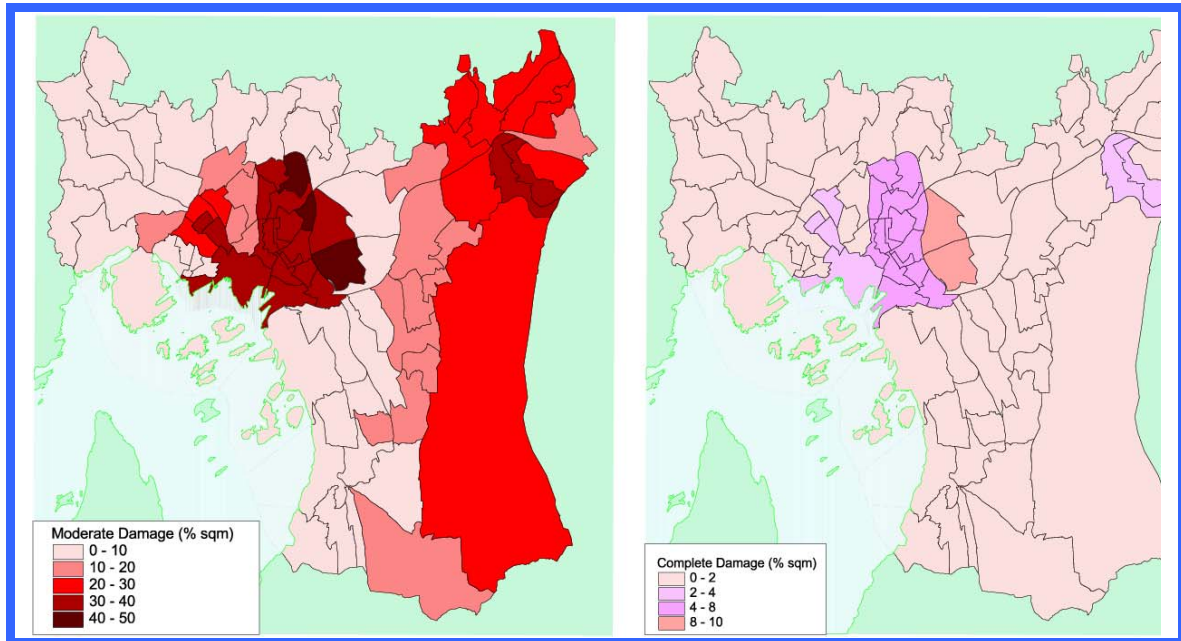


# HAZUSIG v1.0: USER AND TECHNICAL MANUAL



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## 1. INTRODUCTION.

The earthquake loss estimation provides local, state and regional officials with a state-of-the-art decision support tool for estimating future losses from scenario earthquakes. This forecasting capability will enable users to anticipate the consequences of future earthquakes and to develop plans and strategies for reducing risk. The GIS-based software (i.e, Arcview), can be utilized at multiple levels of resolution to graphically show losses results and to prepare response strategies.

Some of the first earthquake loss estimation studies were performed in the early 1970's following the 1971 San Fernando earthquake. These studies put a heavy emphasis on a loss of life, injuries and the ability to provide emergency health care. More recent studies have focused on disruption to roads, telecommunications and other lifeline systems.

With the most recent state of the art in loss estimations studies, the National Institute of Buildings Sciences (NIBS) has developed a tool (HAZUS-MH) for the Federal Emergency Management Agency (FEMA) in order to provide a powerful technique for developing earthquake loss estimates for use in:

- Anticipating the possible nature and scope of the emergency response needed to cope with and earthquake-related disaster,
- Developing plans for recovery and reconstruction following a disaster, and
- Mitigating the possible consequences of earthquakes.

Use of the methodology will generate an estimate of the consequences to a city or region of a “scenario earthquake”, i.e., an earthquake with a specified magnitude and location. The resulting “loss estimate” generally will describe the scale and extent of damage and disruption that may result from a potential earthquake. The following information can be obtained:

- Quantitative estimates of losses in terms of direct costs for repair and replacement of damaged buildings and lifeline system components; direct costs associated with loss of function (e.g. loss of business revenue, relocation costs); casualties; people displaced from residence; quantity of debris; and regional economic impacts.
- Functionality losses in terms of loss-of-function and restoration times for critical facilities such as hospital, and components of transportation and utility lifeline systems and simplified analyses of loss-of-system-function for electrical distribution and potable water systems.
- Extent of induced hazards in terms of fire ignitions and fire spread, exposed population and building value due to potential flooding and locations of hazardous materials.

All the system, methods, and data have been coded into a user-friendly software that operates through a Geographical Information System (GIS) which is called HAZUS-MH.

In a simplified form, the steps followed by the HAZUS methodology are:

1. Select the area to be studied. This may be a city, a county or a group of municipalities.
2. Specify the magnitude and location of the scenario earthquake. In developing the scenario earthquake, considerations should be given to the potential fault locations.
3. Provide additional information describing local soil and geological conditions, if available.
4. Using formulas embedded in HAZUS, probability distributions are computed for damage to different classes of buildings, facilities, and lifeline system components and loss-of-function estimates are made.
5. The damage and functionality information is used to compute estimates of direct economic loss, casualties and shelter needs. In addition, the indirect economic impacts on the regional economy are estimated for the years following the earthquake.
6. An estimate of the number of ignitions and the extent of fire spread is computed. The amount and type of debris are estimated. If an inundation map is provided, exposure to flooding can also be estimated.

The earthquake-related hazards considered by the methodology in evaluating casualties, and resultant losses are collectively referred to as Potential Earth Science Hazards (PESH). Most damage and loss caused by an earthquake is directly or indirectly the result of ground shaking, but also there are other features of earthquakes (fault rupture, liquefaction and landsliding) that can cause permanent ground displacements and have an adverse effect upon structures, roadways, pipelines, and other lifeline structures, which are also considered.

Soil type can have a significant effect on the intensity of ground motion at a particular site. The software contains several options for determining the effect of soil type on ground motions for a given magnitude and location.

Tsunamis and seiches are also earthquake-caused phenomena that can result in inundation or waterfront damage. In the methodology, potential sites of these hazards may be identified but they are evaluated only if special supplemental studies are performed.

The type of buildings and facilities considered are as follows:

General Building Stock: The commercial, industrial and residential buildings in the studied region are not considered individually when calculating losses. Instead, they are grouped together into 36 model building types and 28 occupancy classes and degrees of damage are computed for groups of buildings.

Essential Facilities: They include medical care facilities, emergency response facilities and schools. Specific information is compiled for each building so loss-of-function is evaluated in a building-by-building basis.

Transportation lifeline systems: They include highways, railways, light rail, bus systems, ports, ferry system and airports and they are broken in components such as bridges, stretches of roadway or track, terminal, and port warehouses. Then, damage and losses are computed for each component of each lifeline.

Utility lifeline systems: They include potable water, electric power, waste water, communications, and liquid fuels (oil and gas), are treated in a manner similar to transportation lifelines.

High potential loss facilities: They include dams, nuclear power plants, military installations and damage and losses needs supplemental specific studies to be evaluated.

The downside of these fascinating developments is that it has been so intimately connected to US environments that it has nearly been impossible to apply to the rest of the world.

We have in the present study developed and adapted the HAZUS methodology to greater flexibility and freed the methodology from the ArcGIS “grip”. A logic tree scheme with weighted input of uncertain parameters has been incorporated, and an example of seismic damage scenarios for the city of Oslo have been conducted and submitted for publication.

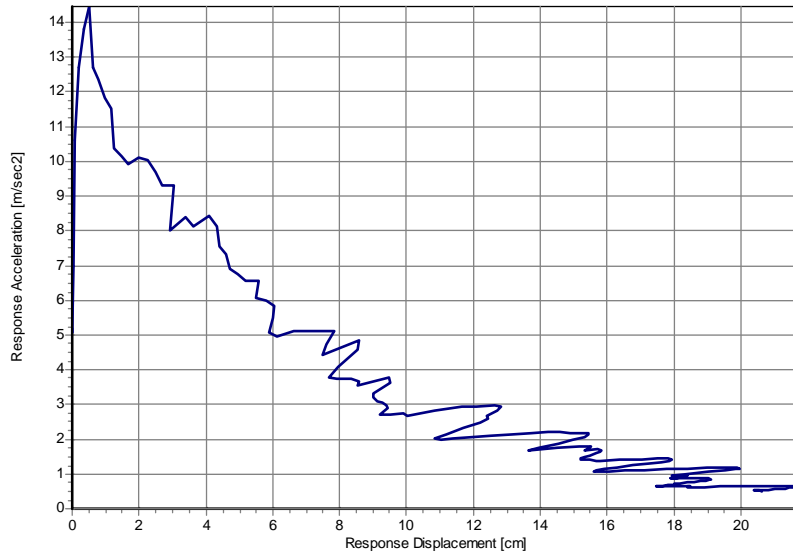
## **2. TECHNICAL DESCRIPTION.**

While the HAZUS approach is attractive from a scientific/technical perspective, the fact that it is tailored so intimately to US situations and specific GIS software makes it difficult to apply in other environments and geographical regions. One goal of the present study was therefore to implement the HAZUS methodology and computation schemes in a different environment, and we have to this side implemented the computational core methodology in MATLAB™. We have also expanded the method into a logic tree scheme so that parameters can be included with weights.

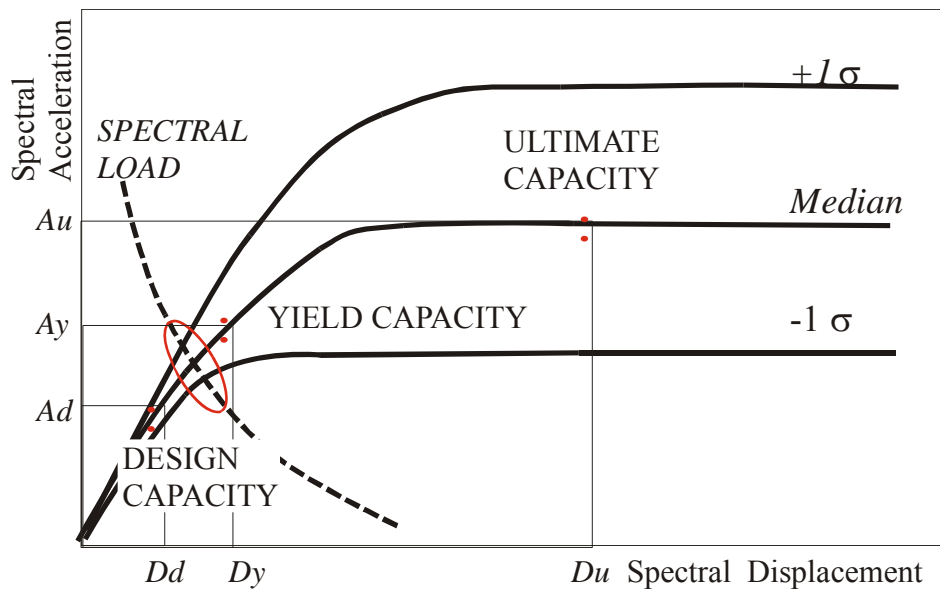
The approach is often called the “capacity-spectrum method”, because it combines the ground motion input in terms of response spectra (spectral acceleration versus spectral displacement as shown in Figure 1) with the building specific capacity curve. The philosophy is that any building is structurally damaged by its permanent displacement, (and not by the acceleration by itself). For each building and building type the inter-story drift (relative drift of the stories in a multi story structure) is a function of the applied lateral force that can be analytically determined and transformed into building capacity curves (capacity to withstand accelerations without permanent displacements). Building capacity curves naturally vary from building type to building type, and also from region to region reflecting on building regulation and local practice. Under the HAZUS umbrella FEMA developed capacity curves for 36 building types in four earthquake load regimes (reflecting the variation in building regulations as function of time across the US). These 144 capacity curves are developed analytically, but adjusted so that empirical knowledge is incorporated in the curves whenever possible. The building capacity curve is defined through three control points: *Design*, *Yield* and *Ultimate* capacity (Figure 2). Up to the yield point, the building capacity curve is assumed to behave elastically linear. From the yield point to the ultimate point, the capacity curve changes from an elastic to a fully plastic state (curved form), and the curve is assumed to remain plastic past the ultimate point (linear form). A bilinear representation (two linear parts) is sometimes used to simplify the model shown in Figure 2. The vulnerability curves (also called fragility curves) are developed as lognormal probability distributions from the capacity curves (Figure 3).

The structural damage states are (as in most other proposed schemes) divided into four damage states, *slight*, *moderate*, *extensive* and *complete*. A detailed description of these

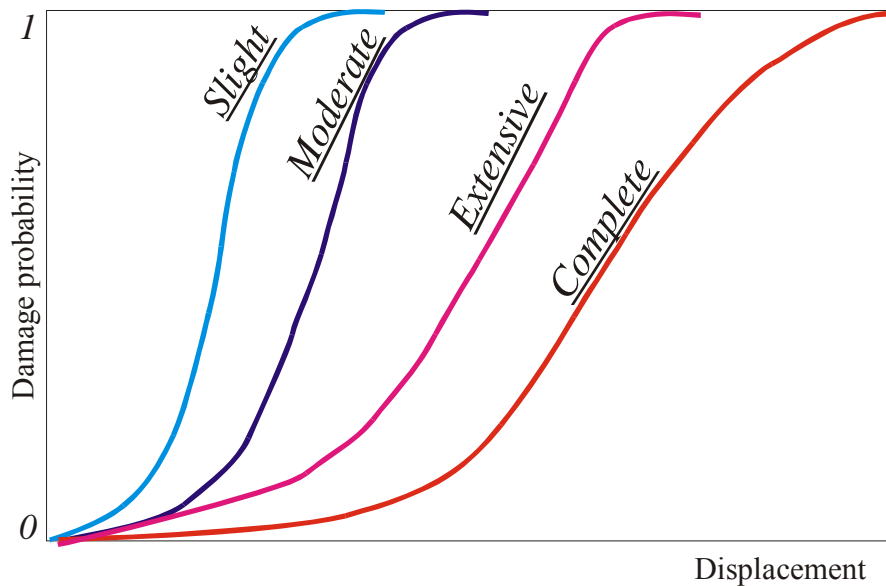
damage states are found many places (Figure 4 show the description for light frame wood buildings).







**Figure 1.** The methodology is based on presenting the ground motion response spectral ordinates (at given damping levels) of acceleration versus spectral displacement. The response spectral values above are relatively smooth because they are computed from a synthetic accelerogram adapted to a piecewise linear response spectrum.



**Figure 2.** The principle of the building specific capacity curve intersected by the load curve



**Figure 3.** The derived vulnerability (or fragility) probability functions.

Damage State		Description
	<b>Slight</b>	Small plaster cracks at corners of door and window openings and wall-ceiling intersections; small cracks in masonry chimneys and masonry veneers. Small cracks are assumed to be visible with a maximum width of less than 1/8 inch (cracks wider than 1/8 inch are referred to as “large” cracks).
	<b>Moderate</b>	Large plaster or gypsum-board cracks at corners of door and window openings; small diagonal cracks across shear wall panels exhibited by small cracks in stucco and gypsum wall panels; large cracks in brick chimneys; toppling of tall masonry chimneys.
	<b>Extensive</b>	Large diagonal cracks across shear wall panels or large cracks at plywood joints; permanent lateral movement of floors and roof; toppling of most brick chimneys; cracks in foundations; splitting of wood sill plates and/or slippage of structure over foundations.
	<b>Complete</b>	Structure may have large permanent lateral displacement or be in imminent danger of collapse due to cripple wall failure or failure of the lateral load resisting system; some structures may slip and fall off the foundation; large foundation cracks. Three percent of the total area of buildings with Complete damage is expected to be collapsed, on average.

**Figure 4.** The four damage states described for light frame wood buildings.

### 2.1 HAZUSICG overview.

The HAZUS methodology covers a wide range of different damage and losses to buildings, lifelines, people, etc. but in this work we only have implemented the first part of the methodology that is, the estimation of damage to the general building stock and providing results in which uncertainties can be easily incorporated so a median value and percentiles can be easily obtained.

In order to apply HAZUSICG some information has to be compiled and properly formatted into input files which will be explained latter.

The most important part (because of its difficulty) is the building database. This information has to be provided by local agencies or governments and as much detailed as possible in order to get an accurate seismic risk scenario. Anyway less detailed information will also provide seismic risk scenarios but with a higher uncertainty.

The building information has to contain as much detail as possible about building materials, building techniques, built area, floors of the building, foundations, seismic regulations used in its construction, use of the building, building dwellers (if human losses are going to be computed), year of construction, etc.

Secondly, the information can be classified according to building type as built square meters in each one of the census tracts which form the region under study or as an individual building if a site-specific study is going to be done.

The building type classification can be done according to HAZUS methodology (see [www.fema.gov/hazus](http://www.fema.gov/hazus) documents or previous HAZUS reports), and then pushover (capacity) curves can be selected from those provided in HAZUS documents or a new building classification can be done and an analytical program as SAP2000 (CSI, 2000) can be used to model the building and to compute the pushover and fragility curves.

In third place, another key point in any seismic risk assessment is the information on ground motion. Currently the HAZUSICG m-script can compute deterministic ground motion scenario from historical or user-provided earthquakes. The ground motion is obtained through two possible attenuation relationships: Ambraseys et al. (1996) and Douglas et al. (2004), both for rock sites. The obtained results needed to estimate the seismic risk using HAZUSICG are the PGA and the spectral acceleration at 0.3 s and 1.0 s all in gravity units. The ground motion is amplified taking into account the soil information provided by the user. Currently the soil amplification factors were taken from the 1997 NEHRP provisions as proposed in HAZUS methodology. On the other hand the user can also provided a probabilistic ground motion scenario, modified by soil amplification, as an input file, as it will be explained later on.

### Amplification of Ground Motion-Local Site Conditions

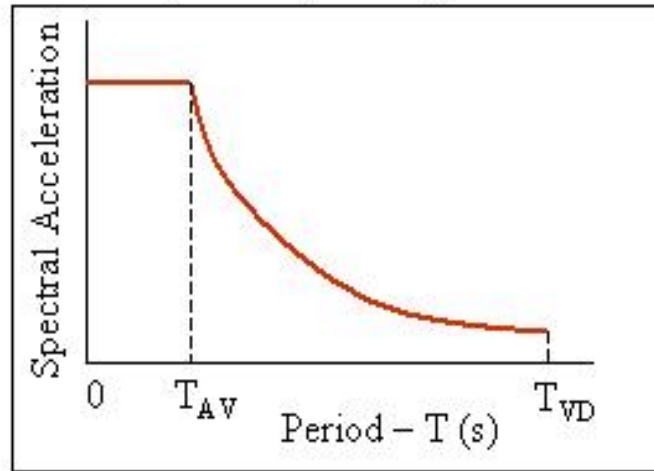
The methodology characterizes ground shaking using a standardized response spectrum shape, which consists of four parts: peak ground acceleration (PGA), a region of constant spectral acceleration at periods from zero seconds to  $T_{AV}$  (seconds), a region of constant spectral velocity at periods from  $T_{AV}$  to  $T_{VD}$  (seconds) and a region of constant spectral displacement for periods of  $T_{VD}$  and beyond (Figure 5).

The region of constant spectral acceleration is defined by  $S_a$  at 0.3 s. The constant spectral velocity region has  $S_a$  proportional to  $1/T$  and is anchored to  $S_a$  at 1.0 s.

$$\begin{aligned}
 S_a(T) &= S_{a@0.3} && \text{if } 0 < T < T_{AV} && \text{(short periods – acceleration domain)} \\
 S_a(T) &= S_{a@1.0} / T && \text{if } T_{AV} < T < T_{VD} && \text{(long periods – velocity domain)} \\
 S_a(T) &= S_{a@1.0} T_{VD} / T^2 && \text{if } T > T_{VD} && \text{(very long periods – displacement domain)}
 \end{aligned}$$



*5% damped response spectrum*



**Figure 5.** Standard Shape of the response spectrum

The period  $T_{AV}$  is based on the intersection of the region of constant spectral acceleration and constant spectral velocity and its value varies depending on the values of spectral acceleration that define these two intersecting regions.

$$T_{AV} = Sa@1.0 / Sa@0.3$$

The constant spectral displacement region has spectral acceleration proportional to  $1 / T^2$  and is anchored to spectral acceleration at the period  $T_{VD}$ , where constant spectral velocity transitions to constant spectral displacement. (Not plotted in Fig. 5).

The period  $T_{VD}$  is based on the reciprocal of the corner frequency,  $f_c$ , which is proportional to stress drop and seismic moment. This frequency is estimated from Joyner & Boore (1988) relationship as a function of moment magnitude, so:

$$T_{VD} = 1 / f_c = 10^{(M-5)/2}$$

where  $M$  is the moment magnitude. When the moment magnitude is not known (probabilistic earthquake scenario), the period  $T_{VD}$  is assumed to be 10 seconds ( $M = 7.0$ ).

Amplification of ground shaking to account for local site conditions is based on the site classes and soil amplification factors proposed for the 1997 NEHRP Provisions. The NEHRP Provisions do not provide soil amplification factors for PGA or PGV. The Methodology amplifies rock (Site Class B) PGA by the same factor as that specified in Table 1 for short period (0.3 s) spectral acceleration, as expressed in the following expression:

$$PGA_i = PGA \cdot FA_i$$

where  $PGA_i$  is PGA for site class  $i$  (in units of  $g$ );  $PGA$  is for site class B (in units of  $g$ ) and  $FA_i$  is the short period amplification factor for site class  $i$ , for spectral acceleration  $SA_S$ . Also, it amplifies rock (Site Class B) PGV by the same factor as that specified in Table 1 for 1.0-second spectral acceleration using the expression:

$$PGV_i = PGV \cdot FV_i$$

where  $PGV_i$  is  $PGV$  for site class  $i$ ;  $PGV$  is for site class B and  $FV_i$  is the short period amplification factor for site class  $i$ , for spectral acceleration  $SA_1$ .

The Construction of Demand Spectra including soil effects are done using the following equation for short periods:

$$SA_{Si} = SA_S \cdot FA_i$$

and the following equation for long periods:

$$SA_{Li} = SA_1 \cdot FV_i$$

and the period,  $T_{AV}$ , which defines the transition period from constant spectral acceleration to constant spectral velocity is a function of site class, as given in the following equation:

$$T_{AVi} = (SA_1 / SA_S) (FV_i / FA_i)$$

where  $SA_{Si}$  is the short-period spectral acceleration for Site Class  $i$  (in units of  $g$ );  $SA_S$  is the short-period spectral acceleration for Site Class B (in units of  $g$ );  $FA_i$  is the short period amplification factor for site class  $i$ , for spectral acceleration  $SA_S$ ;  $SA_{Li}$  is the 1-second period spectral acceleration for Site Class  $i$  (in units of  $g$ );  $SA_1$  is the 1-second period spectral acceleration for Site Class B (in units of  $g$ );  $FV_i$  is the short period amplification factor for site class  $i$ , for spectral acceleration  $SA_1$  and  $T_{AVi}$  is the transition period between constant spectral acceleration and constant spectral velocity for Site Class  $i$  (sec).

Finally the period,  $T_{VD}$ , which defines the transition period from constant spectral velocity to constant spectral displacement is not a function of site class and it is defined by the equation:

$$T_{VD} = 1 / f_c = 10^{[(M-5)/2]}$$

where  $f_c$  is the corner frequency and  $M$  is the moment magnitude, as explained previously.

For evaluation of building damage is better to plot the response spectrum as a function of the spectral displacement (rather than the period). This could be done due to the relation between the different spectral parameters:

$$Sa / \omega = Sv = Sd \omega$$

where  $\omega$  is the circular natural frequency of the oscillator (i.e,  $\omega = 2 \pi f$ , where  $f$  is the frequency in Hz).

**Table 1.** Site amplifications factors provided by NEHRP Provisions. (\*) Values based on judgement by HAZUS developers because they are not provided by NEHRP.

<b>Site Class B Spectral Acceleration</b>	<b>Site Class</b>				
<b>Short-Period, SA<sub>s</sub> (g)</b>	A	B	C	D	E
≤ 0.25	0.8	1.0	1.2	1.6	2.5
(0.25, 0.50]	0.8	1.0	1.2	1.4	1.7
(0.50, 0.75]	0.8	1.0	1.1	1.2	1.2
(0.75, 1.0]	0.8	1.0	1.0	1.1	0.9
> 1.0	0.8	1.0	1.0	1.0	0.8*
<b>1-Second Period, SA<sub>1</sub> (g)</b>					
≤ 0.25	0.8	1.0	1.7	2.4	3.5
(0.1, 0.2]	0.8	1.0	1.6	2.0	3.2
(0.2, 0.3]	0.8	1.0	1.5	1.8	2.8
(0.3, 0.4]	0.8	1.0	1.4	1.6	2.4
> 0.4	0.8	1.0	1.3	1.5	2.0*

The final result of this process in the computation of a 5% damped response spectrum at the center of each census tract (where values of ground motion were computed) or the specific site under study.

#### Damage due to ground shaking

The building response (e.g. peak displacement) is determined by the intersection of the demand spectrum and the building capacity curve. The demand spectrum is based on PESH input spectrum reduced for effective damping (when effective damping exceeds the 5% damping level of the PESH input spectrum).

The elastic response spectra provided as a PESH input apply only to buildings that remains elastic during the entire ground shaking time history and have elastic damping values equal to 5%. This is generally not true on both accounts. Therefore, two modifications are made to elastic response spectra: a) demand spectra are modified for buildings with elastic damping not equal to 5%, and b) demand spectra are modified by the hysteretic energy dissipated by buildings “pushed” beyond their elastic limits. Modifications are represented by reduction factors by which the spectral ordinates are divided to obtain the damped demand spectra. The methodology reduces demand spectra for effective damping greater than 5% based on statistically-based formulas of Newmark and Hall (1982). These relationships estimates elastic response spectra at different damping ratios,  $B$  (expressed as a percentage) and represent all site classes (soil types) distinguishing between domains of constant acceleration and constant velocity. Ratios of these formulas are used to develop an acceleration-domain (short-period) reduction factor,  $R_A$  and a velocity-domain (1-second spectral acceleration) reduction factor,  $R_V$ , for modification of 5%-damped, elastic response spectra. These reduction factors are based on effective damping,  $B_{eff}$ , :

$$R_A = 2.12 / (3.21 - 0.68 \ln (B_{eff} ))$$

$$R_V = 1.65 / (2.31 - 0.41 \ln (B_{eff} ))$$

where  $B_{eff}$  is the effective damping given by the expression:

$$B_{\text{eff}} = B_e + B_h$$

where  $B_e$  is the elastic damping and  $B_h$  is the hysteretic damping, which is a function of the yield and ultimate capacity points (ATC-1996), (see figure 2) as follows:

$$B_h = 63.7 k [A_y/A_u - D_y/D_u]$$

where  $k$  is a degradation factor that defines the effective amount of hysteretic damping as a function of earthquake duration.

$B_e$  is the elastic (pre-yield) damping of the model building type (5% for Mobile Homes-MH, 5%-7% for Steel buildings-S, 7% for Concrete-C and Precast-Concrete buildings-P, 7%-10% for Reinforced Masonry buildings-RM, 10% for UnReinforced Masonry URM and Masonry buildings-M and 10%-15% for Wood buildings-W) following the recommendations of Newmark and Hall (1982).

The methodology recognizes the importance of the duration of ground shaking on building response by reducing the effective damping (i.e.  $\kappa$  factors) as a function of shaking duration. For scenario earthquakes of magnitude  $M \leq 5.5$ , effective damping is based on the assumption of ground shaking of Short duration ( $\kappa=0.80$ ), if the magnitude is  $M \geq 7.5$  the it is assumed a ground shaking of Long duration ( $\kappa=0.40$ ) and for all the other earthquakes it is assumed a ground shaking of Moderate duration ( $\kappa = 0.20$ ).

The new demand spectral acceleration,  $SA(T)$ , in units of acceleration (g) is defined at short periods (acceleration domain), long periods (velocity domain) and very long periods (displacement domain) using the 5% damped response spectrum and dividing by the before mentioned factors following the expressions:

$$\begin{aligned} Sa(T) &= SA_{si} / R_A && \text{if } 0 < T < T_{AVB} \text{ (short periods – acceleration domain)} \\ Sa(T) &= (SA_{li} / T) / R_V && \text{if } T_{AVB} < T < T_{VD} \text{ (long periods – velocity domain)} \\ Sa(T) &= (SA_{li} \cdot T_{VD} / T^2) / RV(B_{TVD}) && \text{if } T > T_{VD} \text{ (very long periods – displ. domain)} \end{aligned}$$

where:

$SA_{si}$ , is the 5% damped, short-period spectral acceleration for site Class  $i$  (in units of g), as defined previously.

$SA_{li}$ , is the 5% damped, 1-second period spectral acceleration for site Class  $i$  (in units of g), as defined previously.

$B_{TVD}$ , is the value of effective damping at the transition period,  $T_{VD}$ .

$T_{AVB}$ , is the transition period between acceleration and velocity domains as a function of the effective damping at this period and it is defined by the equation:

$$T_{AVB} = T_{AVi} ( R_A (B_{TAVB}) / RV (B_{TAVB}) )$$

where:

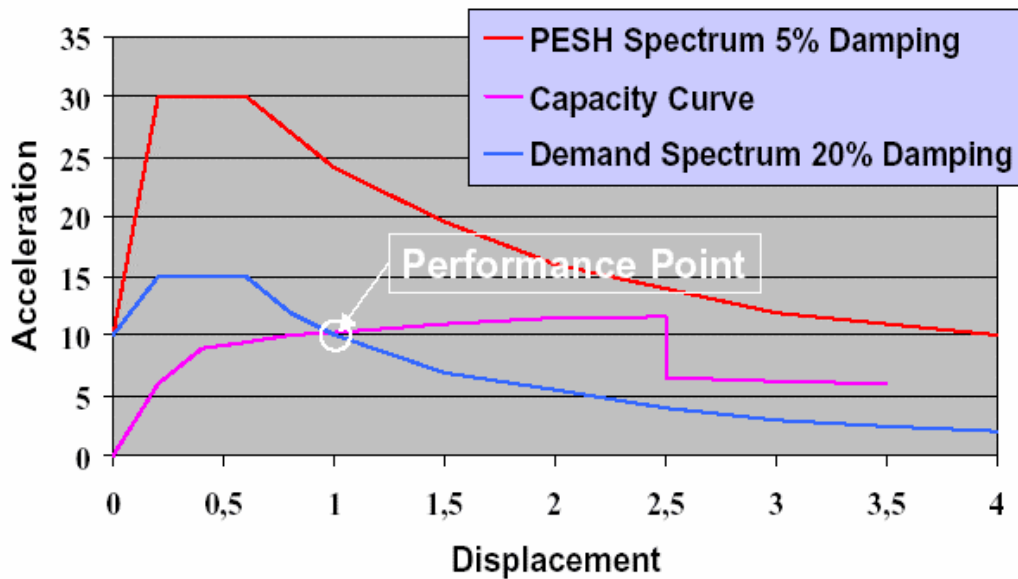
$T_{AVi}$  is the transition period between 5%-damped constant spectral acceleration and 5%-damped constant spectral velocity for Site Class  $i$ , as defined previously.

$B_{TAVB}$  is the value of effective damping at the transition period,  $T_{AVB}$ .

The transition period  $T_{VD}$  is independent of effective damping (only depends of moment magnitude), as previously said.

In summary, the steps for calculating damage state probabilities are the following ones:

1. Calculate the spectral accelerations and spectral displacements at the site in question, taking into account soil response. This is in the form of a response spectrum.
2. Modify the response spectrum to account for the increased damping that occurs at higher levels of building response (non-linear behaviour). Computation of  $B_e$  and  $B_h$  and reduction factors  $R_A$  and  $R_V$ .
3. Create or choose a capacity curve for the model building type which shows how the building responds as a function of the laterally applied earthquake load.
4. Overlay the building capacity curve with the modified response spectrum (demand curve). The building displacement (performance point) is estimated from the intersection of the building capacity curve and the response spectrum (Figure 6).
5. The estimated building displacement is used to interrogate the fragility curve and get the damage probability (Figure 7).



**Figure 6.** Estimation of building displacement from a given PESH input.

The conditional probability of being in, or exceeding, a particular damage state,  $ds$ , given the spectral displacement,  $S_d$ , (or other seismic demand parameter) is defined by:

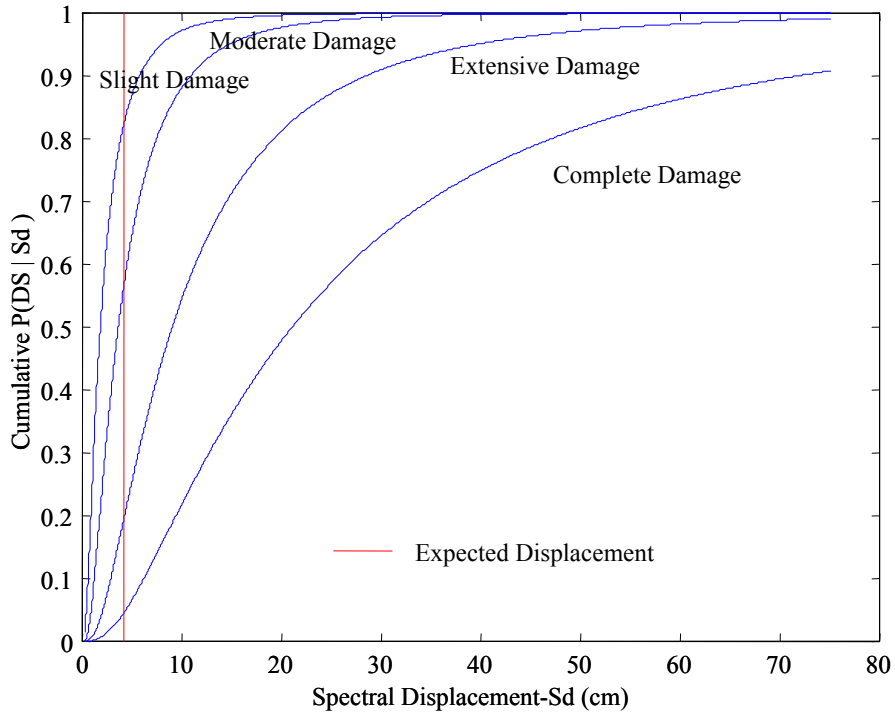
$$P[ds|S_d] = \Phi \left[ \frac{1}{\beta_{ds}} \ln \left( \frac{S_d}{\bar{S}_{d,ds}} \right) \right]$$

where:

$\bar{S}_{d,ds}$  is the median value of spectral displacement at which the building reaches the threshold of damage state, ds,

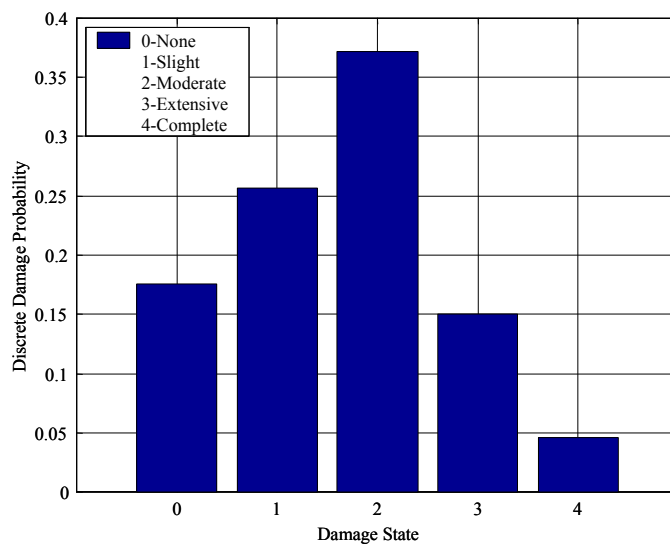
$\beta_{ds}$  is the standard deviation of the natural logarithm of spectral displacement for damage state, ds, and

$\Phi$  is the standard normal cumulative distribution function.



**Figure 7.** The expected displacement (obtained from the performance point) is used to interrogate the fragility curves in order to compute the damage probability in each one of the damage states.

Cumulative probabilities are differenced to obtain discrete probabilities of being in each of the five damage states (Figure 8).



**Figure 8.** Discrete damage probabilities.

Final damage results can be given as percentage of built square meters normalized by the total built area in each census tract or normalized by the total built area in the studied region (summed all census tracts). Also results can be given as percentage of number of buildings normalized by the total buildings in each census tract or normalized by the total number of buildings in the studied region (summed all census tracts).

### **3. THE HAZUSICG M-SCRIPT (v.1.0).**

#### **3.1 HAZUSICG installation.**

The full program is composed of 6 m-script files:

- *Hazusicg.m*: Core file of the software which has to be run under MATLAB 5.3 or higher.
- *Gmotion.m*: Function file which gets the ground motion at the center of each census tract from a deterministic earthquake provided by the user. The attenuation relationships provided are: Ambraseys et al. (1996) and Douglas et al. (2004) for rock sites. The function also computes ground motion amplification for possible plotting. This function is called by *hazusicg.m*.
- *Damagep.m*: Function file which computes the probability of damage for the building stock using the capacity spectrum method (HAZUS methodology). This function is called by *hazusicg.m*.
- *Fitcapcurv.m*: Function file which finds the performance point fitting the capacity curve to an analytical function with the following form:  $y=a*(1-\exp(-x*b))$ . This function is called by *damagep.m*.
- *Squaredam.m*: Function file which computes the percentage of square meters of built area damaged normalized by total built area in each census tract or total built area in all the studied area. This function is called by *damagep.m*.
- *Numdam.m*: Function file which computes the percentage of number of buildings damaged normalized by total number of buildings in each census tract or total number of buildings in all the studied area. This function is called by *damagep.m*.

All these files have to be copied to the folder in which the input data is going to be stored.

The following 5 input files are needed to run HAZUSICG properly:

***Censuscenter.txt***: Input file containing the information about the geographical coordinates of the center of each census tract in which the studied region has been divided. This file also contain a column with the soil type associated to that census tract. Once the shapefiles with all the census tracts has been created in Arcview the center of each census tract is easily obtained using the internal scripts of Arcview.

Example:

% TRACT	LATITUDE	LONGITUDE	SOIL
0100100001	59.91401	10.7187	2
0100100002	59.91562	10.71144	2

In the example file the TRACT column has a string format of 10 characters, because it was obtained to fit HAZUS input files but in the HAZUSICG program can have numerical format (integer). Coordinates have to be provided in geographical coordinates for better representation and latter on Arcview can be used to project the map in other different coordinate system if desired. The soil column has the following code: (Hard Rock: 1; Rock: 2; Very dense soil and soft rock: 3; Stiff Soils: 4 and Soft Soils: 5). The shear wave velocities and descriptions of the different soils are given in the 1997 NEHRP Provisions (FEMA, 1997), Hazus documents and previous HAZUS reports).

**Vulnerability.txt:** Input file containing the information of the different capacity (push-over) curves and its corresponding fragility curve for each one of the different model building types.

Example:

%mbt	dy	ay	du	au	k	be	smedian	sbeta	mmedian	mbeta	emedian	ebeta	cmmedian	cbeta	
1	0.24	0.2	4.32	0.6	0.3	7	0.40	1.01	1.00	1.05	3.09	1.07	7.56	1.06	%W1
2	0.16	0.1	2.35	0.25	0.2	5	0.69	1.04	1.71	0.97	5.29	0.90	12.96	0.99	%W2
3	0.15	0.062	2.75	0.187	0.2	5	1.04	0.85	1.65	0.82	3.50	0.80	8.64	0.95	%S1L
4	0.44	0.039	5.33	0.117	0.2	5	1.73	0.70	2.76	0.75	5.84	0.81	14.40	0.98	%S1M
5	0.16	0.1	1.88	0.2	0.2	5	0.86	1.01	1.38	0.96	3.46	0.88	8.64	0.98	%S2L
6	0.61	0.083	4.85	0.167	0.2	5	1.44	0.73	2.30	0.75	5.76	0.80	14.40	0.98	%S2M
7	0.16	0.1	1.88	0.2	0.2	7	0.43	1.06	0.69	1.03	1.73	1.07	4.73	0.89	%S3
8	0.27	0.067	2.46	0.15	0.2	7	1.15	0.81	1.85	0.80	4.62	0.94	12.60	1.00	%S4M
9	0.12	0.1	1.2	0.2	0.2	10	0.52	1.20	1.04	1.11	2.59	1.08	6.05	0.95	%S5L
10	0.34	0.083	2.27	0.167	0.2	10	0.86	0.85	1.73	0.83	4.32	0.94	10.08	0.99	%S5M
11	0.29	0.052	3.46	0.156	0.2	7	1.20	0.73	1.92	0.77	4.80	0.83	12.00	0.98	%C1M
12	0.26	0.083	2.60	0.208	0.2	7	0.96	0.86	1.83	0.83	4.74	0.80	12.00	0.98	%C2M
13	0.26	0.083	1.95	0.188	0.2	10	0.72	0.90	1.44	0.86	3.60	0.90	8.40	0.96	%C3M
14	0.24	0.2	2.4	0.4	0.2	10	0.32	1.15	0.65	1.19	1.62	1.20	3.78	1.18	%URML
15	0.27	0.111	1.81	0.222	0.2	10	0.50	0.99	1.01	0.97	2.52	0.90	5.88	0.88	%URMM

The first column *mbt* is the index of building type; (*dy*, *ay*) is the yield capacity point in units of inches and g respectively; (*du*, *au*) is the ultimate capacity point in units of inches and g respectively; *be* is the elastic damping in percentage, for each one of the model building types according to the recommendations of Newmark & Hall (1982) for materials at or just below their yield point (explained in the technical description of this report); *smedian* is the median value of spectral displacement at which the building reaches the threshold of the damage state, slight; *sbeta* is the standard deviation of the natural logarithm of spectral displacement of damage state, slight; the next column are the same for damage states: moderate (*mmedian* and *mbeta*), extensive (*emedian* and *ebeta*) and complete (*cmmedian* and *cbeta*). The last column is only a reference to know which model building type correspond to each number.

ATTENTION: In the example file, fragility curves were taken from HAZUS and they were obtained as probability functions in terms of spectral displacement in inches, that's the reason because spectral displacement is given in this file in units of inches. If other units are used in the input file then changes has to be made in the code.



**Header.txt:** Input file containing the needed headers to create the damage output files to be plotted with Arcview.

Example:

```
%CTRA LONGI LATIT SOILT W1N W1S W1M W1E W1C W2N W2S W2M W2E W2C S1LN S1LS S1LM S1LE
S1LC S1MN S1MS S1MM S1ME S1MC S2LN S2LS S2LM S2LE S2LC S2MN S2MS S2MM S2ME S2MC S3N S3S
S3M S3E S3C S4MN S4MS S4MM S4ME S4MC S5LN S5LS S5LM S5LE S5LC S5MN S5MS S5MM S5ME S5MC
C1MN C1MS C1MM C1ME C1MC C2MN C2MS C2MM C2ME C2MC C3MN C3MS C3MM C3ME C3MC URMLN
URMLS URMLM URMLE URMLC URMMN URMMMS URMMM URMME URMMC NUMB
```

It is all one text line with the following labels: The first column *CTRA* is the label for the identification of the census tract; the *LONGI* and *LATIT* are the labels for geographical coordinates of the center of the census tract; the *SOILT* is the label for the soil type in each census tract, the next labels are repeated for each damage state and for each model building type. So if more building types are added then new labels have to be written in the input file. For example, if we have a new model building type called *NB*, then five labels have to be added: *NBN*, *NBS*, *NBM*, *NBE*, *NBC* (for the damage states *N-None*, *S-Slight*, *M-Median*, *E-Extensive* and *C-Complete*). Finally the last label *NUMB* is for a column with an order number.

**Builtarea.txt:** Input file containing the total built area of each model building type (in square meters) for each census tract.

Example:

```
% census W1 W2 S1L S1M S2L S2M S3 S4M S5L S5M C1M C2M C3M URML URMM NONE
1 8964 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 466779 11697 3175 55755 0.0 97850
2 5549 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 356913 0.0 6722 67675 0.0 11551
```

The first column *census* is a number with the order of each census tract and it has to be in the same order that the one given in the file *censuscenter.txt*. The next column has the built area information for each one of the model building types. If more building types are included then more columns has to be added. The last column contains the built area which can not be assigned to any of the model building types because of the lack of information.

This type of input file can be easily obtained through the databases provided by the local agencies using Access or Matlab.

**Numbuild.txt:** : Input file containing the total number of buildings of each model building type for each census tract.

Example:

```
% TRACT W1 W2 S1L S1M S2L S2M S3 S4M S5L S5M C1M C2M C3M URML URMM NONE
0100100001 10 0 0 0 0 0 0 0 0 0 202 1 1 33 0 49
0100100002 10 0 0 0 0 0 0 0 0 0 164 0 1 39 0 29
```

The first column *TRACT* is a number with the order of each census tract and it has to be in the same order that the one given in the file *censuscenter.txt*. The next column has the number of buildings for each one of the model building types. If more building types

are included then more columns have to be added. The last column contains the number of buildings which can not be assigned to any of the model building types because of the lack of information.

This type of input file can be easily obtained through the databases provided by the local agencies using Access or Matlab.

These last two files are not needed at the same time if only one of the damage results are desired.

As a summary, the folder in which HAZUSICG is going to be run should contain all the m-scripts, the input files: *censuscenter.txt*, *vulnerability.txt* and *header.txt* and at least one of the input files: *builtarea.txt* or *numbuild.txt*.

### 3.2 HAZUSICG flowchart.

The HAZUSICG computation can be summarized in the following flowchart (figure 8)

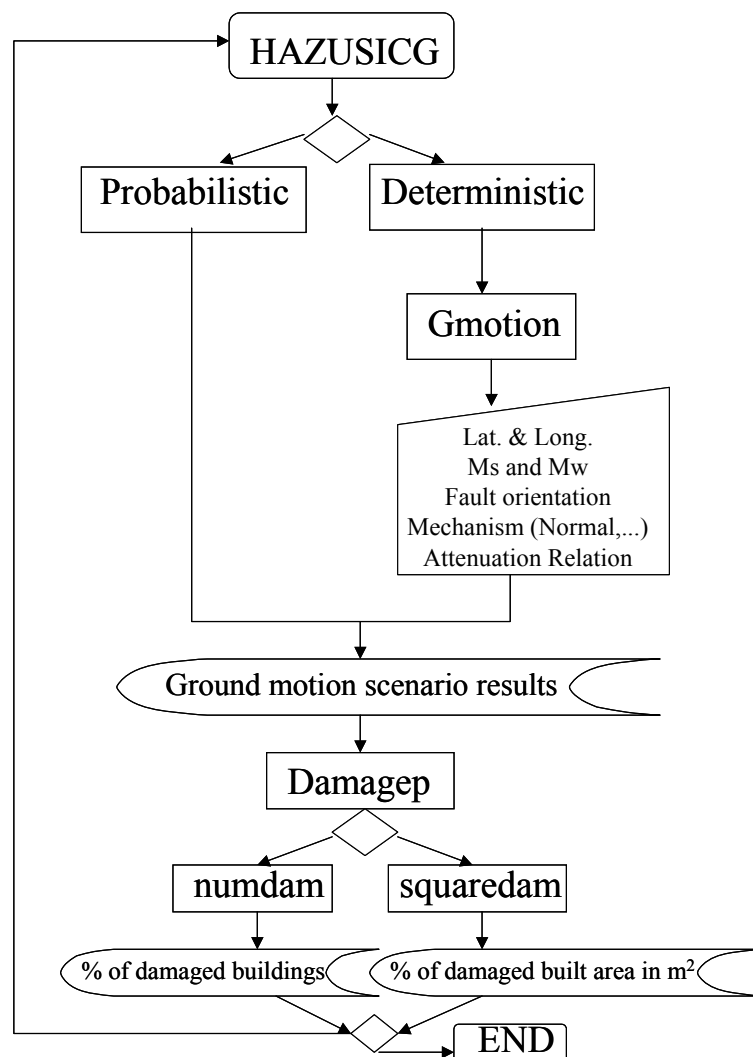


Figure 8. HAZUSICG v. 1.0 flow chart.

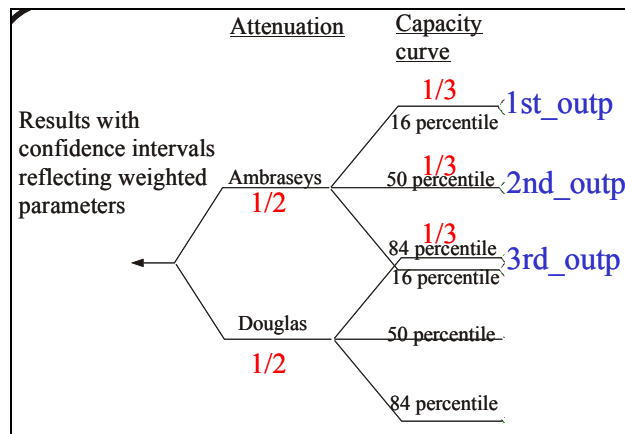
User has to input data from the keyboard in order to compute the ground motion scenario. That is, latitude and longitude of the epicentre, surface wave and moment wave magnitude, fault orientation (degrees from North), Mechanisms (Strike-slip/Normal, Reverse or All, in order to choose one of the Wells & Coppersmith relation (1994) for estimation of surface and subsurface rupture), and the attenuation relationship (Ambraseys et al., 1996 or Douglas et al. 2004, currently implemented).

Also the user will be asked if saving data is desired in some moments of the process and a name for the output file has to be provided.

Finally the user will be asked to end the process or to repeat it again with other parameters.

#### 4. DEALING WITH UNCERTAINTIES.

This part of the software is still developing. Currently, the user can run HAZUSICG several times so different output files are obtained. User has to carefully assign each output file to a logic structure as the shown in Figure 9.



**Figure 9.** Logic tree structure with weights and corresponding output files.

The median value and corresponding percentiles can be easily obtained using Matlab statistical tools taking into consideration that each output files has to be multiplied by their corresponding weights. For example, 1st\_outp has to be multiplied by (1/2) (1/3) and the same with the other output files before obtaining the final result and uncertainties (percentiles).

The ground motion attenuation relationship is easily changed by the user while running HAZUSICG but the capacity curve has to be changed directly in the folder where the input files are stored. The suggestion is to start the analysis copying in the HAZUSICG folder three different input files with capacity curves (i.e., vulnerability\_median.txt; vulnerability\_plussigma.txt; vulnerability\_minussigma.txt) and copy vulnerability\_median as vulnerability.txt, so the first analysis will be runned with the median vulnerability curves. When the user wants to obtain output results with other capacity curves, he has only to copy vulnerability\_plussigma.txt as vulnerability.txt and overwrite the existing file, and run HAZUSICG.

Future version will provide a more flexible and easily way of running the logic tree approach.

## 5. PLOTTING DAMAGE RESULTS IN ARCVIEW

Output files have been prepared so they are easily read with EXCEL. User can import the text file in EXCEL as *delimited format* with *Tab* and *Comma* as delimiters. In some column you will see a  $-1.0$  value, that means that there no data (built are or number of buildings) so the damage has not been computed and a dummy value of  $-1$  has be assigned.

User can now use EXCEL to sum all columns with moderate damage (for example) and get a column with moderate damage for all the building types or sum all columns with moderate damage, extensive damage and complete damage obtaining a column with at least moderate damage for all the building types. In the sum user has to be carefully about the dummy value of  $-1$  in some cells, so a suggestion is to change this dummy value to 0 before summing.

Finally, the files to be plotted in Arcview have to be saved as dbf (Dbase 4) files and they must contain at least the following columns:

%CTRA LONGI LATI othercolumnstobeplotted NUMB

Then user has to run Arcview, create a new project, add a new view, include a theme in the view (for example the theme with Oslo census tracts) and add a table (the dbf file which is going to be plotted).

User has to click, in the view window, in Theme+table so the main table of the oslo census tract is opened. Now in the table window is possible to see two different tables (Attributes of ..., which is tha main table, and output.dbf (for example) which is the output file which is going to be plotted). Both tables should have a common column (maybe with different header but with the same data, for example CTRA or NUMB. Then, user has to click first in the common column of output.dbf (make click in the header of the column) and the has to click in the common column of Attributes of ... (also in the header of the column), in that way it is possible to go to Join both tables using (CTRL+J), and the theme which is currently in the view window will contain all the information of the output results.

User the can make click in THEME+EDIT LEGEND and choose a Legend Type: Graduated Color and choose as Classification Field the column which is going to be plotted. Then user can can make click in START EDITING and SAVE the EDITS AS a new theme file which will be added to the view. Then the process can be repeated for other columns keeping always the original theme without changes.

Probably a GIS expert can simplify this process but for a non-expert user is a easy way of plotting and creating new themes.

The same methodology of plotting can be used to plot results from ground motion.

## **6. SUMMARY AND CONCLUSIONS**

A Matlab-based seismic risk tool has been developed and named HAZUSICG. Obviously this tool is still in development but it can provide damage results for the general building stock of a city or country and also for the essential facilities as schools, hospitals, emergency response facilities, etc. if they have provided as input file (censuscenter.txt where the latitude and the longitude correspond to the location of the facility).

The code has been written so it runs easily with some inputs from the user using the keyboard. Uncertainties are included by running the code several times and changing input parameters, so different output files are obtained which are multiplied by their corresponding probabilities (weights of the branches of the logic tree) and treated with the statistical tools of Matlab to get the median and standard deviation.

The input files are so transparent that they can be easily adjusted to any part of the world, just only taking into consideration the possibility of new model building types with other capacity and fragility curves. That's an advantage with respect to HAZUS which has lower flexibility in terms of non-USA areas and building types.

The m-scripts which form HAZUSICG are commented so user can go through the lines and easily change them if necessary.

Future development will be focused to try to include lifelines and human losses to damage results and also to investigate the possibility of including landslides as a damage agent so earthquake damage and landslide damage can be obtained and combined.

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Finally, an example of application of this methodology has been submitted as a paper to the Journal of Earthquake Engineering (ICG Contribution Number 61) and it will be presented as a poster (ICG Contribution Number 60) in the XXIX General Assembly of the European Seismological Commission (12-17 September, 2004).

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