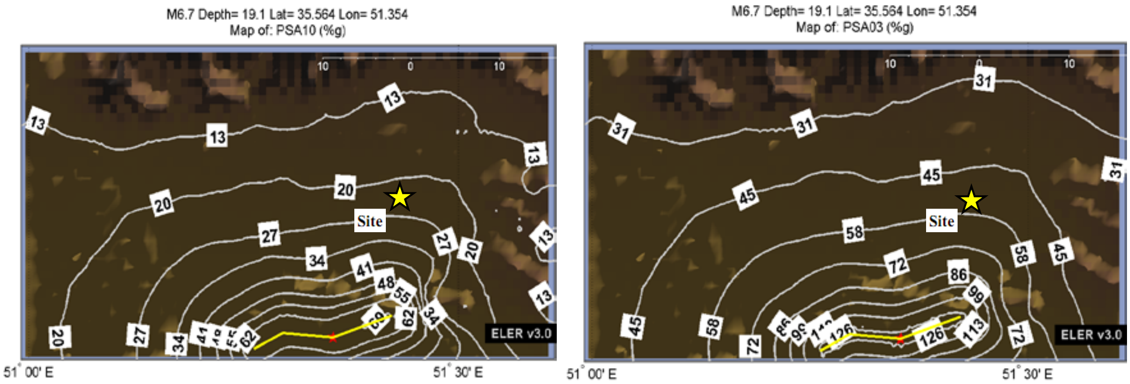

Figure 6. *Spectral accelerations (%g) at T=0.3 sec & T=1.0 sec obtained from the Boore and Atkinson, 2008 ground motion prediction equation (Rey fault)*

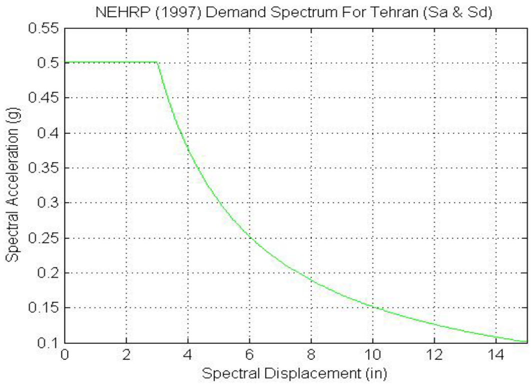

Figure 7*. Demand Curve for Tehran according to NEHRP 1997*

Figure 7 shows the demand curve in the ADRS coordinate system according to the site condition of the area of interest following the NEHRP 1997 procedure.

The capacity curve is a simplistic representation for the dynamic behaviour of the entire structure by considering a SDOF system. The selected structural types for this research are tabulated in Table 2. The capacity curves are determined by two sets of points, the yield and the ultimate capacity points, where the first point indicate the limit for linear response and the second point is related to the nonlinear part of the capacity curve. For example Figure 8 depicts the structural capacity curve for the low quality mid-rise concrete frame.

Table 2. *Capacity Curves Parameters (from HAZUS comparable to selected Tehran buildings)*

Low-Code Seismic Design Level				
Building Type	**Yield Capacity Point**		**Ultimate Capacity Point**	
	D_y (in)	A_y (g)	D_u (in)	A_u (g)
C1L	0.10	0.062	1.47	0.187
C1M	0.29	0.052	2.88	0.156
URML	0.24	0.200	2.40	0.400
URMM	0.27	0.111	1.81	0.222
Pre-Code Seismic Design Level				
Building Type	**Yield Capacity Point**		**Ultimate Capacity Point**	
	D_y (in)	A_y (g)	D_u (in)	A_u (g)
C1L	0.10	0.062	1.76	0.187
C1M	0.29	0.052	3.46	0.156
URML	0.24	0.200	2.40	0.400
URMM	0.27	0.111	1.81	0.222

C1: Reinforced Concrete Moment Frame   URM: Unreinforced Masonry Bearing Walls
L: Low-rise   M: Mid-rise

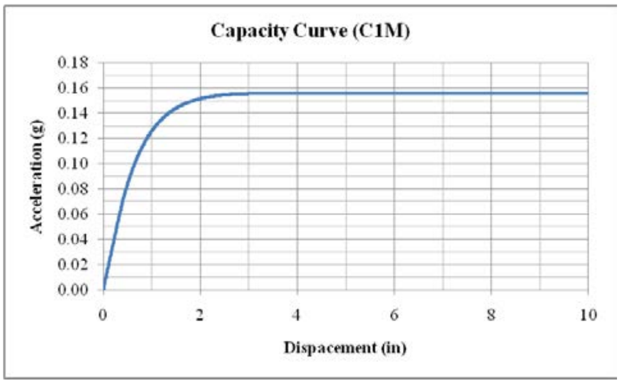

Figure 9. *C1M Building Capacity Curves - Low-Code Seismic Design Level*

2.2.3. Fragility Curve Derivation

According to the Kircher method, the capacity and the demand curves are interacted together till the equilibrium is reached between the dissipated hysteretic energy of the structure and the demand curve by considering and effective damping (Kircher, 1997). The equilibrium points are considered as the median spectral displacement in the ADRS coordinate system. These values are computed and shown in Table 3. Using these values, the lognormal standard deviation of 64% (from the expert judgment), lognormal fragility curves are obtained for four damage states namely, Slight, Moderate, Extensive and Complete. The fragility curves have been derived for all four building categories as discussed earlier. The superposition of the "Complete" damage state fragility curves are shown in Figure 10 and Figure 11.

***Table 3.** Median Spectra Acceleration for selected buiding Types*

Building Type	Median Spectral Acceleration (g)	Probability of Damage			
		Slight	Moderate	Extensive	Complete
Low-Code Structures					
C1L	$\bar{S}_{a,ds}(g)$	0.09	0.11	0.22	0.45
C1M	$\bar{S}_{a,ds}(g)$	0.08	0.12	0.26	0.54
URML	$\bar{S}_{a,ds}(g)$	0.09	0.16	0.23	0.45
URMM	$\bar{S}_{a,ds}(g)$	0.07	0.12	0.23	0.46
Pre-Code Structures					
C1L	$\bar{S}_{a,ds}(g)$	0.07	0.09	0.16	0.32
C1M	$\bar{S}_{a,ds}(g)$	0.07	0.09	0.2	0.41
URML	$\bar{S}_{a,ds}(g)$	0.10	0.16	0.23	0.37
URMM	$\bar{S}_{a,ds}(g)$	0.05	0.09	0.17	0.33

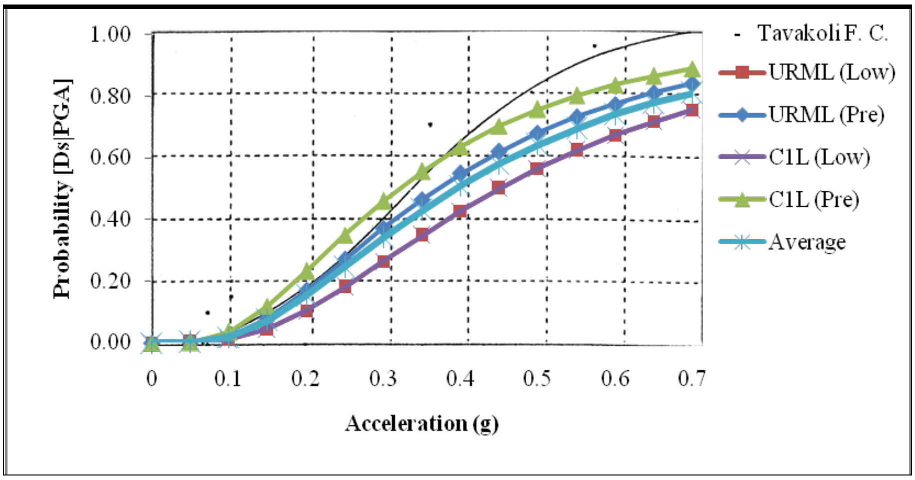

***Figure 10**. Fragility curves for selected Low-rise buildings according to "Complete" damage state*

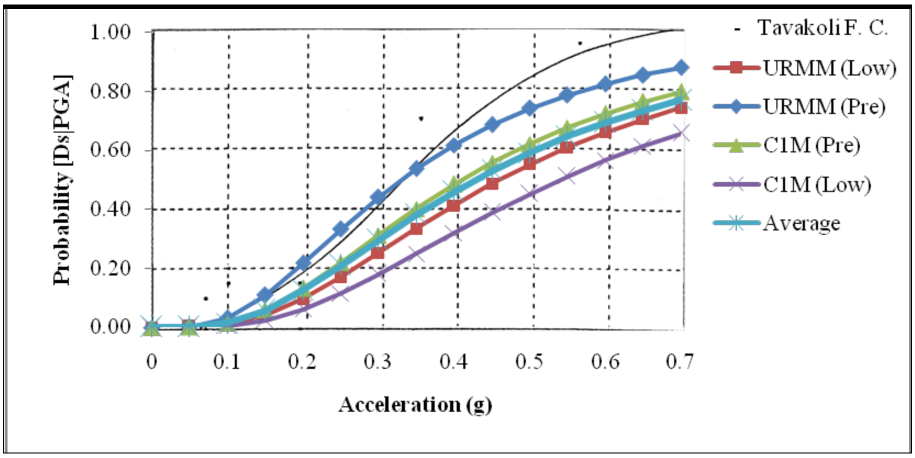

***Figure 11**. Fragility curves for selected Mid-rise buildings according to "Complete" damage state*

3. CONCLUSION

Rapid generation of risk maps in urban area is an indispensable task in today's demand for risk and disaster management studies. In an attempt to provide a basis for analytical fragility curve development, this research focuses first on creating low-cost and rapid seismic microzonation maps benefiting from the ELER computer code (developed for the WP4 project) and considering some approximation in considering the overall site effect for central part of Tehran. This process can easily be expanded for the entire city or a bigger region as required. The procedure includes the derivation of fragility curves according to the Kircher method for some most common structural types of Tehran taxonomy.

Empirical fragility curves are generally preferred for regions that have experienced devastating earthquakes. But, because such data are not available for Tehran, these analytical results are proposed for Tehran. These curves are compared with the data from the devastating Manjil-Rudbar Earthquake of 1990, Iran as processed by Tavakoli &Tavakoli, 1993. For the "Complete" building damage state. The results are in summarized in Figure 10 and Figure 11 and considering the urban fabric of Tehran and mostly rural fabric of Manjil data, the curves compare well.

5. REFERENCES

1. **Wells, D.L., and Coppersmith K.J.,** 1994, New Empirical Relationships among Magnitude, Rupture Length, Rupture Width, Rupture Area, and Surface Displacement, Bull. Seism. Soc. Am., Vol.84, No.4.
2. **Applied Technical Council (ATC)** Applied Technical Council (ATC), 1985, Earthquake Evaluation Data for California (ATC-13).
3. **HAZUS99** User's Manual (1999). Federal Emergency Management Agency, Washington, D. C.
4. **Technical Manual and Users Guide of ELER©** v3.0 (Earthquake Loss Estimation Routine), Prepared by Bogazici University, Department of Earthquake Engineering Istanbul, July 2010
5. **Federal Emergency Management Agency. 1997 NEHRP** Recommended Provisions for Seismic Regulations for New Buildings, (in press) Washington, D. C., Developed by the Building Seismic Safety Council (BSSC) for the Federal Emergency Management Agency (FEMA).
6. **ATC (1991)**. "Seismic vulnerability and impact of disruption in the conterminous united states." Tech. Rep. ATC-25, Applied Technology Council.
7. **Naiem F**, "Earthquake Engineering Handbook".
8. **Tavakoli, B., and Tavakoli, S.**, 1993. Estimating the vulnerability and loss functions of residential buildings, Natural Hazards 7, 155–171.
9. **Kircher, C. A., Nassar, A. A., Kustu, O., and Holmes, W. T.,** 1997. Development of building damage functions for earthquake loss estimation, Earthquake Spectra 13, 663–681.