# SEISMIC HUMAN LOSS ESTIMATION IN TEHRAN USING GIS

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**ABSTRACT :**

Tehran is surrounded by known active faults and the region is identified with high seismic hazard. The high level of losses related to recent earthquakes in Iran (i.e. Manjil 1990, and Bam 2003) is mainly due to bad construction and urban texture. In-depth evaluation of the seismic characteristics of the region in conjunction with urban studies will help in assessing earthquake losses more realistically. The results of such studies are essential for a proper seismic risk and disaster management. For this study, the municipality district 17 of Tehran is the area of interest because it consists largely of extremely vulnerable unreinforced masonry buildings.

To mitigate the risk, it is essential to have a comprehensive knowledge of the consequences of devastating events such as to be able to plan especially for the full cycle of disaster management (mitigation, preparedness, disaster response, and recovery). This paper describes our GIS-based methodology for modeling and estimating the severity and the spatial distribution of human loss as a function of building damage. The methodology has four major stages; namely seismic hazard assumption as an input, building inventory development, building and human vulnerability functions developments and implementations, and finally producing the results in GIS.

## 1. INTRODUCTION

GIS has been a powerful tool in modeling/analyzing urban risk and also in producing various risk maps. In this research, the district 17 of Tehran has been chosen for modeling/estimating the severity and the spatial distribution of human loss as a function of building damage. The seismic hazard map (microzonation map) is obtained from the estimated Ray fault model (JICA 2000). The building inventory has been produced using aerial remote sensing cartographic and survey data that reflect parcel information including attributes such as building height information. The population statistics is from the 1996 database aggregated for each census zone (Iran Census Center). In order to distribute the data in data is interpolated for each individual dwelling.

The structural vulnerability functions for different structural typologies have been developed by modifying the Hazus (FEMA) methodology and incorporating domestic parameters. Since the great majority of the buildings in the area of study are low-rise unreinforced masonry, this building type is focused and the related vulnerability functions are produced. For the human loss case, the Hazus methodology uses selected casualty functions and coefficients that describe the United States building stock and conditions. The human vulnerability assessment, reported in here, is based on an adaptation to the Hazus procedure where the domestic

**KEYWORDS:**     Seismic Risk, Human Loss, GIS, Earthquake Risk Management, Disaster Management

coefficients are obtained from the Bam earthquake (December 2003) human loss statistics. The estimation pronounces the probability or the percentage of the building population for different severity levels.

## 2. METHODOLOGY

The geodatabase was developed considering the Ray fault scenario microzonation map (as shown in figure 1) and integrating building inventory data. The parcel maps and building height information were extracted from 1:2000 scale digital maps provided by the National Cartographic Center (NCC) of Iran. The data was complemented with field survey provided by EMCO Iran consultant company. This survey data consists of three major building categories namely "steel frame", "reinforced concrete frame", and "brick and steel". The buildings not older than 10 years are regarded as high quality, buildings constructed between 10 to 30 years ago are considered low quality and dwellings older than 30 years have the poorest quality. In this district, 64% of all structures are two-story where 94% of them are unreinforced masonry and 86% of the latter are recognized as very poor in quality that must be destroyed. The total population reported in year 1996 for this district is 290539 where 174757 people are assumed to reside in URML structures. Since the population statistics is reported in numerous census zones, the estimated per parcel population was calculated (interpolated) using the average occupancy rate per living area for the entire district in which the share for the URML buildings were extracted.



**PGA (g)**

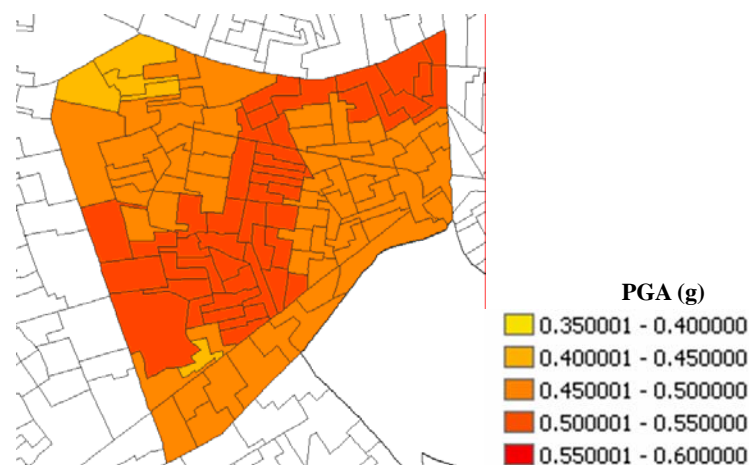| | |
|---|---|
| | 0.350001 - 0.400000 |
| | 0.400001 - 0.450000 |
| | 0.450001 - 0.500000 |
| | 0.500001 - 0.550000 |
| | 0.550001 - 0.600000 |

Figure 1 The Ray fault scenario earthquake microzonation map for Tehran district 17

Figure 2 is the flow diagram showing the major steps involved in this research. To model the human loss, seismic building loss must be assessed first. For this, the related building damage functions were developed by an analytic method used in the Hazus program after Kircher et al. (1997) that estimate the probability of a structure being in four predefined damage states specified as Slight "S", Moderate "M", Extensive "E" and Complete "C". Using this analytical procedure in companion with expert judgment, fragility curves are created for low-rise unreinforced masonry structures "URML" for the area of interest. In order to estimate the building stock physical loss, structural performance parameters must be available. All the URML buildings are poorly constructed and without seismic code, therefore; they are considered as "Pre-Code" according to Hazus categorization.
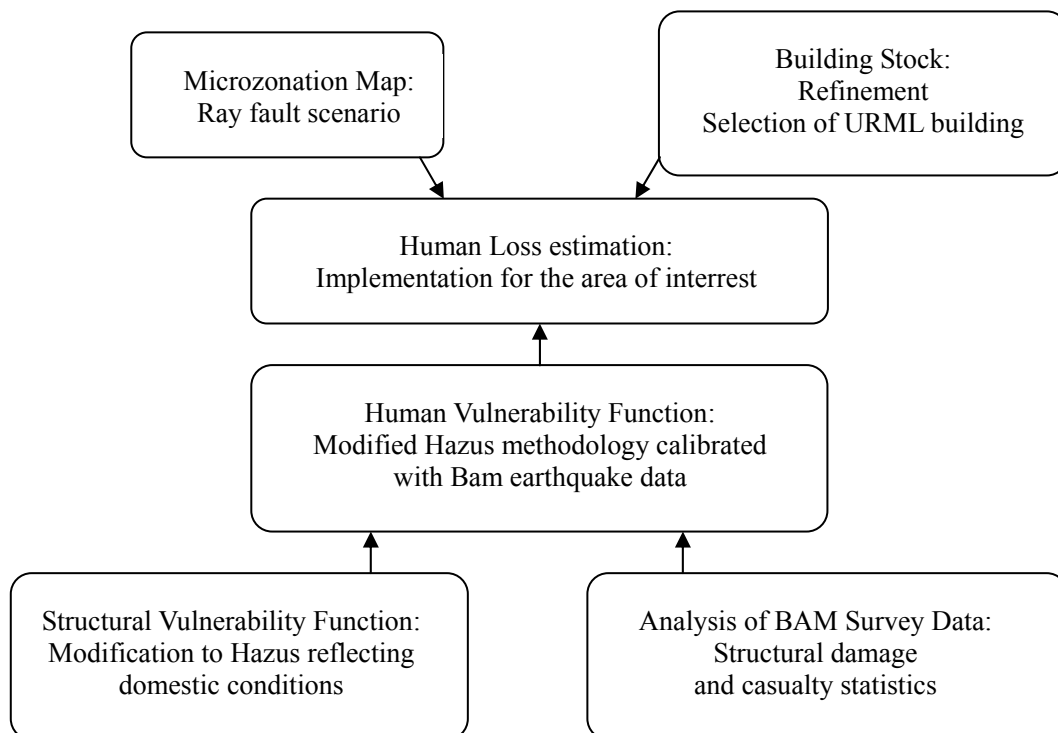
Figure 2 The flow diagram summarizing the methodology

### 2.1. Structural Vulnerability Function

It is evaluated that the structural damage is primarily a function of building displacement rather than force. In inelastic ranges, the lateral force can remain constant (or decrease) while the displacement can progressively increase. The procedure involves the creation of building capacity curves using above parameters. Such a curve has both linear and nonlinear parts and represented by yield capacity and ultimate capacity points as indicated in Table 1. In Table 2, the median threshold spectral displacement values are indicated for four damage states (S: Slight, M: Moderate, E: Extensive, C: Complete) according to the Hazus methodology. Considering each damage state threshold and intersecting the demand spectra with the building capacity curves, the performance points and the building response is determined (Kircher et al. 1997).

Table 1 – Yield and ultimate capacity points for the selected building type - from Hazus

| Building Type: | Pre-code seismic design level | | | |
| | Yield capacity point | | Ultimate capacity point | |
| | Dy (in.) | Ay (g) | Du (in.) | Au (g) |
| URML | 0.24 | 0.200 | 2.40 | 0.400 |

Table 2 – Median threshold for spectral displacement (inches) – from Hazus

| Building Type: | Pre-code seismic design level | | | |
| | S | M | E | C |
| URML | 0.32 | 0.65 | 1.62 | 3.78 |

The elastic response spectra is applicable to buildings that remain elastic during the entire ground shaking with an elastic damping value of 5-10% of critical value depending on the structural type. Since no site-specific spectra is available for the area of study, the 5% damped design spectrum proposed by the Iranian Earthquake Standard of practice (2800 Code) has been used for the area of study. The soil type III (semi-compact soil equivalent to type D in UBC) best represents the property of the study area and is considered for the computational process. The demand spectrum is based on the 5-10% damped response spectrum with considering the effective damping in nonlinear ranges. The effective damping considers both elastic and inelastic hysteretic response. The hysteretic damping depends on the nonlinear response and is obtained from the area enclosed by the hysteresis loop relative to the peak response and considering each damage state threshold displacement.

As mentioned earlier, the scenario earthquake for the Ray fault is estimated to have a moment magnitude of 6.7 Mw. It is considered as moderate duration in accordance with the HAZUS procedure. In bellow, elastic damping values and degradation factors are listed for our selected building classes. These values are partially according to the suggested values by Kircher and also from our expert judgment. For URML structures, considering the construction materials and the practice method, the elastic damping is taken as 5% of the critical.

Table 3 Elastic damping and degradation factors for the building stock

| Building Type | Elastic damping $\beta_{elastic}$ | Degradation factor: κ |
|---|---|---|
| | | Pre-code Moderate duration |
| URML | 5% | 0.2 |

Figure 3 depicts the set of fragility curves that was obtained corresponding to URML (un-reinforced masonry and low-rise) considering local conditions for the area of interest. In the next section, using these functions and considering the input microzonation maps and the inventory database, the estimated physical loss to URML buildings are computed. Then, by developing the casualty functions and calibrating the parameters considering the Bam earthquake, human loss is estimated.
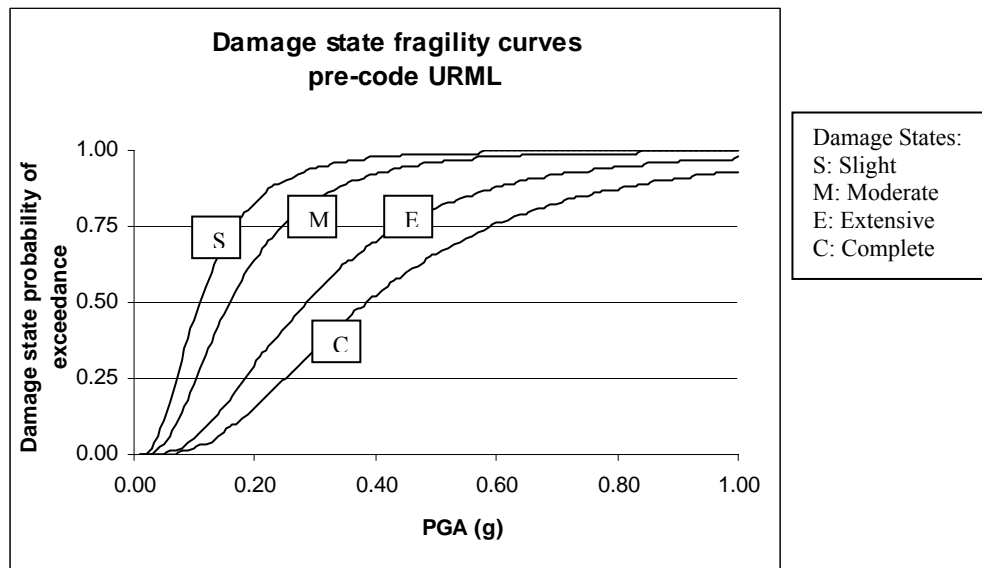


Figure 3 URML pre-code fragility curves according to domestic considerations

## 2.2. Human Vulnerability Function

To calculate the human vulnerability functions, it is assumed that the casualty statistics of the Bam earthquake can relate to the case of the study area. The scope of this work is to calculate the loss for the worst case scenario

(night time). It is worth nothing that the Bam earthquake occurred at early morning when almost all the population were indoor.In this section first the Hazus methodology will be explored and then the functions will be calibrated using the after-event (Bam) data.

*2.2.1 Hazus Functions*

The Hazus program defines casualty as four levels of severities as shown in Table 4. For each severity level, a linear combination of the different damage states (Slight, Moderate, Extensive and Complete) values (probability of a building being in distinctive damage states) describe the probability of the occupant population being affected. The distinct probability values for building damage states are computed from differentiating successive fragility curves.   "Severity 1" is minimal and not considered in here. Table 5 shows the functions describing the casualty probability for the URML building type for the worst case (night time) scenario.

Table 4 Hazus severity injury level definition (from Hazus manual)

| Injury Severity Level | Injury Description |
|---|---|
| Severity 1 | Injuries requiring basic medical aid that could be administered by paraprofessionals. These types of injuries would require bandages or observation. Some examples are: a sprain, a severe cut requiring stitches, a minor burn (first degree or second degree on a small part of the body), or a bump on the head without loss of consciousness. Injuries of lesser severity that could be self treated are not estimated by HAZUS. |
| Severity 2 | Injuries requiring a greater degree of medical care and use of medical technology such as x-rays or surgery, but not expected to progress to a life threatening status. Some examples are third degree burns or second degree burns over large parts of the body, a bump on the head that causes loss of consciousness, fractured bone, dehydration or exposure. |
| Severity 3 | Injuries that pose an immediate life threatening condition if not treated adequately and expeditiously.  Some examples are: uncontrolled bleeding, punctured organ, other internal injuries, spinal column injuries, or crush syndrome. |
| Severity 4 | Instantaneously killed or mortally injured |

Table 5 Casualty functions for URML structural type as affected population probability

| Severity Levels | Probability |
|---|---|
| Severity 2 | $(S*0 + M*0.4 + E*0.2 + C*(0.85*2 + 0.15*20) )$ |
| Severity 3 | $(S*0 + M*0.001 + E*0.002 + C*(0.85*0.02 + 0.15*5) )$ |
| Severity 4 | $(S*0 + M*0.001 + E*0.002 + C*(0.85*0.02 + 0.15*10) )$ |

(S: Slight Damage , M: Moderate Damage, E: Extensive Damage, C: Complete Damage)

*2.2.2 Adoption to the Model Using Bam data*

In order to compute the human loss coefficients that describe the portion of the population affected by the earthquake, three levels of human casualty are defined according to the BAM post-disaster survey data that was gathered by the Census Center of Iran. These three levels are: "Uninjured", "Injured", and "Dead". For the city of Bam only, 55167 people were reported uninjured, 8136 people were reported injured and 22391 people were announced dead. This data also describes roughly three levels of structural loss as "Undamaged", "Damaged" and "Destroyed". The "Undamaged" level means that no or ignorable damage was introduced. The "Damaged" means that the structure is repairable and "Destroyed" means that the building must be completely replaced. The survey data was presented in ~1450 zones (building block) as shown in Figure 4 as overlay boundaries. The set of 590 zones were selected randomly after pre-filtering (discarding) the inadequate blocks for the purpose of statistical inferring. To calculate the loss coefficients (for the human loss model) a large number of sample data (building blocks) was randomly selected and the coefficient matrix was solved directly considering the casualty and building loss levels and the affected population. The results were checked against the remaining portion of

the data and a good confidence level was achieved. The normalized root mean square errors for "# of uninjured", "# of Injured" and "# of Dead" were computed as 0.27, 0.09 and 0.23 respectively. Eqn. 2.1 and Eqn. 2.2 show the procedure in computing the # of affected people considering three levels of structural loss per each building block or zone.



Figure 4 The BAM post disaster survey zones incorporated in GIS and overlaid on panchromatic optical image (includes: three levels of building damages in addition to three levels of human casualties)

$$\begin{bmatrix} \# \text{ of Uninjured} \\ \# \text{ of Injured} \\ \# \text{ of Dead} \end{bmatrix} = \left( \frac{\# \text{ of Population}}{\# \text{ of Buildings}} \right) \begin{bmatrix} -0.073 & 1.040 & 0.650 \\ 0.071 & 0.047 & 0.062 \\ 1.001 & -0.087 & 0.289 \end{bmatrix} \begin{bmatrix} \# \text{ of Intact Buildings} \\ \# \text{ of Damaged Buildings} \\ \# \text{ of Destroyed Buildings} \end{bmatrix} \quad (2.1)$$

and

$$\# \text{ of Uninjured} + \# \text{ of Injured} + \# \text{ of Dead} = \# \text{ of Population} \quad (2.2)$$

To be able to translate the damage levels defined in hazus with the survey data, Table 6 is introduced.

Table 6 Damage level definition and translation between Hazus and survey data jargons

| Hazus structural Damage levels | Interpreted Structural damage range according to Bam survey data |
|---|---|
| Slight | Intact |
| Moderate | Damaged |
| Extensive | Destroyed |
| Complete | |

## 3. RESULTS

In this section, the results corresponding to the GIS implementation of the functions described in Table 5 and also using the concept described by the Eqn. 2.1 and Eqn. 2.2 (extracted from Bam statistics) are presented. These are estimated results for district 17 of Tehran and only for URML structure residents.

### 3.1. Implementing Hazus Casualty Functions

Table 7 Results by implementing Table 5 functions (extracted solely from Hazus procedure)

| Severity Level | Number of population affected |
|---|---|
| Severity 2 | 7344 |
| Severity 3 | 1168 |
| Severity 4 | 2309 |

### 3.2. Implementing Adopted Casualty Functions

Table 8 Results by implementing the Bam model for Tehran for URML residents

| Severity Level | Number of population affected |
|---|---|
| Uninjured | 154916 |
| Injured | 7517 |
| Fatality | 12324 |

## 4. CONCLUSION

The use of the Hazus functions directly and with no modification for the study area seem to severely underestimates the casualties. Different building typologies in the US are judged to perform better seismically since the concept of life safety has been introduced from long time ago. The roof system in URML buildings in the US are usually lighter with better integrity. In contrast, URML buildings in Iran, usually consists of weak masonry bearing wall and a heavy roof system that is simply laid on the wall top. These roofs usually consist of steel beams in parallel with vaulted brick slabs that can be easily disintegrated during earthquake jolts and can claim a huge number of the population leaving under it. This was the case experienced in the Bam earthquake of 2003.

The building vulnerability functions were developed after the Kircher's method and considering the local condition of district 17 of Tehran as the study area. Also the human casualty functions suggested by Hazus were calibrated with the Bam (after event) survey data in order to give more realistic figures. The results of the calibrated human losses with Bam statistics are much more higher and predicts that in the case of the scenario earthquake a five-fold higher number of fatality is expected.

## 5. ACKNOWLEDGEMENT

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