ISC: SERVING EARTHQUAKE ENGINEER COMMUNITY

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ABSTRACT

The ISC has developed an on-line tool (http://www.isc.ac.uk/mapbuilder/wfs-t/engineer/index.html) to provide a first order approximation of seismicity parameters frequently used in the process of assessing seismic hazard, primarily for engineering applications. Seismicity data are retrieved from the extensive ISC database based on spatial and temporal requirements from the user. Declustering to exclude fore-shocks and after-shocks can be done either through setting of spatial, temporal and magnitude user's requirements at the time of the request. Further procedures are divided in two main steps: data collection and seismicity parameters computation. The Data Collection involves earthquake origin data retrieval from the ISC database, magnitude conversions from the ISC bulletin to Unified Magnitude and display of magnitude frequency relations for total and cumulative number of events. Seismicity parameters a, b, α and β of the Gutenberg-Richter distribution and a peak ground acceleration estimation are computed in the second step.

1. INTRODUCTION

Regional hazard maps are used to evaluate seismic risk for the purposes of planning to build an engineering structure in a specific location. Earthquakes are regarded as one of the most unpredictable, destructive and terrifying of hazards, being responsible for almost 30% of all deaths from natural disasters over the last 30 years (EM-DAT 2008).

Although earthquakes cannot be prevented, modern science and engineering are providing tools that can be used to reduce their effects. Seismologists are now in a position to identify with considerable accuracy where earthquakes are likely to occur and what forces they will generate while engineers offer the design and construction of structures that will withstand these forces.

The calculations for seismic hazard can be quite complex. First, regional geological features have to be analyzed. Seismicity patterns are then examined using newly installed seismic networks and known earthquake locations. Seismotectonic models with zones of similar seismicity potential are drawn. Source potentials are associated to each zone: number of earthquakes per year, relative number of small to large earthquakes (the Gutenberg-Richter b value, Gutenberg 1944), and the maximum size of earthquakes (maximum magnitude). Finally, an attenuation formula that gives the hazard indicators for a given earthquake size and distance is obtained. Peak ground acceleration or velocity is often used whilst for more advanced projects the response spectral ordinates are required.

The Probabilistic Seismic Hazard Analysis (PSHA) method (Cornell 1968) is typically used to integrate over all the zones and produce probability curves for the key ground motion parameter. The final result gives a 'chance' of exceeding a given value over a specified amount of time. Standard building codes for homeowners might be concerned with a 1 in 500 year chance, while nuclear plants look at the 10,000 year time frame. A longer-term seismic history can be obtained through paleoseismology.

Following recommendations of the Global Seismic Hazard map Project (GSHAP, McGuire 1993), the International Seismological Centre (ISC) implemented a new on-line service to provide first order approximations of seismicity parameters which are commonly used in engineering applications using the probabilistic approach. This is consistent with the ISC's general objective of providing new on-line tools using ISC data or showing how these data can be used. This service has no intention to substitute the work done by seismologists in much regional

scale and accuracy, but to complement or provide information by means of the extended seismic database compiled through the years at the centre. The compilation of a uniform seismicity catalogue is done based on the ISC database. Data are selected by choosing a geographic area and time period of interest.
This service is specifically designed to be on-line. Therefore this service ought to fulfill user's expectations of a reasonably fast output. This is why the correct balance between the speed of this service and the accuracy of results had to be found.

Attenuation relations represent ground shaking as a function of earthquake size. Attenuation relations suggested by the GSHAP have been associated to the Flinn-Engdahl seismic regions (Flinn and Engdahl 1965), even though these regions are usually much larger than local seismotectonic areas. Computations of the probability of occurrence are performed following the Cornell (1968) method.

2.- TECHNICAL ON-LINE IMPLEMENTATIONS

One of the main requirements for seismic hazard assessment studies is the choice of the most complete seismic catalogue for the zone of interest. The International Seismological Centre (ISC) is charged with the final collection, analysis and publication of standard earthquake information all over the world. Although many small earthquakes (mb < 3) are not included in the ISC Bulletin, the ISC database contains one of the most complete catalogues of earthquakes currently available (ISC 2001).

Another requirement is careful mapping of the zone to study. Usually seismic hazard studies are focused on zones within 100 to 300 kilometers of a specific point of interest. Mapping such zones is always a time consuming task. This innovative on-line service provides a new tool which can assess in the process of describing a main zone and several sub-zones of interest when their coordinates are not well known.

The Web Feature Service (WFS) interactive map provides a visual display of one or more data layers. Users can view layers containing different types of data, adding reference information such as continents, rivers, political boundaries, general geology, significant earthquakes and tsunamis, all known active volcanoes and main tectonic plates if desired. General features like zoom, pan, identify, search, find and various drawing capabilities are also available.

These maps may contain large graphics and may take a long time to load, especially when slow a internet connection is used. They also require current browsers with JavaScript enabled. MapBuilder (mapbuilder 2007) is an open source project that implements framework dynamic web page content from XML documents. The techniques used by this package are now being called AJAX which is shorthand for Asynchronous JavaScript + XML.

Mapbuilder consists of a JavaScript library that implements the Model-View-Controller (MVC) design pattern. It was originally conceived to render Web Map Context documents to create interactive mapping applications on the web. However the modular design framework allows Mapbuilder to be extended to handle almost any XML document type.

The WFS allows interaction with web remote servers and displays different kind of maps in an XML configuration. The most relevant WFS capabilities available for the seismology community are displayed and constantly updated.

Again, a balance between the speed of this service and the accuracy of presented data is observed. A typical case is the layer called Significant Earthquakes. It only represents those events with magnitudes bigger than 6.0 for the last 30 years compiled from the NOAA Satellite and Information Service, without narrowing down the number of events the time necessary to load all existent information would be unbearable for the user.

3.- DATA COLLECTION

3.1.- Preliminary Data

The area of interest has to be delimited using the map tools shown in *Figure 1a*. Detailed instructions describing the required course of action are given throughout the process.

The preliminary map can be populated with either revised ISC/ISS solutions or solutions that ISC considers primary. The selection of the former leads to a lower number of events for computations on magnitudes and seismic parameters, but with the ISC guarantee of data consistency. The latter involves magnitudes reported to the ISC that have not been checked by seismologists with their consequent lack of consistency among values. If necessary a file with all the information related to location, magnitudes and magnitude heritage can be downloaded.

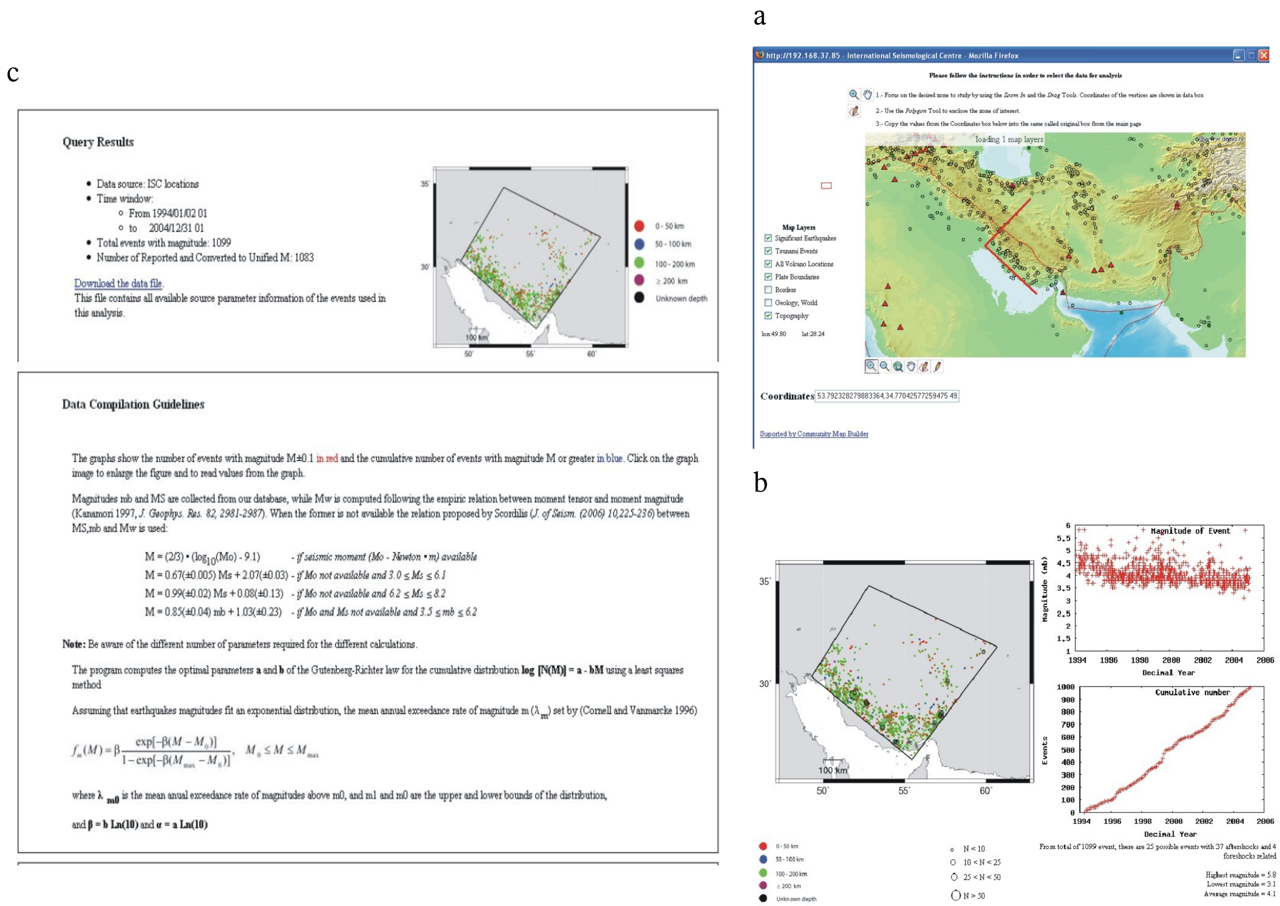


Figure 1: Complex or simple zones can be drawn using this service. a) Here an example of the main features of mapbuilder than can be used when plotting a zone or polygon. b) Results of loading preliminary data into the area are shown with possible related shocks. Magnitude and cumulative number of events per year are shown to identify possible shocks series. c) Final results of compiled data are shown on the next page with some general headlines and an explanation of the methods used in the service to perform the calculations.

Other useful information can be displayed (*Figure 1b*) in addition to the map with collected events. Time lines of magnitude and cumulative number of events will be presented as they are useful tools to visually recognize patterns of shocks. The number of main events and detected possible aftershocks or foreshocks will also be shown if the declustering boxes have been filled.

3.2.- Declustering

It is important for seismic hazards studies to be able to analyze background seismicity free from aftershocks and/or foreshocks. Such lists of events are called declustered catalogues. At the moment a simple time-window declustering method can be used, relaying on the user's knowledge of the area of study. A minimum magnitude for the possible main-shocks is required so that individual earthquakes can be identified as mainshocks and part of future kernel (*Figure 1b*). These events will be compared within a suggested time window and clustering distance with all other available events. Depending on the dimensions of the study zone these are critical factors to link the adequate shocks to the main events.

Although the distance and time windows may vary with magnitude and place, the chosen values are arbitrary and related to the seismotectonic characteristics of the zone, which for a basic evaluation can be considered similar if the zone is reasonably homogeneous.

Foreshocks and aftershocks will be removed from further computations although accessible through the downloadable file or a list compiled at the end of the calculations together with the more relevant hazard parameters. The declustering process can be avoided by leaving the boxes empty.

We are working on a global catalogue of declustered events based on the single link clustering (SLC) method (Frohlich and Davis 1990). This is a fast straightforward method used to quantify the degree of clustering or isolation of groups of elements in a set of earthquakes. The SLC procedure connects elements of a measured metric and then removes all the edges longer than a certain distance d_0. This metric does not depend on magnitude and is invariant under shifts in space and time. Although the SLC method can be integrally equal to the time window one, it is unable to work equally for different ranges of mainshock magnitudes (Molchan and Dmitrieva 1992).

3.3.- Unified Magnitude

To compute the Unified Magnitude M, magnitudes mb, MS and M_0 are collected from our database and then converted following the empiric relation between moment tensor and moment magnitude (Kanamori 1997) for M_0 and relations proposed by Scordilis (2006) for MS and mb (Table I, *Figure 1c*).

Regional geo-tectonic conditions can substantially affect these relations. To avoid this problem and improve the quality of the service we are working on regional magnitude relations for the Unified Magnitude based on ISC data, where M_L (local magnitude) will be included.

Table I: Unified Magnitude conversion from seismic moment (M_0), surface magnitude (MS) and unified body magnitude (mb).

Moment magnitude	Condition
M = (2/3) • (log10(Mo) - 9.1)	- *if seismic moment (Mo - Newton • m) available*
M = 0.67(±0.005) Ms + 2.07(±0.03)	- *if Mo not available and 3.0 ≤ Ms ≤ 6.1*
M = 0.99(±0.02) Ms + 0.08(±0.13)	- *if Mo not available and 6.2 ≤ Ms ≤ 8.2*
M = 0.85(±0.04) mb + 1.03(±0.23)	- *if Mo and Ms not available and 3.5 ≤ mb ≤ 6.2*

3.4.- Magnitude of completeness

The magnitude of completeness (M_C) is defined as the lowest magnitude at which 100% of the events in a space-time volume are detected (Rydelek and Sacks, 1989). Below this magnitude a fraction of events is missed by the network because they are either too small to be recorded by the necessary 3-4 stations, or because they are below the magnitude of interest or because they are mixed with the coda of a larger event and therefore remained undetected. M_C can vary from over 5, for places with poor local seismograph coverage, down to magnitude 1 in places with good network coverage. In practice M_C varies with time, and this must be considered in the earthquake magnitude recurrence calculation. The minimum considered magnitude (M_{min}) as used in the Cornell method is the smallest earthquake that will be used in the hazard integration, and depends on the structure being considered (e.g. magnitude 5.0 or larger for a large dam, and possibly magnitude 4.0 or less for a general building code for houses).

The choice of a minimum magnitude earthquake used in the ground motion recurrence computation is based on engineering or risk mitigation considerations and may significantly affect the results of a hazard study when small, non-damaging earthquakes are considered (Gibson and Brown 1999).

Completeness is an important parameter for seismicity analysis. No *a priori* assumptions regarding the completeness have been applied to the ISC's catalogue, although a basic analysis is performed based on the Maximum Curvature method (Woessner and Wiemer 2005). This method estimates M_C as the point of maximum curvature (MAXC) for the magnitude of completeness by computing the value of the first derivate of the frequency-magnitude curve and assigning M_C to that data point where the derivate is maximum (Figure 3). This is a fast and reliable methodology, although the value of M_C tends to be underestimated.

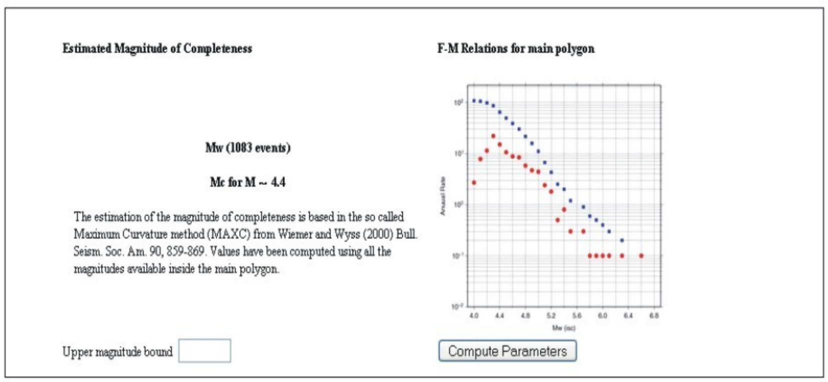


Figure 3: Frequency-magnitude relation and the estimation of magnitude of completeness according to the MAXC (Woessner and Wiemer 2005) for this set of data. The upper bound magnitude allows the user to make a first order approximation of a mean annual exceedance rate of magnitudes above M_C together with the main seismic parameters

4.- DATA ANALYSIS AND RESULTS

4.1.- b-value and seismic parameters

A compiled list of events with their parametric location data, declustering flag and unified magnitude is a desired starting point for most studies. Such list of events is presented with their main hypocentral parameters, unified magnitude and declustering results if available on the results page.

This on-line service aims to be useful to the widest possible range of users and therefore also offers estimation of b-value or peak ground acceleration (PGA) based on the selected data set.

Most of the probabilistic seismic hazard assessment calculations are done following Cornell (1968) method. This method assumes that earthquakes follow a Poisson process and are distributed uniformly within several specific areas delimited by the analyst. The relationship for the incremental function used (i.e., for magnitudes M±0.1), is known as the Guttenberg-Richter relationship. This relationship is log-linear from a threshold magnitude (M_{min}) onwards. M_{min} is often recognized as the lowest magnitude for which the data set is considered to be complete or, as described above, M_C.

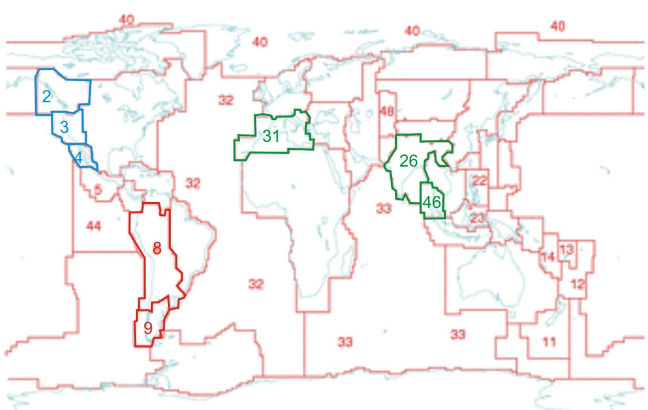
This linearity of the dataset is better observed on the cumulative distribution (*Figure 3*). Submitting the maximum magnitude believed to be possible in the analyzed region, a mean annual exceedance rate of magnitudes above Mc (α) can be estimated. Parameters a, b are computed adjusting the cumulative frequency-magnitude through least square method. Each cumulative value is weighted according to a simple frequency analysis based on Mc.

4.2.- Attenuation relations and PGA

Based on GSHAP and the main seismic region of the area of study we will suggest some attenuation functions. Combining these functions and the parameters obtained from fitting the data, peak horizontal ground acceleration estimation (PGA) will be represented.

Peak ground acceleration and displacement are fairly good indicators of the response of structures possessing respectively very high and very small natural frequencies. Peak velocity is correlated with the response of intermediate-period systems, but the correlation is less precise than that tying the former parameters; hence, it is natural to formulate seismic risk evaluation and engineering design criteria in terms of spectral ordinates.

We have collected around 20 attenuation relationships applicable in various regions distributed around the world. This collection is constantly being updated. *Figure 4* compares several of them used by this procedure.



Seismic Region	Att. Relationship
2,3,4	Boore et al 1997
8,9	Sadigh et al 1997
26,31,46	Joyner and Boore 1981

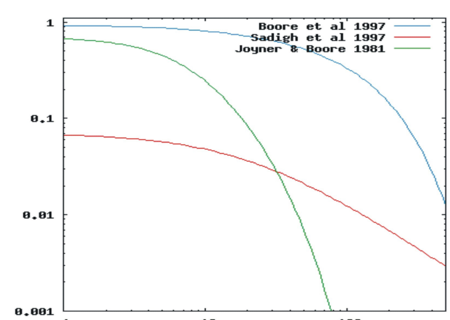


Figure 5: Example of possible attenuation relationship in the engineering service depending on the seismological region where the map has been centered.

5.- CONCLUSIONS

Results of the processing described above can be divided in two main blocks.

a) Seismic hazard data for seismologists: At the end of the data collection there is a list of all the events selected for the area of interest. This list compiles the main parameters required for a seismic hazard study: location of the event, location errors and location related parameters, magnitude and magnitude heritage, declustering and unified magnitude. Original values are also available in the downloadable file.

b) First order approximation parameters for engineering applications: The service also provides a first order approximation of the seismic hazard parameters: b-value, parameters α, β, quality factor and the regression coefficient of the fitting procedure. If the upper bound magnitude has been introduced, a mean annual exceedance rate of magnitudes above Mc will also be estimated. This same value will be used to plot the PGA function and if not available the maximum value determined from the Guttenberg-Richter relation will be used.

This is a new, fast and easy to use method to estimate seismic parameters for engineering applications based on a probabilistic method has been developed. It is just a complementary tool for more accurate and thoughtful studies performed by seismologists and engineers. The main purpose is to show the process of evaluating a seismic hazard assessment using the ISC extended database of events, and to provide a first order approximation of the main seismic parameters used in engineering purposes.

This is a dynamic service and is in constant development. New features will be introduced in the near future making the service more appealing for a wider range of users.

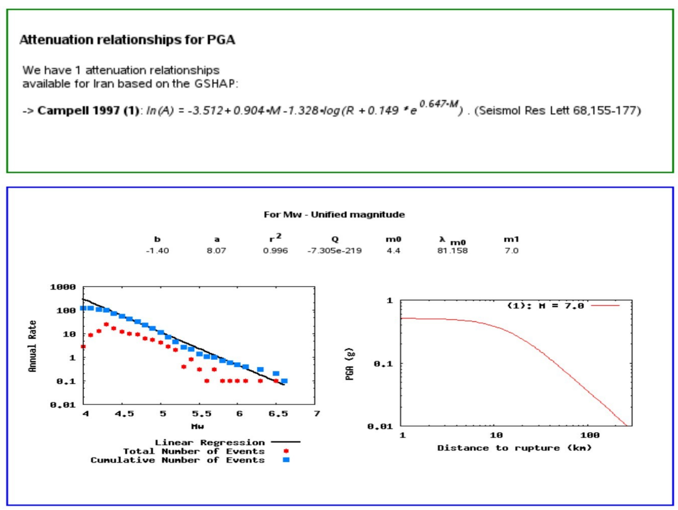


Figure 5: Results of the b-value and PGA computations. a) Description of the formulae of the attenuation relation used. b) b-value α, β and quality parameters for the weighted least square fit of the frequency-magnitude relations and graphical representations of the F-M relation and PGA values.

Efforts are made to create new and better capabilities, e.g.: a world-wide declustered catalogue where main, after and foreshocks could be identified; regional magnitude relationships to produce more accurate values of Unified Magnitudes; time windowed assessment, so the same parameters can be compared between periods of time and response spectra ordinates and more up to date attenuation functions are to be included.

The service accounts for many possible options providing different sorts of information and data related to ISC Catalogue: simple declustering method; magnitudes mb, MS and Mw conversion to Unified Magnitude; magnitude of completeness estimation; attenuation relationships according to GSHAP and first order approximation of seismicity parameters for engineer applications

Testing and comparing results for different zones with published studies has to be done yet so that the uncertainties and accuracy of results can be evaluated.

The long term objective is to make this ISC service a reliable user friendly tool to estimate and overview alternative seismic hazard results.

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