Development of A GIS Interface for Seismic Hazard Assessment

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By

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ABSTRACT

This thesis introduces a method to design a user interface for Ilwis using Visual Basic for seismic hazard assessment. In most cases, either numerical program such as FRISK, SEISRISK, or GIS package is used for the seismic hazard assessment. One of the problem resulted is either large amount of spatial data, which are highly valuable for seismic hazard assessment, could not be fully incorporated, or the sophisticated numerical methods for seismic hazard assessment have to be abandoned in GIS environment.

The aimed low-cost, user-friendly Ilwis/Visual Basic application in this study has certain advantages. First, it provides both good numerical calculation and good spatial analysis capabilities. Second, the user interface encapsulates procedures that make some of the operations automatically done. Third, a user interface is easier to handle, thus it improves efficiency. Fourth, the user interface can be flexible to accommodating different needs and different data availabilities. Therefore, it is more useful than the Ilwis scripts and the user can select some of the parameters without difficulties associated with subsequent changes that have to be made manually.

As a first step towards an Ilwis/Visual Basic application for seismic hazard assessment, a simple Ilwis/Visual Basic application was designed without considering the soil condition and topographic effects. This application can perform ground motion calculation with two deterministic methods and one probabilistic method. Each of the method as well as their realization is explained in the thesis. The deterministic methods need more human decisions to be made compared with the probabilistic method. The simplified probabilistic method does not adopted the sophisticated models in order to make it be realized easily, but it is still good enough as far as to prove validity and feasibility of such an approach for seismic hazard assessment is concerned.

Some suggestions for further improvement of the user interface are also given. For a practical application using the similar method, it must be improved to produce better results.

Some technical problems and their solution in programming are discussed, too. First of all, it is necessary to use the created 'mission' file to manage the steps of seismic hazard assessment, so that the results got from different steps can be linked together for further analysis later. Some examples to carry out Ilwis operation using DDE are given. But, over all, Visual Basic is suitable to program for the Ilwis/Visual Basic application.

Key words: seismic hazard, Ilwis, Visual Basic, GIS interface, ground motion

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1.1 Earthquake hazard and earthquake hazard in developing countries

Earthquakes, though rare event, are increasingly costly and dangerous. The increasing urbanization worldwide makes the seismic risk even serious than before. Of the 50 largest cities in the world with half having populations over 10 million, half of them lie within 200 kilometres of faults known to produce earthquakes of magnitude 7 or greater. A global seismic hazard map is shown as Fig 1.1. It can be seen that around half part of the world is under seismic hazard at different levels.

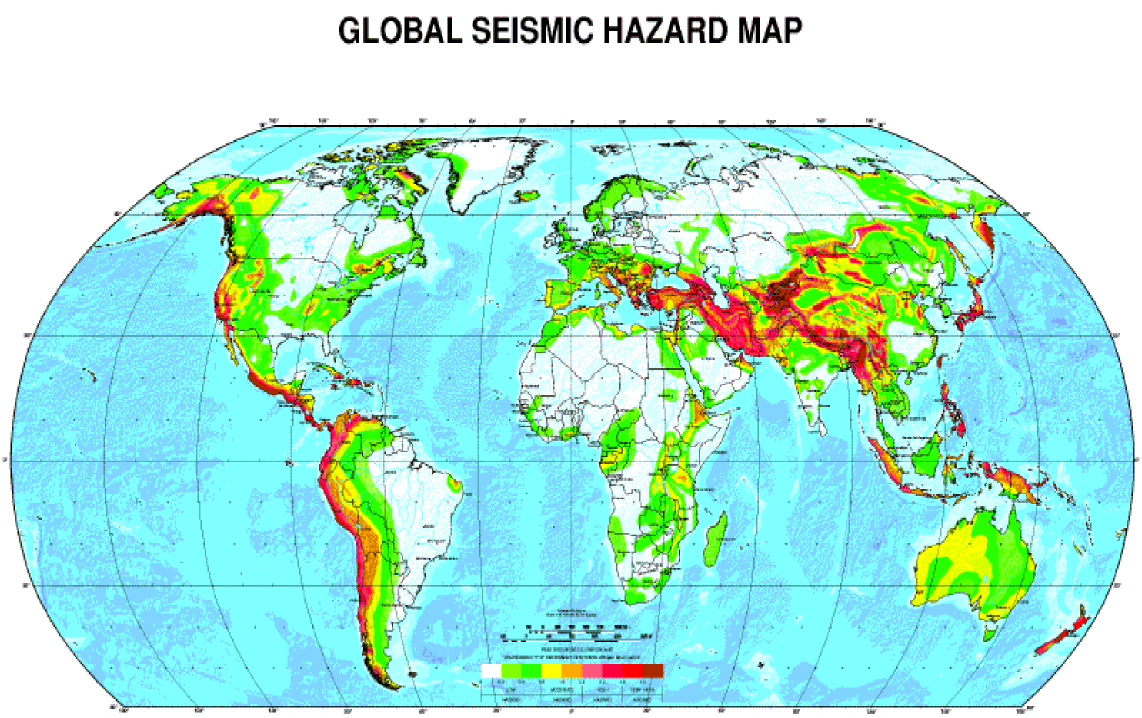

Figure 1.1 Global Seismic hazard map (Global Seismic Hazard Assessment Program, GSHAP, 1999)

While the seismic risk reduction in developed countries improved rapidly at high expense, the situation in most of the developing countries is somewhat disappointing. Due to lack of proper Geoinformation data and long-term-interest management, small and medium-size cities in developing countries have often caught in severe human sufferings as we saw in India and Central America in recent years.

1.2. GIS application and limitations

GIS application now is considered to be a useful tool for various natural hazard reduction studies. GIS is powerful for seismic hazard study, too. With it spatial representation and analysis utilities, it is much easier to explore and present a problem concerned with seismic hazard and risk reduction.

Furthermore, now more and more data are collected in forms, which can only be fully used within GIS. In this sense, the application of GIS is not only important but also inevitable. Evidently, more and more seismic hazard professionals would prefer to use GIS to improve their study.

However, GIS has some limitations when it comes to a systematic approach for seismic hazard and risk reduction study. There are numerous cases that many of the numerical analytical method now widely adopted are not convenient to be done with GIS. On the other hand, programs designed with many popular programming platforms are much better on this aspect.

Apart from the two points mentioned, GIS applications often require higher professional skills and also incur higher costs. This may not be a serious problem for developed country, but it may well daunt the small and middle-sized cities in developing countries to do so. Therefore, there is still the need to provide an easy user GIS interface at low cost.

1.3. Challenges for a user-friendly and low-cost GIS application

As an important part of effective and public-awareness-evoking seismic risk reduction, the development of suitable GIS-based techniques for seismic hazard assessment will help both decision makers and the public know where and how to deal with the seismic risk more efficiently. As a tentative study, a GIS interface for seismic hazard assessment will be designed for this purpose.

The challenges for such a GIS interface development are:

1) It should be user-friendly and efficient.
2) It should be flexible to meet the different needs and available data.
3) It should provide better performance for both spatial and non-spatial data analysis to make the interface powerful.
4) It is should enlighten the similar work at an advanced level.

1.4. Objectives

The proposed study tries to meet the challenges, though it may not be able to fulfil all the tasks with this study alone. It aims to establish a suitable and reliable GIS interface for seismic hazard assessment.

The overall objective is to develop a practical method with certain flexibility for seismic hazard assessment using GIS and design an Ilwis/Visual Basic application that will apply the method.

The objectives of the study can be summarized as the following:

1) Develop method for input data standardization for seismic hazard assessment

Mainly, data pre-processing in order to use data from different sources and make automatic processing possible in Ilwis.

2) Develop A GIS based method for seismic hazard assessment
   2.1 PGA calculation using deterministic methods
   2.2 PGA calculation using probabilistic method

3) Design of an Ilwis/Visual Basic application for implementation of developed methods
   3.1 Realization of Ilwis operation with easy-going interface using DDE
   3.2 Visual Basic components for auxiliary analysis that is difficult to be handled by GIS.

Obviously, although many good methods for seismic hazard have been developed, it is another thing if we try to make them workable in GIS and particular for the medium-sized cities in developing countries. Not only the complicated models will be beyond capacity of most GIS packages, but also the numerous parameters and constants required will by no means to be procured for the whole area. Hence, practical and proper ways to tackle the unique problems are essential.

Chapter 2. Literature Study

2.1. Important Terms

First of all, a summary is given for the most often used definitions on the seismic hazard and seismic risk (revised after Finn, 1994):

Seismic hazard (H) means the probability of occurrence within a specified period of time and a given area of a potentially damaging earthquake or level of ground shaking.

$$H = F(P \mid H) \qquad (2\text{-}1)$$

Vulnerability (V) means the degree of loss to a given element or set of elements at risk resulting from the occurrence of a specific seismic hazard. It is expressed on a scale from 0 (no damage) to 1 (total loss). It is a function of the seismic hazard intensity and the types of element at risk (e.g., type of structure and number of floors for building.)

$$V = F(E_i, H_i) \qquad (2\text{-}2)$$

Where E_i and H_i are respectively certain element or elements at risk and a specific seismic hazard.

Specific risk (R_s) means the expected degree of loss due to the specified seismic hazard. It may be expressed as the product of probability of hazard, H, V and repair/replacement cost of element at risk.

$$R_s = P_{H_s} * V * f(E) \qquad (2\text{-}3)$$

Where P_{H_s} is the probability of specific seismic hazard, V is the vulnerability and $f(E)$ is the repair/replacement-associated cost.

Elements at risk (E) mean the objects, which are threatened by a hazardous event. It can mean population, number of buildings or any other collection of entities for which loss can be calculated and are concerned.

Total risk (R_t) means the total expected number of lives lost, persons injured, damage to property, or disruption of economic activity in an event. It is the sum of all the specified risk (R_s) of all the elements at risk of all specific seismic hazards. Thus

$$R_t = \sum_{j=1}^{m}\sum_{i=1}^{n}(R_{si})_j = \sum_{j=1}^{m}\sum_{i=1}^{n}[P_{H_s} * V * f(E_i)]_j \qquad (2\text{-}4)$$

Where the inner summation is the total of specific risk of all elements at risk under certain specific seismic hazard while the outer summation is the total risk resulted from all seismic hazards.

Seismic zonation is the generic name for the procedure of subdividing a region into sectors with identical, or at least similar, behavior of relevant parameters of seismic hazard (Mater, Jiménez, 2000). It is often divided into microzonation and macrozonation. ***Seismic Macrozonation*** is the seismic zonation at a regional level, which based on seismogenic evidences and active tectonic etc. ***Seismic Microzonation*** is the finer and more detailed geographical and quantitative subdivision of a general zonation map. It takes into account the soil condition, topographical amplification etc. for a more precise indication of the seismic hazard (Mater, Jiménez, 2000). The area covered in microzonation ranges from a municipality to a site.

2.2. Seismic risk assessment and seismic hazard assessment

Seismic risk assessment is to evaluate the expected loss from certain earthquake scenario and thus help with risk reduction and urban planning and. The information coming from seismic risk assessment reveals how serious the risk is and provides information considering how to prepare and mitigation the seismic risk, which, especially in term of investment and loss reduced, is vital for decision maker to have very reliable seismic risk assessment results.

Seismic hazard assessment is the first step in the evaluation of the seismic risk, which is obtained by combining the seismic hazard with local site effects (anomalous amplifications tied to soil conditions, local geology and topography) and with the vulnerability factors (type, value and age of buildings and infrastructures, population density, land use, date and time of the day.) (Giardini, 1999).

Fig 2.1 shows the flowchart of seismic risk assessment. Since seismic hazard is the basic input for analysis of seismic risk assessment, it is the foundation of all other work and therefore, determines the reliability of the whole work.

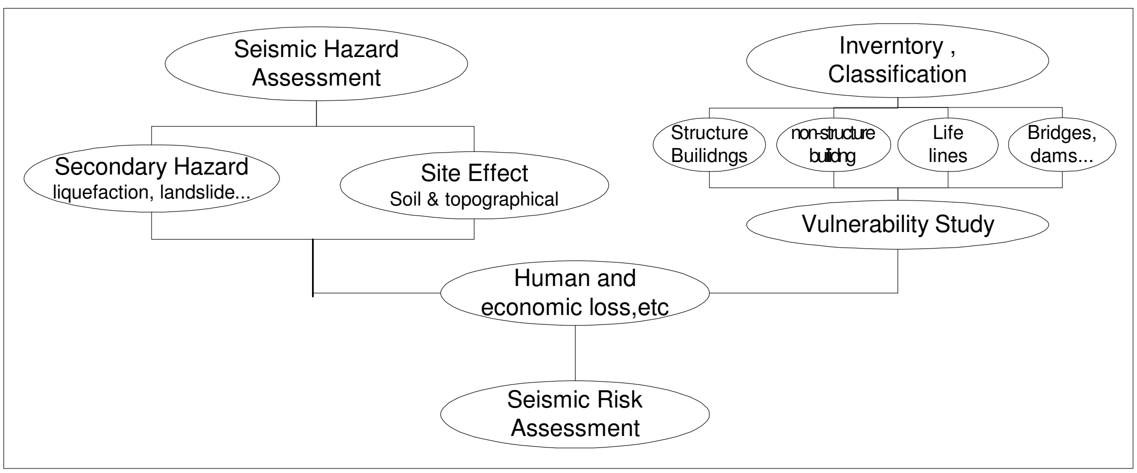

Figure 2.1 A simple flowchart for seismic risk assessment

Thus seismic hazard assessment is to provide information on seismic hazard with either a deterministic or probabilistic approach for certain site or for a large area. The measurement mostly used for seismic hazard are MMI (Intensity modified Mercalli intensity), PGA (peak ground acceleration), PGV(peak ground velocity), SA (spectral acceleration), or response spectrum. The output can be a value, a map or a hazard curve.

Seismic hazard study covers a wide range of topics and also has various methods to be adopted. Generally, the methods for seismic hazard study can be classified into two categories: deterministic methods and probabilistic methods.

Deterministic methods are based on earthquake scenarios and do not consider the probability of seismic hazard explicitly, though sometimes the determination of seismic hazard more or less related to probability. The deterministic methods calculate the expected maximum values of ground motion on seismogenic potential basis at the investigation point surroundings. The results provided by deterministic method do not reflect the probability of the seismic hazard that will be expected in the future rather than the maximum seismic hazard is estimated based on seismogenic and seismotectonic evidences or earthquake records with deliberation.

The work scheme for a deterministic hazard study consists of:

- Seismotectonic/seismogenic study of the area based on the hazardous seismogenic faults and other evidences such as historical records.
- Estimation of the maximum breaking dimension of the fault found or intensity.
- Calculation of the expected ground motion at the site.

The probabilistic methods, however, deal with both the level of seismic hazard and probability of such a seismic hazard level expected within certain period. Probabilistic methods calculate values of ground motion specifying the probability in which they can or cannot be overcome in a given time period. Probabilistic methods now are widely accepted by professionals as a better-informed method for seismic study, they are also known as PSHA (probabilistic seismic hazard analysis).

The basic elements of modern PSHA seismic hazard assessment can be grouped into four main categories (Cornell, 1968):

- Earthquake catalogues.
- Seismotectonics and earthquake source zones: the creation of a master seismic source model to explain the spatial-temporal seismology; mapping of active faults, geodetic estimates of crustal deformation, remote sensing and geodynamic models to constrain the earthquake cyclicity in different tectonic provinces.
- Strong seismic ground motion: the evaluation of ground shaking as function of earthquake size and distance, taking into account propagation effects in different tectonic and structural environments and using direct measures of the damage caused by the earthquake (the seismic intensity) and instrumental values of ground acceleration.
- Computation of seismic hazard: the computation of the probability of occurrence of ground shaking in a given time period, to produce maps of seismic hazard and related uncertainties at appropriate scales.

There are at least three kinds of PSHA methods (Giardini, 1999):

- Historical probabilism builds a statistical model of seismogenic sources to estimate the seismicity (location in space and time, frequency-size distribution).
- Seismotectonic probabilism incorporates geological evidence (prehistoric record of paleoseismic activity, geomorphology, rates of crustal deformation from land and space geodesy,

neotectonic and geodynamic modeling) to supplement the historical record of seismicity in building a seismic source model covering earthquake cycles up to a few thousands years.

- Time-dependent seismotectonic probabilism: the use of non-poissonian statistics allows to take into account not only the periodicity of earthquake recurrence but also the time elapsed since the last significant earthquake, as a most significant parameter in assessing the future seismic activity.

2.3. Current development in seismic hazard study

At present, the advancement of methods for seismic hazard assessment shows an ever-promising prospect. Both probabilistic and deterministic methods are widely applied in many countries.

The probabilistic approach has been effectively applied to micro-zonation studies, while the deterministic approach, which is based on recent development in the study of seismic sources and seismic wave propagation, has attracted increasing attention in seismology and engineering seismology and has allowed seismologists to obtain important results for understanding of the observed phenomenology and for modeling of the empirical knowledge in relevant topics such as attenuation and abnormal distribution of intensity, and linear and nonlinear site-response effects (Wu, 2001).

Some of the recent advancement in seismic hazard assessment can be summarized as:

- Multidisciplinary cooperation of seismologists, geologist and engineers for seismic hazard assessment in regional and global levels (Giardini and Bochi, 1999). The GSHAP (1992-1999) is a good example for this, which aims to make a breakthrough of limiting of seismic hazard studies by the political boundaries to avoid the deficiency and improve seismic hazard assessment worldwide. Others like IDNDR (International Decade of Natural Disaster Reduction) undertaken by United Nations and WSSI (World Seismic Safety Initiatives), which is an undertaking of International Association of Earthquake Engineering (IAEE) have been carried out or are working on seismic hazard assessment with better coordination among multidisciplinary experts. All these efforts, not only made and will make extraordinary progress in seismic hazard assessment, but also popularised the knowledge on seismic hazard study and reduction for the welfare of millions of people around the world.

- Application of so called 3S(GIS, GPS and RS) technology. These are effective and powerful tools for data collection and data manipulation. The use of GIS databases efficiently handles not only the mapping of the parameters involved (directly or indirectly obtained) but also the interrelation among the different parameters required for seismic hazard study (Mater, Jiménez, 2000). The use of GIS provides more sophisticated way to data management and exploration. As a result, many GIS approaches for seismic hazard that incorporate important spatial data are now developed. GPS and RS play an active role in many advanced studies on seismic hazard assessment. For example, the high accuracy of tectonic movement measurement using GPS is proved to be vital to estimate the fault activities for seismic hazard study. RS can be applied in many ways to provide better data or give a new look of the seismic hazard environment, including geologic description, topographic feature revelation, etc.

- Application of advanced mathematical methods. Mathematical methods are the backbone of the development of natural sciences. Since the introduction of the probabilistic method for engineering seismic hazard analysis by Cornell (1968), it actually started a new era of seismic hazard assessment in some sense. Many numerical methods that enable advanced models and accuracy calculation, which little by little change the situation of “Earthquake risk estimation is presently more an art than a science." (Rojahn and Sharpe, 2000). Other methods such as random point process, or fuzzy logic are also finding their place in seismic hazard studies.

- Lessons from recent disastrous earthquakes. Unlike other sciences, seismic hazard study cannot depend on experiments. But the lessons we learned from the earthquakes are important to improve our understanding and capability of preparation for future ones. In recent years, several destructive earthquakes occurred, with significant social and academic impact. The observation of ground motion amplification and aftershock sequences as well as the damaging scenery from these earthquakes, to take some examples, the 1995 Kobe earthquake, the 1999 Chi-Chi earthquake, and the 2001 Gujrat earthquake, provide seismology and earthquake engineering with valuable data, experiences and lessons, and raise some important scientific problems (Wu, 2001). These have resulted in a significant expansion of knowledge in seismic hazard assessment.

2.4. Radius and Hazus methodology for seismic risk assessment and their comparison

The Radius and Hazus methodology for seismic risk assessment provided very typical examples of seismic hazard assessment for different application.

The Radius methodology is recommended by IDNDR for preliminary seismic risk assessment without high quality data input. It is easy to implement. The methodology applied is simple as Fig 2.2 shows.

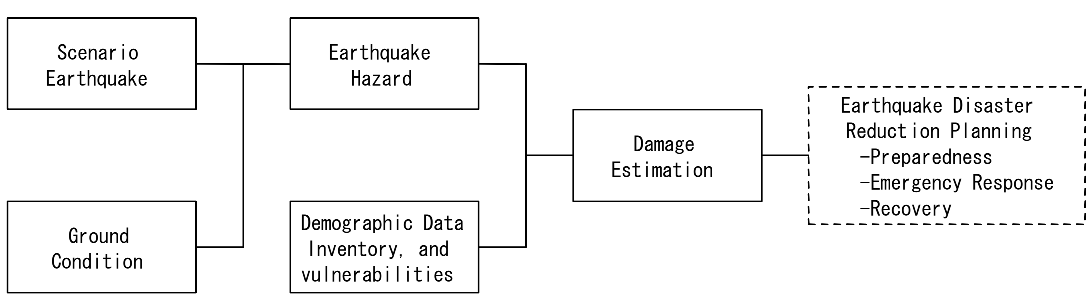

Fig 2.2. Sketch on Radius Tool methodology (Valdiosera)

This methodology is holistic and can be used in many occasions. However, it is neither flexible nor sophisticated for seismic risk assessment.

As far as seismic hazard is concerned, there are three parts of Radius method related: earthquake scenario, ground condition and then hazard calculation. The earthquake scenario can be selected using historical earthquakes or manipulated by the users with magnitude and distance from epicentre assumed. The scenario earthquake is generated either based on a past damaging earthquake or an active fault. The historical earthquakes supplied in Radius Tool are helpful when deciding scenario earthquake parameters. The user is required to specify more parameters such as location, depth, magnitude and occurrence time (hour during the day or night when the event strikes) of the earthquake, if he wants to set a scenario without using the historical earthquakes. The ground condition refers to the zoning of soils into crude types named “hard rock”, “medium soil”, and “soft soil” etc. without concern on depth and topographic effect. Each of the soil class is associated with an amplification factor, which can be used to time seismic hazard. The seismic hazard calculation is based on one of the three attenuation formulas. PGA is calculated and then converted into MMI using empirical formula (Fig 2.3). The defect is the worldwide popular formulas provided for choosing may not reflect well the local condition. But it is always ready to work without too much requirement on data.

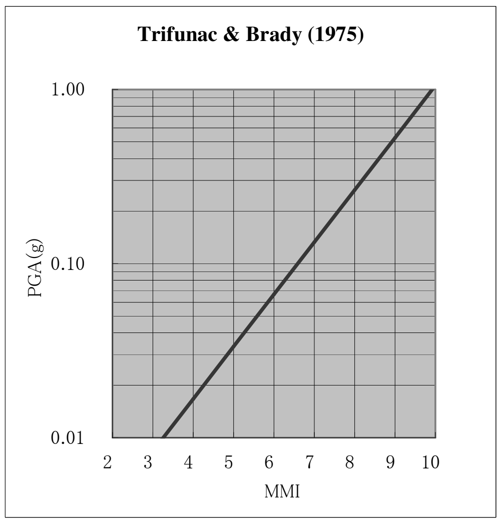

Fig 2.3 Empirical PGA ~ MMI conversion (OYO group, 2000)

Hazus is developed for the Federal Emergency Management Agency (FEMA) by the National Institute of Building Sciences (NIBS) to provide a tool for developing earthquake loss estimates for use in:

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

Hazus provides an earthquake loss estimation methodology to be a tool for local, state and regional officials to plan and stimulate efforts to reduce risk from earthquakes and to prepare for emergency response and recovery from an earthquake. It also provides the basis for assessment of nationwide seismic risk. It can be used by a variety of users with needs ranging from simplified estimates that require minimal input to refined calculations of earthquake loss (Technical manual of Hazus 99). The sketch of methodology is shown in Fig 2.4.

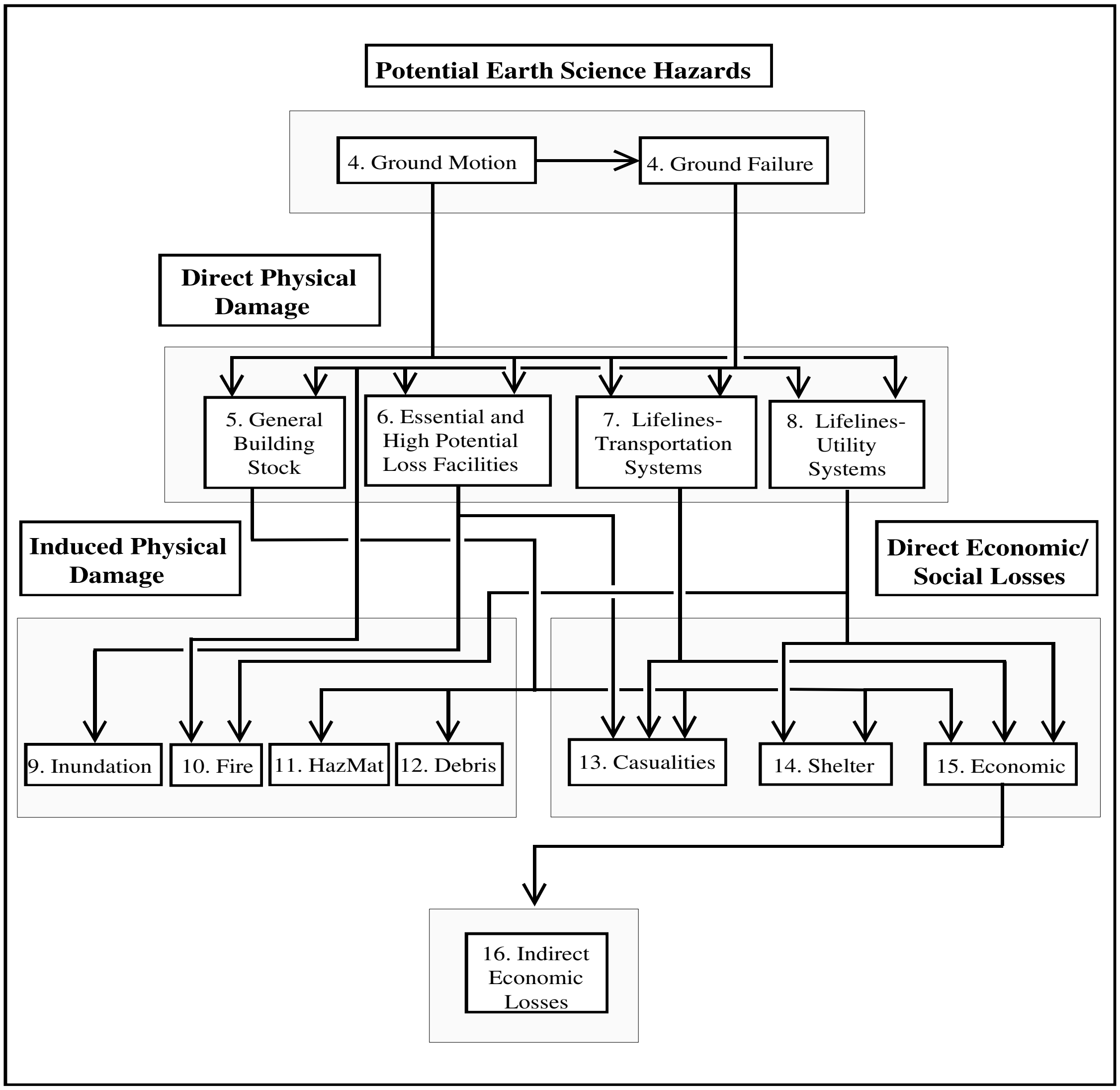

Fig 2.4 Flowchart of Hazus Methodology (Hazus 99 technical manual)

Seismic hazard or the potential earth science hazards (PESH) as it is referred in Hazus includes ground motion, ground failure (i.e., liquefaction, landslide and surface fault rupture) and tsunami/seiche. This means that all of the possible secondary seismic hazards that may follow an earthquake are taken into consideration. But to be focused on the topic of this study, only the section on ground motion will be discussed here.

In Hazus, ground motion is characterized by any of the three: (1) spectral response, based on a standard spectrum shape, (2) peak ground acceleration and (3) peak ground velocity. The spatial distribution of ground motion can be determined using one of the following methods or sources:

- Deterministic ground motion analysis (using incorporated calculation methodology)
- USGS probabilistic ground motion maps (using maps supplied with HAZUS)
- Other probabilistic or deterministic ground motion maps (using user-supplied maps)

Deterministic seismic ground motion parameters are calculated for user-specified scenario earthquakes. For a given event magnitude, attenuation relationships are used to calculate ground motion parameters for rock sites, which is then amplified by factors based on local soil conditions when a soil map is supplied by the user. Hazus also provide many options for local attenuation relationship. The user should specify any of the three options: (1) an event based on a database of seismic sources (faults), (2) an event based on a database of historical earthquake epicentres, or (3) an event based on an arbitrary choice of the epicentre.

The USGS probabilistic seismic hazard contour maps provide estimates of PGA and spectral acceleration at periods of 0.3 second and 1.0 second, respectively. Ground shaking estimates are available for eight hazard levels: ranging from the ground shaking with a 39% probability of being exceeded in 50 years to ground shaking with a 2% probability of being exceeded in 50 years. Estimation on local soil condition are calculated using a "spectral displacement" conversion method (Fig 2.5)

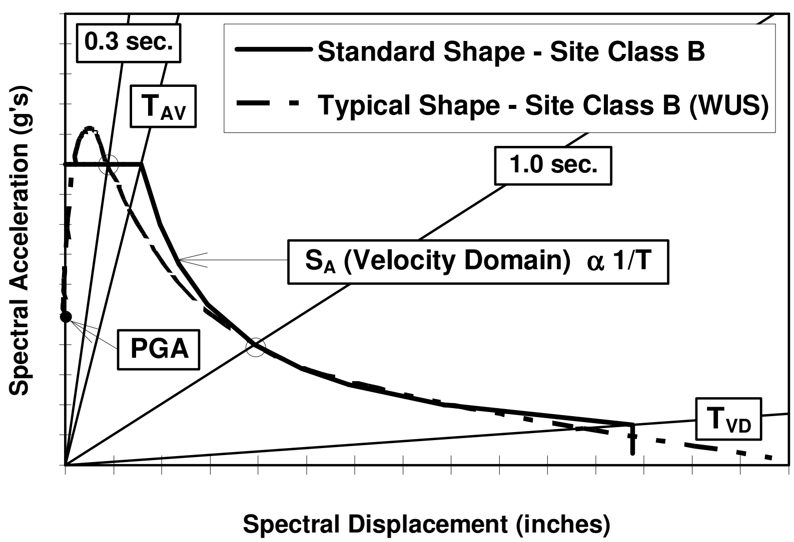

Fig 2.5 Standardized Response Spectrum and spectral displacement for site class B (*Rock, Vs 760-1500m/s*)
(From Hazus technical manual)

Hazus also allows the user to supply PGA and spectral acceleration contour maps of ground shaking in a pre-defined digital format. This option permits the user to develop a scenario event that could not be described adequately by the available attenuation relationships, or to replicate historical earthquakes. .

Also, Hazus is a multi-module system with each module carry out assessment on one part of the whole work. These components are related to each other by one's output acting as input for another module. Although the seismic risk assessment should be done in a systematic way predefined by Hazus, Hazus provides means to change the level of the simplicity to accommodate the need of different users. Since Hazus already contain some data on US, so generally speaking, it is more reliable and versatile in terms of analysis on different kind of hazards. Since the data requirement is high in Hazus, standardization methods are invented to use data coming from different sources and in different forms.

A comparison can be made between Radius and Hazus summarily:

1) Radius use easy-to-understand terms and a deterministic method to carry out seismic hazard assessment. The data requirement of Radius is lower than that of Hazus.
2) Hazus adopted more advanced method for seismic hazard assessment including deterministic and probabilistic methods. But since there are already database on seismic sources, historical earthquakes and USGS probabilistic seismic hazard ground shaking maps available, it reduced the difficulty for application much. Yet, users of Hazus need more professional background than that of Radius to handle the application properly.
3) The results produced from Hazus can be treated seriously for risk reduction and emergency measures, if the input data is good. But the Radius provides preliminary results on seismic risk, which may only be able to evoke the risk reduction and prevention awareness of the communities. Radius results are far from reliable due to very limited data and technique simplicity.
4) Hazus is more flexible in choosing suitable model for analysis as far as application in United States is concerned, but it has higher data requirement. What's more, Hazus is very hard to be applied elsewhere outside US while Radius has no such restriction.

2.5. Ilwis and Visual Basic

Ilwis (Integrated Land & Water Information System) is a GIS/RS software developed by International Institute of Geoinformation Science and Earth Observation (ITC). Ilwis is mainly a Raster based GIS package, which can handle Raster maps easily in many ways for spatial analysis. It consists of: (ITC, Ilwis Help, 2002)

- Display of Raster and multiple vector maps in map windows
- Display of tables in table windows
- Interactive retrieval of attribute information
- Image processing facilities
- Manipulation of maps in a Map Calculator
- Manipulation of tables in a Table Calculator
- GIS analysis tools
- Script language to perform 'batch' jobs

Although, Ilwis is not the same as the commercial successful ESRI® product ArcGIS in many ways, Ilwis is very suitable for small projects and user with less professional background can be trained in a short time to work with it. Especially, in terms of cost and professional skills of staff, Ilwis may be better to cope with the realities of middle-sized cities in developing countries.

Visual Basic is an Object-Oriented, Event-Driven Programming Language that facilitates rapid application development using graphical user interfaces within the MS-Windows environment. It is very easy and efficient to program using Visual basic, because Visual Basic uses one of the simplest grammar and many of the features are already capsulated in Visual Basic as a variety of controls, which are ready to be used in very simple way as well. Although Visual Basic is simple, it is powerful too. Visual basic 6.0 is all but deemed by many as really fascinating. Many new features that bolster up programming at will. However, as a programming language, Visual Basic is not supposed to deal with the spatial analysis as a GIS package can do.

2.6. Other Popular software for seismic hazard calculation

1) SHAKE series.

The SHAKE series including PROSHAKE, SHAKE32 and Shake 91 are all based on the Equivalent Linear Seismic Response Analysis method for horizontally Layered Soil Deposits firstly proposed by Idriss and Seed in 1960's.

The SHAKE program has been by far the most widely used program for computing the seismic response of horizontally layered soil deposits. The program computes the response of a semi-infinite horizontally layered soil deposit overlying a uniform half-space subjected to vertically propagating shear waves. The analysis is done in the frequency domain, and, therefore, for any set of properties, it is a linear analysis. An iterative procedure is used to account for the non-linear behaviour of the soils. The object motion (i.e., the motion that is considered to be known) can be specified at the top of any sublayer within the soil profile or at the corresponding outcrop. (National Information Service for Earthquake Engineering, University of California, Berkeley, 1999)

Ever since the original SHAKE program of Schnabel et al. came out in 1972, there were numerous revisions and improvements, which produced a series of SHAKE program.

SHAKE 91 is a major FORTRAN language based revision. The main modifications incorporated in SHAKE91 include the following: the number of sublayers was increased from 20 to 50; all built-in modulus reduction and damping relationships were removed and these relationships can be specified by the user; the maximum shear velocity or the maximum modulus are now specified for each sublayer; object motion is now read from a separate file. (National Information Service for Earthquake Engineering, University of California, Berkeley, 1999)

The commercial version ProShake is a powerful, user-friendly computer program. Written completely from scratch, ProShake features built-in modulus reduction and damping models, graphical display of soil profile and input motion parameters, graphical display of a wide variety of output parameters, and animation of ground response. ProShake is organized into three "managers" - an Input Manager, a Solution Manager, and an Output Manager. ProShake also includes a useful Report feature that allows convenient documentation of analyses. ProShake has been shown to produce results virtually identical to those produced by SHAKE91 and closed form solutions. The educational version of ProShake is EudoShake, which has a limited function available, but still ideal for educational purpose (EduPro Civil System Inc, 2002).

2) SEISRISK, EQRISK, FRISK88M

SEISRISK was developed by USGS in 1970s based on probabilistic Cornell (1968) method for seismic hazard assessment. The revised version SEISRISK III is in widely used by professionals around the world. The earthquake occurrence is considered as a homogenous Poisson process. That is the probability of having one earthquake in T years is: $p = e^{-vT}$, where v is annual rate of occurrence. The exceedance probability is $p = 1 - e^{-vT}$. The probability of having two or more changes in considered interval is approximately zero. This is a time-independent model so that in any time interval the exceedance probability is the same. Source model are based on fault. The attenuation model used is an elliptical model that needs input of the azimuth of seismic source (fault) (USGS, 2002).

EQRISK is developed by McGuire of U.S. Geological Survey in 1976. It is a computer program for the evaluation of earthquake risk at chosen sites. In EQRISK seismic events are considered as point sources. The user defines their occurrence in space. A variety of parameters may be used to quantify ground shaking, such as peak ground acceleration, velocity, displacement, modified Mercalli intensity, spectral velocity, etc. An attenuation function must be specified by the user, and may be in analytical form or (with slight reprogramming) in tabular form. Output gives annual risks for chosen values of the parameter values for pre-selected risk levels. Output is easily obtained for sites on a grid; thus the program is suitable for seismic mapping. EQRISK uses largely the same approach for seismic hazard assessment as SEISRISK (National Information Service for Earthquake Engineering University of California, Berkeley, 1999).

FRISK88M, developed by Risk Engineering, is more sophisticated software package for studying the probabilistic seismic hazard associated with a single site or for seismic hazard mapping. It operates on multiple-weighted assumptions and produces a consolidated risk evaluation. It uniquely accounts for both randomness (variability that cannot be reduced with more or better observations; The only way to reduce randomness is to completely change the model) and uncertainty (inaccurate or incomplete information and can be reduced or eliminated given better models or additional observations), which improves the performance compared with either SEISRISK or EQRISK. FRISK88M requires user to construct a text input file to define seismic sources and attenuation equations. The seismic source can be either a fault or an area. More parameters are required for defining these sources. For example, for a fault the parameters required are fault trace, dip angle, fault depth, slip rate, recurrence type, rapture length, etc. Both the seismic source and ground motion attenuation equation leave to the users to improve the flexibility of the programme. The program produces a wealth of output, much of which can be quickly plotted using other software. The following output is generated: 1. seismic hazard curves; 2. sensitivities to the hazard for different assumptions; 3. Uniform hazard spectra indicating period vs. amplitude for user-defined annual probability of exceedance (Risk Engineering, Inc., 2002).

Chapter 3. Data Standardization

3.1. Data standardization

It is common that the basic input data will differ from place to place. Probably, data coming from different sources express the same thing, or they cannot be put together easily without further processing. For a practical and less locality sensitive technique for seismic hazard and risk assessment, it is necessary to take into consideration data sources and to perform data standardization. Without endeavour to clarify the air of the things that it may come across, the technical personnel may meet trouble to manage the situation to create proper input.

The data problem is of a wide range. Only a narrow part that directly related seismic hazard assessment will be discussed. Data standardization concerned here usually faces two situations:

1) The same property represented by different physical definition;
2) The same properties represented by the same physical definition with nominal difference. A good example for the former is the bedrock PGA estimation (See Table 3.1). The standardization for this usually can be done using the empirical relation or the conversion formula available. For the later, it is better to use a friendly user interface to solve the problem. The different soil type classification is a good example for this.

3.2. Ground motion data

PGA provided by microzonation for the city can be used directly. If it is intensity, it can be transferred to PGA using the empirical method as Table 3.1 shows.

Table 3.1 Empirical corresponding of PGA/PV to MMI (By USGS)

MMI	PGA (gal)	PV (cm/s)
IV	15~20	1~2
V	30~40	2~5
VI	60~70	5~8
VII	100~150	8~12
VIII	250~300	20~30
IX	500~550	45~55
X	>600	>60

3.3. Other data

Soil properties: different kind of soil data such as depth, shear wave velocity, modulus, density and damp ratio are very useful for ground motion calculation. But sometimes the unit and the soil classification may differ for different area.

3.4. Method for data standardization

The method for data standardization can be classified into two categories: 1) conversion and 2) reclassification.

The former can be done automatically using the empirical formulas available while the later may need manual work since the differences in representation may make it impossible to be solved by the application. An interface for PGA – MMI conversion was designed (Fig 3.1).

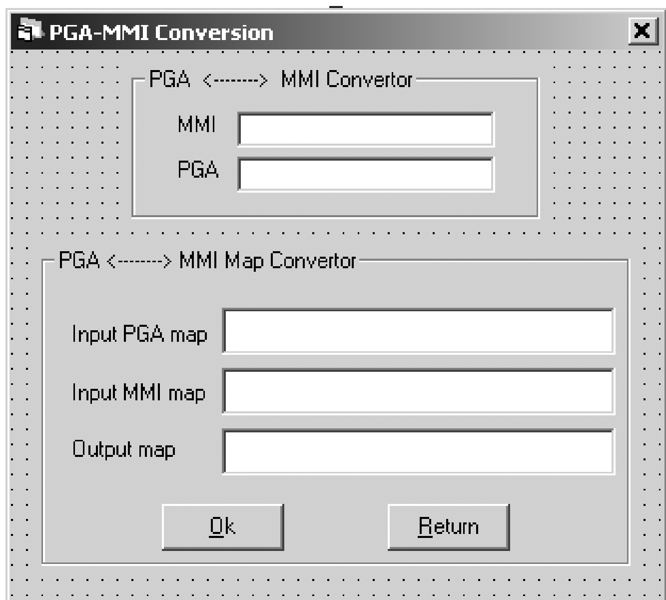

Fig 3.1 Interface for PGA-MMI conversion

The upper part is a PGA –MMI converter, when either PGA or MMI is used as input, the other will be automatically calculated.

The later are largely manual work, but it can be made more efficient with certain interface designed. Fig 3.2 is an interface designed for soil class standardization. It can deal with either soil map with an attribute table (In case there is no attribute table, a new attribute table should be made). The interface does not make any operation on soil class reclassification, but it provides an easier environment for manual work to be done. The real soil standardization was done through a mediate table, in which the original soil classes are made to correspond the standard soil classes. Then, the interface can use the mediate table to reclassify the original soil map and thus standardize the soil map.

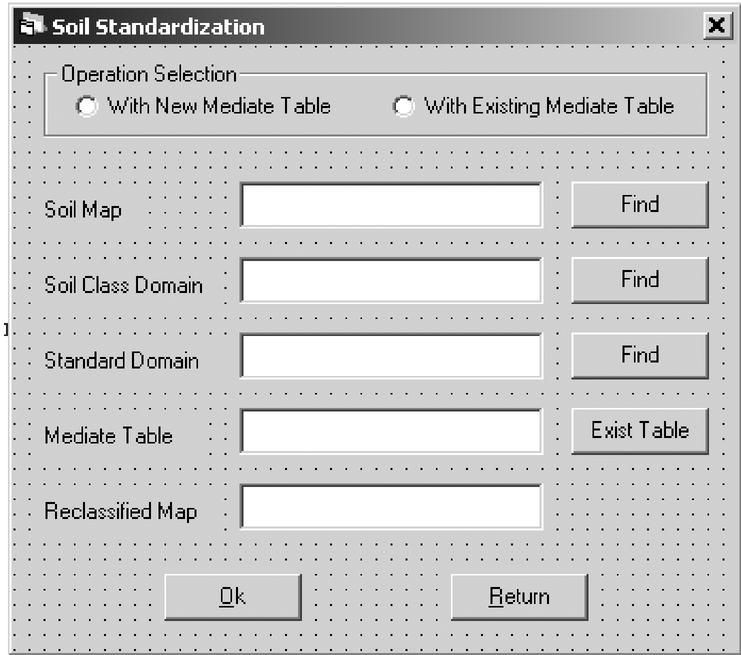

Fig 3.2 An interface for soil standardization

Chapter 4. Ground Motion Calculation

The study of strong ground motion for earthquake hazard and risk plays an important role in seismology and the sustainable development of economy and society. Hazard analysis requires characterization of the seismic sources that can be expected to affect a selected place in terms of location, magnitudes, and frequency of occurrence of potentially damaging earthquakes. Knowledge of the attenuation of ground motion or seismic intensity with distance from the source to the site, integrated whenever possible with realistic modeling of seismic wave propagation, and knowledge of the local geology for site-specific assessment will promote this analysis to a large extent. Using the hazard estimates produced by seismology, risk analysis yields probabilistic estimates of the expected losses of property and lives from earthquakes, which is a convolution of the hazard estimates and vulnerabilities of structures, facilities, and people distributed over the site.

4.1. Ground motion during earthquake

When an earthquake occurs, it generates a large amount of P and S wave, which are called body waves. The total energy of these waves is related to the earthquake magnitude. The propagation of these waves is rather complicated. A simplified model widely used is the layered medium model. As the body wave travel through each layer of medium, the phenomenon of scattering and refraction happens. Not only the body wave changed their incidence angle and strength a little bit, but also surface wave produced during the process.

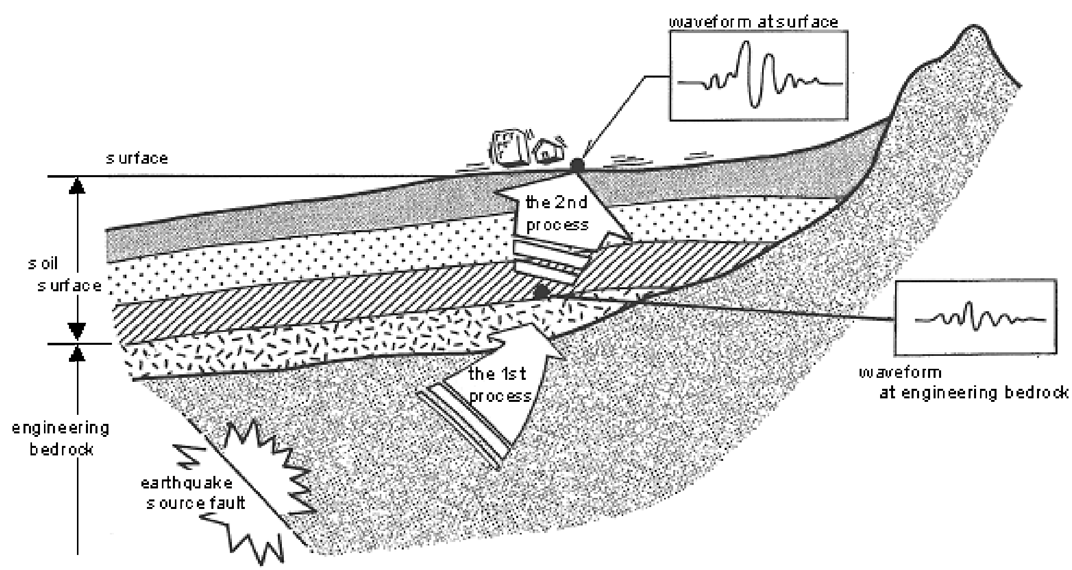

Fig 4.1 Seismic wave propagation through engineering bedrock and soil surface (International Institute of Seismology and Earthquake Engineering (IISEE))

Fig 4.1 shows the two process of seismic wave propagation. Obviously, in the second process, where the ground condition affect the seismic wave much and often there is a great amount of amplification incurred.

Ground motion is the principal effect of earthquake. It refers to the amplitude, frequency, and duration of the horizontal and vertical component of ground vibration. Now many strong motion record observation arrays are deployed in many countries to get precise records on strong ground motion ensuing an earthquake. A typical earthquake ground motion record is like Fig 4.2.

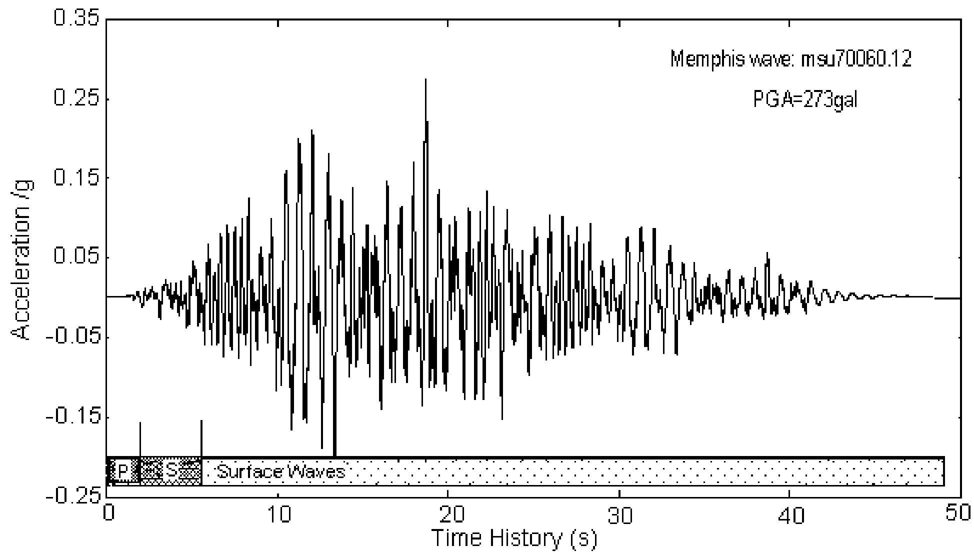

Fig 4.2 A typical ground motion record

As it shows, P waves arrive first and then the S waves. Usually, the surface waves arrive later than P and S waves, but they have the strongest effect on buildings. Not only the surface waves have large amplitude but also their low frequency components are dangerous for the high buildings. But the intensity of surface wave is mainly limited to the very near surface of ground.

4.2. Measurements for ground motion

Different measurements for ground motion are developed.

1) Intensity

Seismic "intensity" is a measure of ground shaking strength at different locations in the region where an earthquake is felt. It is characterized in terms of how the shaking affected or is responded by people and buildings. The intensity thus does not need instruments to measure. It is a measure of damage and response, which is roughly related to the ordinary life of people.

There are several Intensity scales used internationally, however, the most often used is Modified Mercalli Intensity (MMI) Scale.

Originally developed in Italy nearly a century ago, the Mercalli Intensity Scale includes 12 degrees of shaking. It was modified for use in the United States in 1931. Table 4.1 is the description recommended by Federal Emergency Management Agency (FEMA) of the United States.

Table 4.1 Description of MMI (FEMA, 1996)

Intensity	Description
I	People do not feel any Earth movement.
II	A few people might notice movement if they are at rest and/or on the upper floors of tall buildings.
III	Many people indoors feel movement. Hanging objects swing back and forth. People outdoors might not realize that an earthquake is occurring.
IV	Most people indoors feel movement. Hanging objects swing. Dishes, windows, and doors rattle. The earthquake feels like a heavy truck hitting the walls. A few people outdoors may feel movement. Parked cars rock.
V	Almost everyone feels movement. Sleeping people are awakened. Doors swing open or close. Dishes are broken. Pictures on the wall move. Small objects move or are turned over. Trees might shake. Liquids might spill out of open containers.
VI	Everyone feels movement. People have trouble walking. Objects fall from shelves. Pictures fall off walls. Furniture moves. Plaster in walls might crack. Trees and bushes shake. Damage is slight in poorly built buildings. No structural damage.
VII	People have difficulty standing. Drivers feel their cars shaking. Some furniture breaks. Loose bricks fall from buildings. Damage is slight to moderate in well-built buildings; considerable in poorly built buildings.
VIII	Drivers have trouble steering. Houses that are not bolted down might shift on their foundations. Tall structures such as towers and chimneys might twist and fall. Well-built buildings suffer slight damage. Poorly built structures suffer severe damage. Tree branches break. Hillsides might crack if the ground is wet. Water levels in wells might change.
IX	Well-built buildings suffer considerable damage. Houses that are not bolted down move off their foundations. Some underground pipes are broken. The ground cracks. Reservoirs suffer serious damage.
X	Most buildings and their foundations are destroyed. Some bridges are destroyed. Dams are seriously damaged. Large landslides occur. Water is thrown on the banks of canals, rivers, lakes. The ground cracks in large areas. Railroad tracks are bent slightly.
XI	Most buildings collapse. Some bridges are destroyed. Large cracks appear in the ground. Underground pipelines are destroyed. Railroad tracks are badly bent.
XII	Almost everything is destroyed. Objects are thrown into the air. The ground moves in waves or ripples. Large amounts of rock may move.

In Japan, Fusakichi Omori developed a scale that took into account the types of structures there, such as stone lanterns and Buddhist temples, which are characteristic in Japan. Later, it was adopted by Japanese Meteorological Agency (JMA) as national standard. The JMA scale has only 7 degrees. The description of this scale is in Table 4.2.

Table 4.2 JMA Seismic Intensity Scale (JMA)

Intensity	Description
I	Felt only by people standing still or people who are especially sensitive to earthquake detection.
II	Felt my many people, shoji paper sliding doors are noticed to move a little.
III	Buildings shake, shoji paper doors rattle loudly, lights that hang down sway noticeably, surface of water in containers is noticeably disturbed.
IV	Buildings shake intensely, vases may fall over, water in containers splashes out, felt by people walking, many people run outside.
V	Cracks appear in walls; tombstones, stone lamp fixture decorations fall over; chimneys, stone walls collapse.
VI	Up to 30% of buildings collapse, landslides occur, cracks in the earth appear, many people are unable to stay standing.
VII	Over 30% of buildings collapse, landslides occur, crack in the earth and fault lines appear.

Advantage of intensity is that it indicates the direct damage effect to the structures without considering the difference physical measurement. The disadvantage, however, is that the intensity is a combination of strength of ground motion, soil and topographical amplification and the characteristics of the structures as well; it is hard to draw a simple conclusion for the actual ground motion.

2) Peak ground motion

In this class, the measurements are the acceleration, velocity or displacement. The acceleration is directly related to the lateral or vertical loading that can be used for design under many seismic codes. Velocity and displacement are useful for some special structure.

In practice, the most often used are peak values such as Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV). Many of these measurements can be directly obtained from field using seismograph. They are convenient for both seismic hazard zoning and civil engineering design.

3) Spectral ground motion measurements

Spectral ground motion measurements such as Spectral Ground Acceleration (SGA) or Spectral Ground Velocity (SGV) can be regarded as a compromise between the simple peak ground motions measurements and the complicated response spectrum. These measurements indicate the level of ground motion at particular frequencies. These are more useful for the design and assessment of seismic damage for different types of buildings since the response of building are frequency-dependant. The high-rise buildings are affected more by relatively low-frequency oscillations while the low buildings and many lifeline systems are more vulnerable to the high frequency ground motion.

To have an idea of what is the resonant period of a building, a rough rule of thumb principle for the resonant period of oscillation of a multi-storey building is

$$T = N * 0.1 \qquad (4\text{-}1)$$

Where T is the period in seconds and N is the number of storeys. So a ten-storey building will be affected most by ground oscillations with a period of around one second. The frequency range for most of the buildings is within 0.1 – 20 Hz or 0.05 – 10 second in term of period.

In some cases, one set of the SGA can be used to infer other set of SGA. For example, in Hazus, SGA with period of 0.3 second are used to infer SGA at 1.0 second with the input of earthquake magnitude, distance from fault and soil coefficient. The assumption under this is that there is a standard $SGA_{(0.3)}$ / $SGA_{(1)}$ ratio relationship exists for each type of soil classes. In this regard, the SGA are more versatile than peak ground motion parameters.

4) Ground motion spectrum

Since the response of different buildings varies widely to the same earthquake ground motion and conversely, any given building will act differently during different earthquakes, it gives rise to the need of concisely representing the building's range of responses to ground motion of different frequency contents. Response spectrum is such a representing. It is a kind of graph, which plots the maximum response values of acceleration, velocity and displacement against period/frequency. Response spectra are very important "tools" in earthquake engineering. (Multidisciplinary Centre for Earthquake Engineering Research (MCEER))

Figure 4.3 is an acceleration response spectrum of ground motion produced with EduShake.

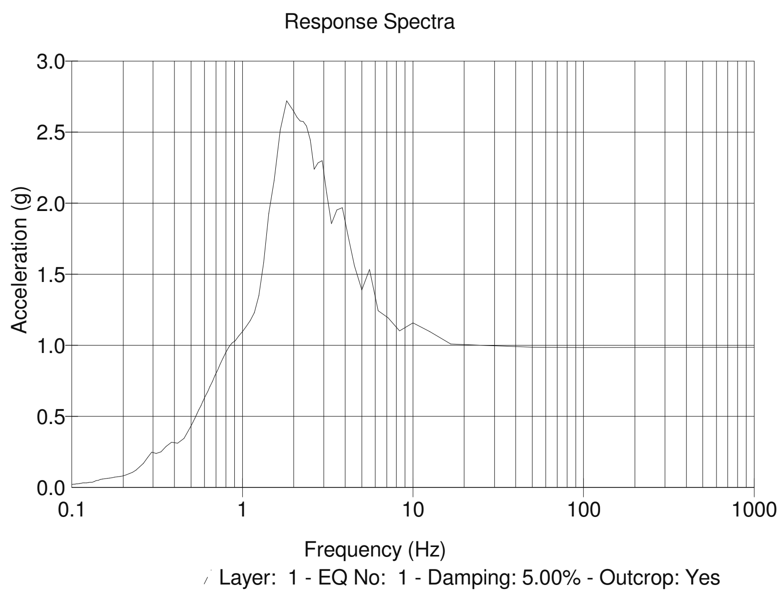

Figure 4.3 An example of acceleration response spectrum

It shows how the response characteristics varies with frequency. Thus from the response spectrum, we have much completed knowledge of the ground motion and it can be applied with higher confidence in building design.

There are different kinds of response spectra used for different purposes. The acceleration response spectrum is the most commonly used. But for design of bridges, cloverleaf junctions, viaduct, pipe systems, power system, viaducts etc., displacement spectrum or velocity spectrum would be preferred.

4.3. Effects on ground motion

Ground motion cannot be observed or calculated everywhere in the same way. Therefore the effects on ground motion caused by attenuation from the epicentre or seismogenic fault, soil layers and topography should be assessed systematically or empirically to derive the ground motion that more likely to represent the reality for all the area that is concerned.

4.3.1. Attenuation

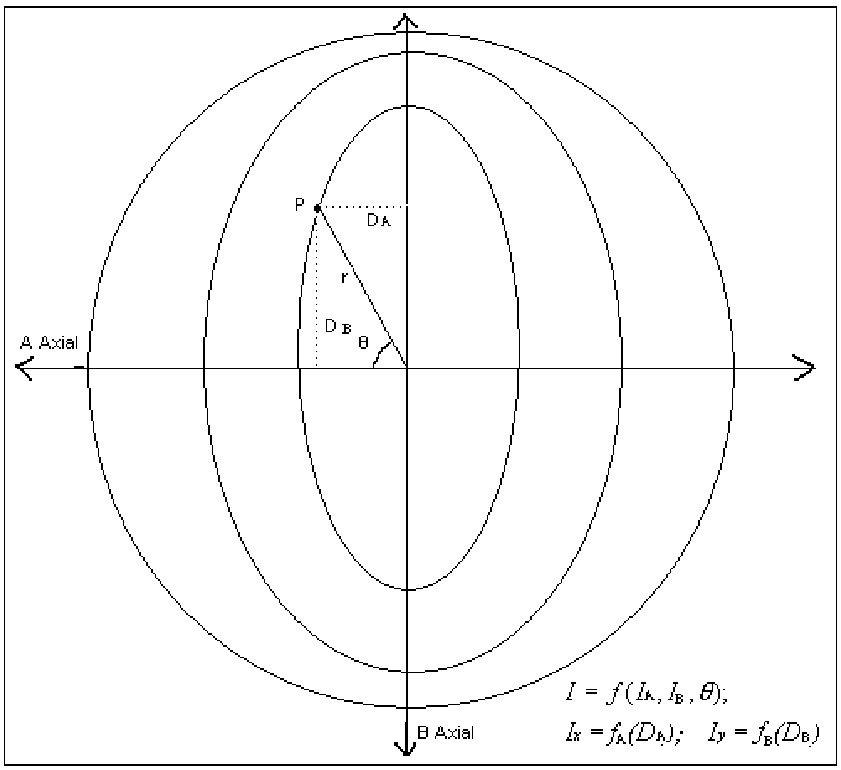

Figure 4.4 An ideal model of ground motion attenuation

An ideal model of ground motion attenuation is like what is shown in Fig 4.4. It is an elliptical ground motion attenuation model. In GIS it can be realized by first calculate the I_A and I_B on two axial direction. Simply assume that $I = \sqrt{I_A{}^2 + I_B{}^2}$, and then I can be calculated using I_A and I_B.

In many areas, the regional elliptical model attenuation formulas are already provided by previous studies. Most of the formulas take form as:

$$I = C_1 + C_2 * M - C_3 Ln(R + C_4) \tag{4-2}$$

Where *I* is intensity, *M* is the magnitude, *R* is the distance from epicenter, C_1 to C_4 are constants.

For example in West China the formulas are (Guo, 1990):

Long axial: $I = 5.643 + 1.538 * M - 2.109 Ln(R + 25)$ (4-3)

Short axial: $I = 2.941 + 1.363 * M - 1.494 Ln(R + 7)$ (4-4)

Where M is Ms, R is the distance to epicentre.

Except from the elliptical model, there are other attenuation relationships proposed by researchers:

Joyner – Boore, 1981

$$\log_{10} Y = -1.02 + 0.249 M_w - \log_{10} D - 0.00255 D + 0.26 P \quad (4\text{-}5)$$

$$D = \sqrt{r_{JB}^2 + 7.3^2} \qquad P = \begin{cases} 0 \text{ for 50 percentile values} \\ 1 \text{ for 84 percentile values} \end{cases}$$

r_{JB} -Closest horizontal distance to the fault vertical projection; Fault rupture above 20 km, Site: soil and rock, $M=M_w$ (West USA) [5-7.7]

Campbell, 1981

$$\ln Y = -4.141 + 0.868 * M - 0.109 * \ln\left[R + 0.0606 e^{0.7M}\right] \quad (4\text{-}6)$$

R - closest distance to fault rupture [km], Worldwide, $M=M_s$ [5-7.7]

Fukushima, Y., Tanaka, T., 1990

$$\log_{10} Y = 1.3 + 0.41 M - \log_{10}\left(R + 0.032 * 10^{0.41 M}\right) - 0.0034 R \quad (4\text{-}7)$$

R: the closest distance to the fault rupture; $0.1 < R < 300$, $M=M_s$[5-8]

The attenuation of ground motion is determined by the geologic tectonics, focal mechanism, magnitude, and site condition etc. therefore it is hard to say which one is better rather than to choose one that based on much similar geological and seismogenic setting.

4.3.2. Soil amplification

The distribution of different soil layers plays a major role in controlling the ground motion severity and their characteristics during an earthquake. It has been recognised long before that the amplification of the soft soil can be huge. In the 1985 Mexico earthquake, the amplification of PGA due to soft soil is estimated as much as 30 time of that near the epicentre.

The soil amplification is frequency-dependent. A certain soil layer amplifies ground motion at certain frequencies much larger than ground motion at other frequencies. The fundamental frequency is the first and foremost resonant frequency of soil, and there are a series of harmonic frequencies, which are also relatively important. Both the fundamental and harmonic frequencies can be evaluated using the shear wave velocity of soil. These expressions are (Day, R.W., 2001):

$$f_0 = \frac{V_s}{4H} \quad \text{(Fundamental frequency)} \tag{4-8}$$

$$f_n = (2 \cdot n + 1) \cdot f_0 \quad \text{(Harmonics frequencies)} \tag{4-9}$$

Where H is the depth of soil deposit, f_0 is the fundamental frequency, V_s is shear wave velocity, n is a positive integer, f_n is the nth harmonic frequency.

Since amplification decreases as time goes on due to damping, so the largest amplification occurs at the fundamental frequency.

The soil amplification is also related to the shear strength. So shear modulus is also important for assessment of soil response, an empirical estimation of G_{max} (Seed and Idriss, 1986) is:

$$G_{\max} = (\rho / g) \cdot V_s^2 \tag{4-10}$$

Where ρ is the mass density, g is the acceleration of gravity, V_s is shear wave velocity.

There are several softwares to compute the soil amplification. One of the most popular is using the numerical program like SHAKE, which gives good results with input of ground motion and soil layer properties.

Another method newly proposed by many experts and engineers are to estimate the soil amplification using the average shear wave velocity of soil layers within 30m depth. It is much efficient for the purpose of seismic hazard zoning. A formula proposed by Mahdyiar (2001) is:

$$F = (V_{ref} / V_{30})^m \tag{4-11}$$

Where F is the factor of ground motion amplification, V_{ref} and V_{30} are respectively reference shear wave velocity and average shear wave velocity of soil 30 depth underground. ^{m} is a parameter related to soil types which can be determined using local test results.

The advantage of this method is that it is easy to apply in use and give better results than the amplification coefficients assigned based on soil classification. Also, with study on local soil condition, it can provide better assessment for PGA. The disadvantage of this method is that it does not deal with the frequency aspect of soil amplification. Japanese scientists (TAMURA, YAMAZAK et al, 2000) try to relate the average shear wave velocity with the soil response spectrum recorded to determine the spectral soil amplification. Although this method may have predominant site limitation, it is a method worthy to be given attention.

4.3.3. Topography amplification

For cities located in the hilly area, the topographic amplification is an important factor that has to be incorporated in seismic hazard study. This study does not manage to study the topographical amplification because of limits in time and means. Here only a brief introduction will be given.

The effect of topographic influence on ground motion can be simplified as two factors: the relative height and the surface area/bottom area ratio. So the topographical amplification can be expressed as:

$$\delta_T = f(h, A'/A) \tag{4-12}$$

Where, δ_T is the topographical amplification coefficient, h is the relative height, A'/A is the surface area/bottom area ratio and $f(h, A'/A)$ represent a function with two independent variables.

A'/A can be deducted as the following for the Raster based GIS.

$$A'/A = \frac{\iint \sqrt{1 + (\frac{\partial z}{\partial x})^2 + (\frac{\partial z}{\partial y})^2} dA}{\iint dA} = \sqrt{1 + (\frac{d_{zx}}{dx})^2 + (\frac{d_{zy}}{dy})^2} = \sqrt{1 + \frac{d_{zx}{}^2 + d_{zy}{}^2}{r^2}} \tag{4-13}$$

Where, A'/A is the surface area to bottom area ratio. A' is the real topography surface area, A is the area of unit raster cell. Z is the height, x and y are respectively coordinates at two directions on the level plane. $(\frac{\partial z}{\partial x})$ and $(\frac{\partial z}{\partial y})$ are partial differential at x and y direction, dA is the differential unit, which is infinite small in theory. Because the raster based GIS can only calculate in discrete mode, so dA is area of raster cell. Since dA appears both at numerator and denominator, it should be cancelled. Also the continuous partial differential at x and y direction should be replaced with the change of height between two neighboring raster cells, namely, $(\frac{d_{zx}}{dx})$, $(\frac{d_{zy}}{dy})$, Where dx and dy are length and width of raster cell, d_{zx} and d_{zy} are height change at two directions which can be determined through the gradient operation in Ilwis. Finally, in the raster based GIS, the cell is a square, so $dx=dy=r$, thus the formula is simplified to have only two variables d_{zx} and d_{zy} all of them can be got from gradient operation.

Fig 4.5 gives an illustration of the idea. This will explain why there is higher amplification effect at the cliff and other isolated terrain features observed from earthquake investigation and ground motion records.

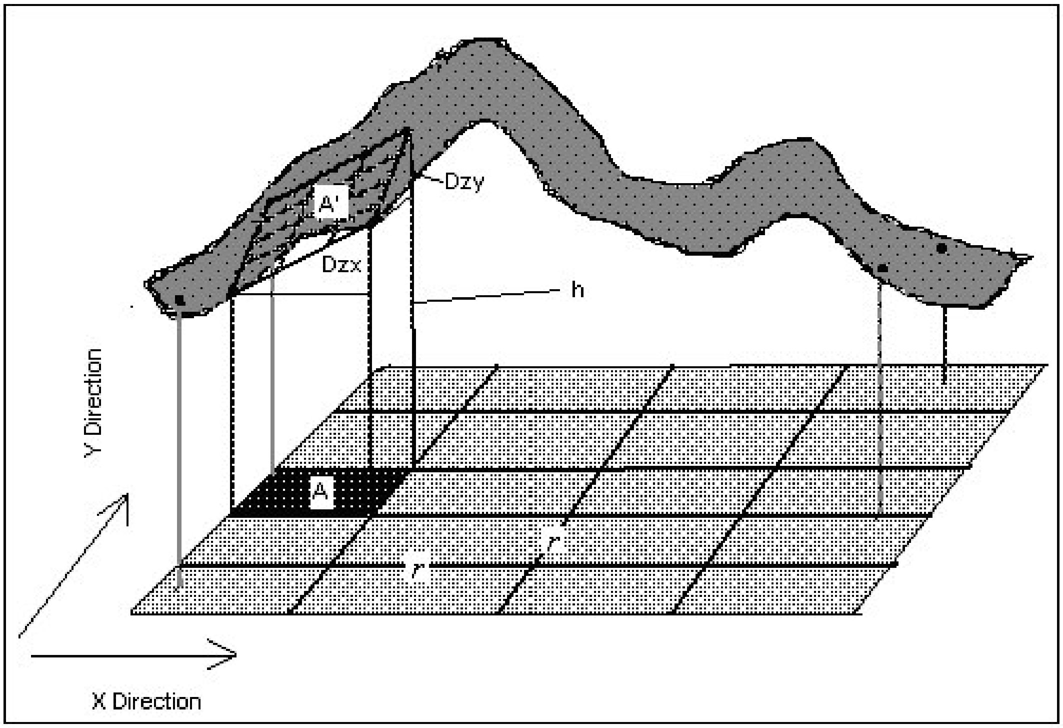

Fig 4.5 The effect of topography on amplification

The simple rationales behind are:

1) The relative height determines the thickness of soil and also causes more body wave interaction, which affects the generation and amplification of the surface waves. So the height from reference horizontal plane is the primary parameter to be considered for soil amplification.
2) The surface area/bottom area ratio is a complement to relative height as it is often noticed that even places of the same height without difference on soil layers show different soil amplification effects with the site on the edge giving a larger amplification than the relatively inner part of the peaks. In theory, this related to the impedance contrast that exists between soil and air. The impedance of a material is defined as:

$$I=V*\rho \, , \qquad (4\text{-}14)$$

V is shear wave velocity, and ρ is the mass density.

The contrast in impedance determines the amount of wave energy that is reflected when a seismic wave passes a layer boundary where the material properties change. This is shown by Zoeppritz's equation (Zoeppritz, 1919).

$$R = \frac{I_2 - I_1}{I_2 + I_1} \tag{4-15}$$

Where R is the reflection coefficient.

At the surface, all of the energy is reflected because in air the shear wave velocity Vs is zero. Thus, higher surface area/bottom area ratio means higher soil-air interface ratio, consequently, more energy remains in the soil and the ground motion will be stronger.

4.4. Using GIS for ground motion calculation

Although the commence of ground motion calculation and also the incorporation of numerical models have nothing to do with GIS, there are often reasons now that with GIS, one can manage, analyse and visualization ground motion better. Particularly, Raster-based GIS are very helpful and efficient for ground motion calculation.

Firstly, the ground motion during an earthquake is regular according to the geological and geotechnical conditions. Obviously, the Raster based GIS analysis has certain advantages for a better representation of local spatial variability than the vector based GIS and also provides operations with simple algorithms for processing. It can cover much more of the area of interest than the often spatially inadequate calculation outside the GIS and provide better spatial resolution than the crisp classification that sacrifices real spatial variation of the physical variables.

Secondly, it is possible to simulate some of the mathematical calculations and deductions with Raster-based GIS analysis, which are necessary for the ground motion phenomenon that cannot easily be expressed in relation model using object-based GIS analysis. The calculation of ground motion is, in one sense, to establish the relation of physical variables and their spatial coordinates. This is not too hard to realize in a raster-based GIS analysis where a raster map can be used as a variable in mathematic formulas.

Furthermore, Raster based GIS can manipulate the irregularity of tectonics, soil condition, hydraulic system etc. more easily than mathematical deduction. Since the spatial distribution of these can be well ready in maps, it is possible to incorporate these factors through various overlay operations.

As a result, the low-cost and Raster-based GIS package Ilwis is a good choice for this study.

Fig 4.6 is an example where both the numerical ground motion attenuation relationship and the irregularity of site condition are taken into account for ground motion calculation with Ilwis. It is worked out firstly by using an elliptical attenuation formula to generate a PGA attenuation map and then by incorporating the soil condition, which is actually to multiply a factor of amplification. The PGA unit is gal, which is 1/1000 of graviton acceleration.

Many of the mature method for ground motion can still be incorporated into Ilwis. Also, combining GIS modelling with the numerical method sometimes can provide an easy and more sophisticated method for seismic hazard assessment. But, at the same time, the data requirement in this case is high in order to avoid misleading results of bad manipulation and poor data quality.

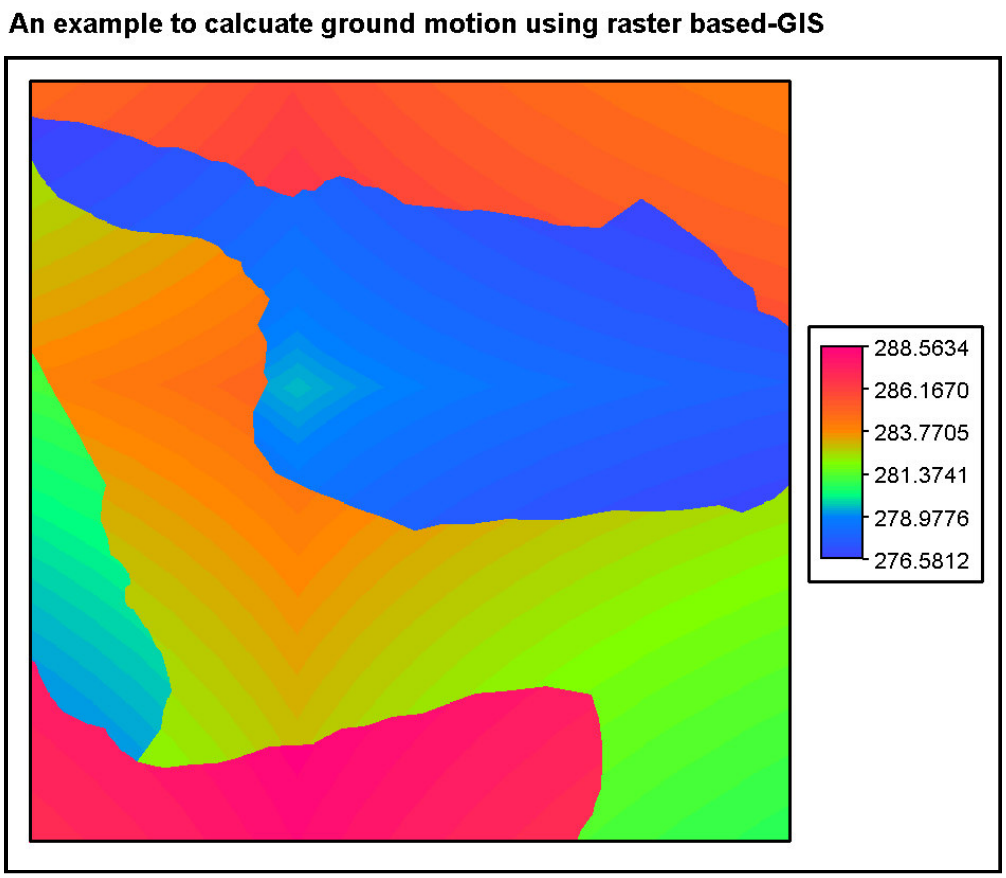

Figure 4.6 A simple example of ground motion calculation using GIS

4.5. Methods for ground motion calculation

There are a number of methods that have been used for ground motion calculation. All of these can be categorized into: observational method, statistical method, deterministic method and probabilistic method (Earthquake and Forensic Seismology and Geomagnetism Program, British Geological Survey, 2002). A brief introduction to the first three methods will be followed in this part. The whole part 4.6 will be allocated for probabilistic method, which is important for this study and also has many technical details need to be explained.

Observational method

Observational method is probably the earliest and simplest method used for ground motion calculation. It is simply by taking the observation results of strong ground motion or intensity to make a judgment of what will happen in the future. With the information of the earthquakes, the area with the similar seismogenic condition can be assigned to the similar value (Earthquake and Forensic Seismology and Geomagnetism Program, British Geological Survey, 2002). At an advanced level, extra information on maximum and mean ground motion can be evaluated in the similar way. The observation method is used in the earlier history in seismic hazard study but now it is rarely, if any, used in practice.

Statistical method

The statistical method goes one step further than the observation method. It tends to do some statistical work in order to provide more information on the seismic hazard level (Earthquake and Forensic Seismology and Geomagnetism Program, British Geological Survey, 2002). The statistical study on the earthquake records and other observation results will provide probability and extrapolation. The underlying assumption is that if we know the extreme earthquake ground motion at the site per year, then by using statistical distributions properties of these values, we can deduct the probability of what the extreme value in the next fifty years will be. But criticism on this method are: 1) the occurrence of earthquakes even in any time scale is not evenly distributed for many areas, so the extrapolation may not be valid. 2) The earthquake records often covers a shorter period of time in term of tectonic movement, so the statistical results may not fit very well because the data source is limited. This is true especially for the strong ground motion with a low annual probability. Because strong earthquakes occur with longer reoccurrence periods, the including or excluding of such event in earthquake catalogue of a certain period can influence the results too much and any conclusion based on either situation can be far away from the truth. So for the high-level seismic hazard, this method has to be treated with caution.

Deterministic method

Deterministic method for ground motion calculation goes beyond observation of effects and looks at the causes of seismicity. With the study on the seismogenic and related topics, deterministic method is to determine what is the worst that could happen in an earthquake. If the design is based on obtained the worst scenario, then the safety will be guaranteed (Earthquake and Forensic Seismology and Geomagnetism Program, British Geological Survey, 2002).

Deterministic method is useful especially where tectonic features are reasonably active and well defined. The focus is generally on determining the maximum credible earthquake (MCE) motion at the site. The steps are as following:

1) Identify the active fault or faults that will likely to cause an earthquake and study the activities of the fault or faults.
2) Assume the largest earthquake happens at the closest position to the site of consideration and determine the focal mechanism and the characteristics of the assumed earthquake.
3) Calculating the ground motion using the proper attenuation relationship and also incorporating other factors.

The advantages of deterministic method:

1) It is relatively easier to carry out than probabilistic method;
2) It is based on the genetic mechanism of earthquake there will be less exaggeration or diminishment caused by statistical results based on limited earthquake records;
3) With the improvement in the study of active tectonics, the deterministic method can do fairly well with better understanding of earthquake,

4) The deterministic method is based on tectonic features, it tends to be conservative since the maximum earthquake the fault is "capable" of generating is assumed to occur at the location on the fault closest to the site. This conservative answer is especially useful for the important structures like nuclear power plants, large dams and storage for hazardous chemicals etc.

Disadvantages:

1) It is not always the case that the seismogenic tectonics is well known or identified. The active tectonics is a relatively meaning under many circumstances. It is still hard to determine precisely the seismogenic mechanism for many areas in the world. A perfect relationship between earthquake and active tectonics is seldom available.
2) The grossly over-conservative values as the largest earthquake possible on a fault may be unpractical for many of the civil structures which last only for decades. It is not an option for seismic design to treat such large event for both technical and economic reasons. So the application of the results obtained from the deterministic method is still a problem to be discussed.
3) The deterministic method does not treat uncertainties well. Rudimentary statistics can be incorporated into the procedure by taking one standard deviation above median at each step (magnitude, PGA, etc.), which gives a very big, very conservative estimate. However, the deterministic method does not account for the probability of an earthquake occurring on a fault.

However, the simplicity of the method is attractive because it can give a sufficient first approximation to the hazard for structures where the consequences of failure are not too great.

Some efforts are made in recent years to improve the deterministic method and some of them are very convincing.

4.6. Probabilistic method

Probabilistic seismic hazard assessment (PSHA) is the one most in favour today. It is flexible, and takes into account as much data as you can have (Earthquake and Forensic Seismology and Geomagnetism Program, British Geological Survey, 2002). The probabilistic method now covers a wide range of seismic hazard assessment including the compiling of seismic zoning maps, microzoning and seismic hazard assessment for engineering structures.

The goal of probabilistic seismic hazard analysis (PSHA) is to quantify the probability of exceeding ground-motion levels at a site (or sites) given all possible earthquakes (Field, 2000). Thus, the probabilistic method provides a clear picture of the intensity of ground motion and its probability within certain period. Probabilistic method rectifies several problems inherent in its deterministic predecessor - the lack of quantification of uncertainty and probability of earthquake occurrence. The uncertainty is quantified by a probability distribution at each step. Distributions are determined for the magnitude of each earthquake on each source f (M), the location of the earthquake in or along each source f(r), and the prediction of the response parameter of interest $P[PGA > a_0|M,r]$((Earthquake and Forensic Seismology and Geomagnetism Program, British Geological Survey, 2002)).

Thus the result from the probabilistic method is far more useful for seismic hazard prevention and civil design, though the validity of the results obtained using PSHA still depends on many factors. With both the level of seismic hazard and its risk, it would be possible for the engineers and other professionals to opt for the seismic hazard level that should be well endured by their structures while the corresponding risk level is acceptable for their structures. Thus, the high cost incurred by the conservative safe value or the unexpected high risk as a result of reduce cost without deliberation are both avoided given that the PSHA are applied in the proper way.

The analytical PSHA approach was first formalized by Cornell in 1968. One of the most comprehensive treatment to date for the PSHA is the SSHAC (Senior Seismic Hazard Analysis Committee) 1997 report "*Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts, US Nuclear Regulatory Commission report* ***CR-6372****, Washington DC*", which covers many important procedural issues (such as the use of "expert opinion", the meaning of "consensus", and how to document results) that are important for the application of PSHA. Except where otherwise noted, the SSHAC report represents the best source of additional information (Field, 2000).

The basic theory of probabilistic method is like this:

1) Select a site as site of interest at a particular area.
2) For this site of interest, it has source zone nearby, and earthquakes in the source zone could affect the site of interest.
3) The source zone can be divided into one or several seismic sources according to tectonics or other seismogenic evidence. (Fig 4.7)

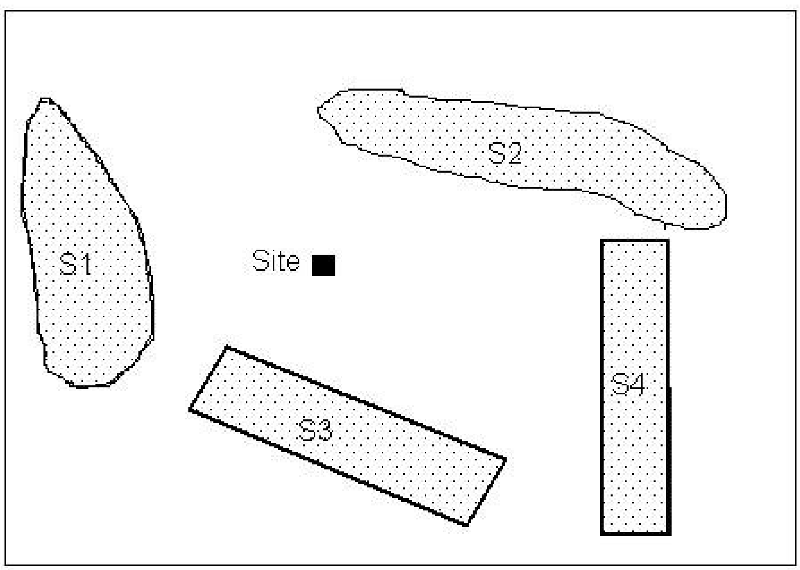

Figure 4.7 Site of interest and seismic sources

4) Each seismic source has certain characteristics. A simple assumption is that earthquakes have an equal probability of occurring at any spot in the source. At an advanced level, the source can have a more complicated model so that the information such as the strike of fault, the sta-

tistical results of spatial distribution of earthquake occurrence, the difference of earthquake magnitude and earthquake mechanism may be identified spatially etc.

5) There is a catalogue of earthquakes that occurred in the source zone available, so the probability of an earthquake of a given magnitude occurring in the zone in a period in future can be worked out. In case that such information is not good enough due to lacking of records or scarce study has been done, further data must be derived from the seismogenic or active tectonics study or comparison between similar situations. The frequency distribution of earthquakes is well described by the Gutenberg and Richter equation (1966).

$$Log(N) = a - bM \tag{4-16}$$

Where N is the frequency of earthquake, M is the magnitude, a and b are both constants.

6) Considering a certain period for seismic hazard level calculating, for example next 50 years. The selection of the period of exceedance probability will mainly depend on what is the hazard level to be considered. If the levels of seismic hazard to be considered are very high such as for the nuclear power plant, then the period should be much longer usually 500 or even 1000 years should be selected. Otherwise, for ordinary civil buildings the period considered should be shorter, usually 50 years.
7) The exceedance probability of ground motion at certain level is the probability that the ground motion will exceed such a level in certain period in the future. So this indicates what is the risk have to be faced if the design of a structure can resist ground motion up to this level of ground motion. With the exceedance probability of ground motion, we can get valuable information on the safety and risk we shall mostly like to have.
8) Consider first a possible level of ground motion, say PGA 0.2g, and a possible magnitude of earthquake, say 6.0. The PGA caused by this earthquake decreases from the epicentre. So an attenuation relationship should be determined to calculate the PGA at the site.
9) The attenuation relationship, which is based on the statistical results of observation, is anything but absolute due to condition variation such as site condition, direction to the focal mechanism, etc. and also the anisotropic nature of the earth crust. The uncertainty of ground motion predicted by the attenuation relationship can be substantial and must be taken into consideration to reflect the reality.

In Fig 4.8 an example of the ground motion relationship developed by Boore, Joyner and Fumal (1997) is used for illustration. The scattering of the real PGA to the attenuation relationship is obvious and its distribution is proved to follow the normal or Gaussian distribution. That is:

$$P(\ln PGA) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(\ln PGA - g(m,D)^2/2\sigma} \tag{4-17}$$

Where P is the distribution probability, σ is the standard deviation of lnPGA distribution. Parameter m and D are respectively the magnitude of earthquake and the distance from the source. g(m, D) is the ln(PGA) value provided by the attenuation relationship, which is also the mean of distribution range and corresponds to the highest probability.

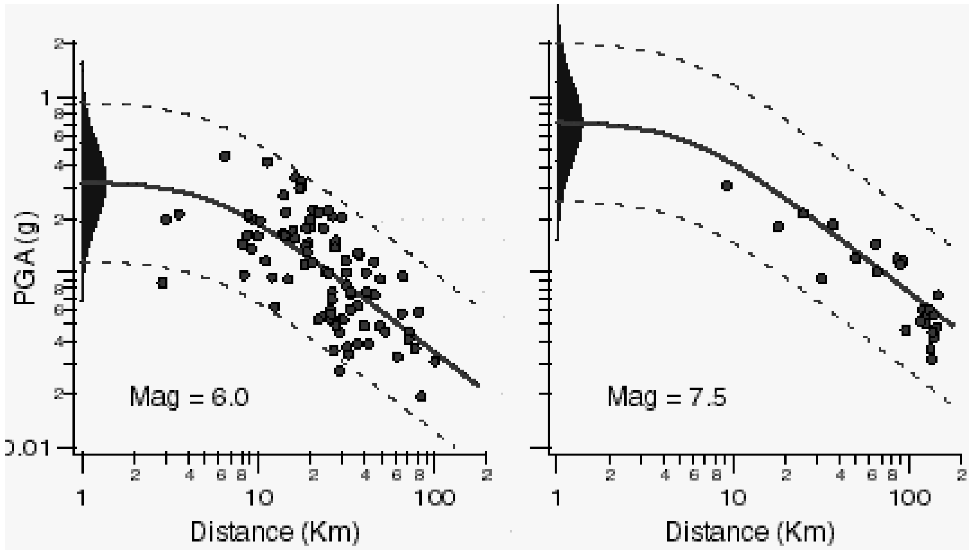

Figure 4.8 PGA values scattering & attenuation relationship (*Revised after Field, 2000***)**

An illustration of the distribution of lnPGA is shown as Fig 4.9.

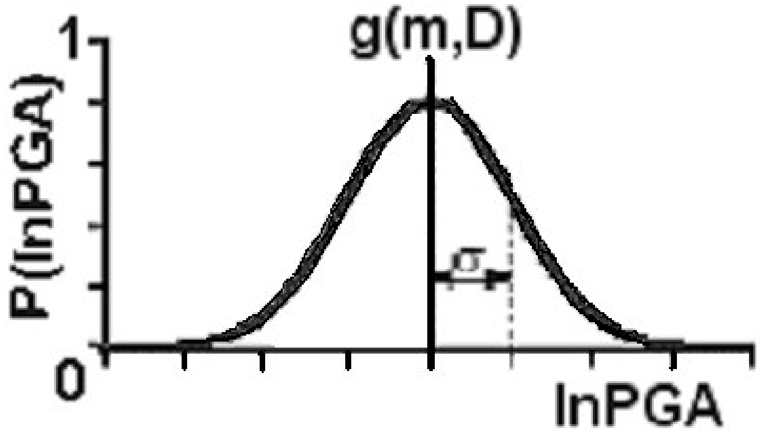

Figure 4.9 the distribution of ground motion (revised after Field, 2000**)**

The standard deviation of lnPGA is typically around 0.5 for this case. According to the rules of normal distribution, 95% percent of the PGA will fall within the rang of ln(PGA) ± 0.5.

The exceedance probability of lnPGA can be determined by integrating the distribution function (4-11), which produces:

$$P(>\ln PGA) = \frac{1}{\sigma\sqrt{2\pi}} \int_{\ln PGA} e^{-(\ln PGA - g(m,D)^2/2\sigma} d(\ln PGA) \quad (4\text{-}18)$$

Fig 4.10 is an illustration on the accumulation of distribution.

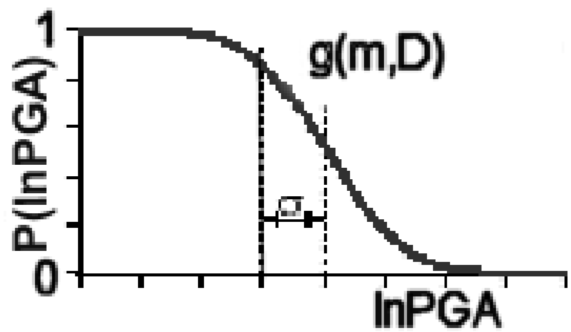

Figure 4.10 exceedance probability of ln(PGA)

It is easily concluded that when the PGA is larger and larger, the exceedance probability approaches to 0. That is, such even are seldom likely to happen. But at the lowest PGA level, the exceedance probability will reach 1, that is to say event like this are surely to occur in future.

Unfortunately, formula (4-18) cannot be integrated directly; it has to be done by using the standard normal distribution table, which can be found from the appendix of statistics books. By using the magnitude and location of site of interest, exceedance probability contributed by this magnitude of earthquake from the source for certain level of ground motion can be calculated.

By the similar way, we can calculated the exceedance probability caused by other magnitudes and sources.

10) Apart from the exceedance probability of ln(PGA), the probability of magnitude in certain period should also be considered. Simply, the annual rate of magnitude derived from the earthquake frequency relationship can be used:

$$R_m(>\ln PGA) = r_m * p(>\ln PGA) \qquad (4\text{-}19)$$

Where R_m and r_m are respectively the annual rate of exceedance probability of ground motion and annual rate of earthquake occurrence, which is different for different seismic source.

But it is actually impossible to calculate the annual rate of all of the magnitudes, because there are so many possibilities. In practice, it is often to divide the magnitude into small partitions, and the annual rates of the partition are used, so that the number of magnitude would be reduced substantially for calculation. Fig 4.11 is an illustration.

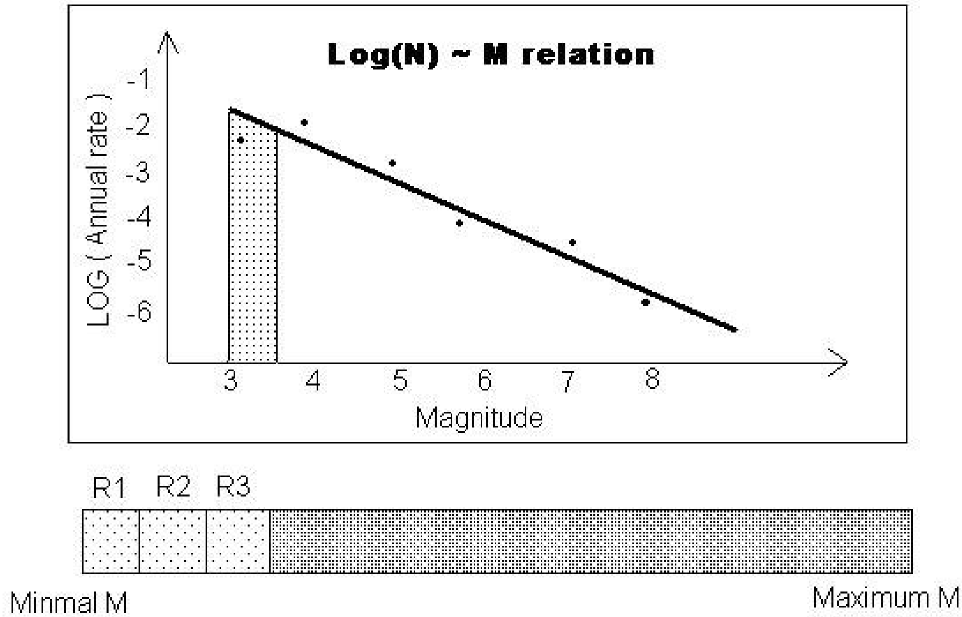

Figure 4.11 the reduction of magnitudes by partition of magnitude range

Also, to make the calculation sense, it is also necessary to exclude the great earthquakes that will never occur in the source and the small earthquakes that will actually cause only trivial ground motion at the site of interest. The Log(N) ~ M relationship is often truncated.

11) Unless the seismic source is relatively small, the difference of the location of the earthquake in the seismic source should also be considered. This also causes another probability on distance. The determination of the probability related to distance varies a lot due to the different seismic source model adopted. Here will not discuss this problem until in the later part, where there will be an explanation of the simple method used in this study. So the final result of annual exceedance probability of ground motion at certain PGA lever can be expressed as:

$$r_i = \sum_{j=1}^{m} \sum_{k=1}^{n} P(M_j) \cdot P(D_k) \cdot P(PGA > a_i | M_j, D_k) \qquad (4\text{-}20)$$

12) For the period concerned the time-independent Poissonian probability distribution is often used to calculate the exceedance probability in certain years. This formula can be expressed as:

$$P_i(PGA > a_i) = 1 - \exp(-r_i T) \qquad (4\text{-}21)$$

Where T is the period in years; $P_i(PGA > a_i)$ is the exceedance probability of PGA level a_i.

13) The exceedance probability of many PGA levels can form a hazard curve, which is more useful for design purpose.

The probabilistic method is ideally suited to compiling hazard maps. Having drawn up the seismic source zone model for a large area, the calculations are made for a grid of points instead of just one, and the values are contoured to give a picture of the spatial variation of the hazard.

Traditionally, peak ground acceleration (PGA) has been used to quantify ground motion, since PGA it's used to define lateral forces and shear stresses in the equivalent-static-force procedures of some building codes, and in liquefaction analyses. Today the preferred parameter is Response Spectral Acceleration (SA), which gives the maximum acceleration experienced by a damped, single-degree-of-freedom oscillator (a crude representation of building response). The oscillator period is chosen in accordance with the natural period of the structure, and damping values are typically set at 5% of critical (Earthquake and Forensic Seismology and Geomagnetism Program, British Geological Survey, 2002).

Some problems related to probabilistic method

Although probabilistic method is well accepted, it is not without critics. Some of the flaws and problems are:

1) The definition of seismic source model is a difficult thing, sometimes. The earthquake catalogue one has to work with is often too short to show all the information on earthquakes that might happen in the future. It is therefore necessary to make a number of interpretative decisions based on both geological and seismological studies in order to build up the proper seismic source model used for calculation. Since sometimes, a small difference in the model can cause quite large effects on the ground motion at a site, it is important to take great care over the details of the seismic source model. This does mean that probabilistic method is a much more major undertaking than in the methodologies described previously. But on the other hand, the large amounts of data that can be used to justify the model do increase the power of the method.

   A further refinement can be introduced: if some parameter (for example, the maximum magnitude that could occur within a zone) is imperfectly known, it is possible to introduce a range of possible values for this parameter, each with a weighting as to how credible the value is. By repeating the analysis for every possible combination of values of each parameter, one can calculate a mean hazard value with error bars that reflect the uncertainties in the original data. This can be very powerful if used carefully; alternatively it is possible to introduce so many arbitrarily assigned weighting values that the model loses touch with reality (Earthquake and Forensic Seismology and Geomagnetism Program, British Geological Survey, 2002).
2) A dilemma is that the actual earthquake can be larger than the hazard analysis predicts, but will likely be smaller than a deterministic estimate. Then, the question of what is to be used to design for becomes difficult. The main purpose of the characterization carried out using probabilistic method is to determine the earthquake ground motions, but which will be used in the design of the structure? While values of peak ground acceleration, velocity and displacement are interesting and important parameters, they provide little useful design information by themselves. Ground motion time histories and response spectra are needed for the design and

analysis of the structure in a more reliable fashion. But still there is a long way to go to find this kind of solution.

3) The calculations and theories are very complex and different individuals use a varying amount of restrictions. Also, many assumptions are involved due to the limited amount of data available.

4) Another objection to PSHA is the degree of subjectivity and personal judgment that have to be used in probabilistic method. Some seismologists are looking for ways round this by using a smoothed version of the original seismicity in place of source zones.

Time dependent or time independent?

Probabilistic method makes use of a principle known as stationarity. This maintains that the seismic hazard at a place is constant in the same length of time, that is the expected intensity in 50 years is the same whether the 50 years in question starts in 1990 or 2000. Commonsense suggests that this is probably not true: in the case of an area where there has recently been a big earthquake, seismic energy has been dissipated and there should now be a long period before it builds up again; conversely there are other areas where a big earthquake appears to be due or even overdue. In this case, the seismic hazard risk should be much higher.

Modifications to the probabilistic method have been made in which parameters describing average inter-event times, and time since last event, are introduced. In some cases this is an improvement of the PSHA method, but it may not be true for other area where large earthquakes have occurred in places where one might have thought the cycle was still building up after a recent earthquake, and seismic gaps have remained stubbornly free of earthquakes that were thought to be imminent. So the comments for time dependent vs. time independent are still not very distinct.

What is an acceptable risk?

A hazard curve produced by probabilistic method tells what the probability is of any particular strength of ground motion, which works quite well for understanding the seismic hazard that will like to face in the future. However, it doesn't indicate which value you should choose to design your building against the seismic hazard. Do you want to be 60% safe, 90% safe, or 95% safe? These are really economic or political decisions, and sometimes are hard to make a simple one (Earthquake and Forensic Seismology and Geomagnetism Program, British Geological Survey, 2002).

Also, one has to bear in mind that low probability events do happen sometimes, and we do not know exactly when it will happen. If the low probability events came up much sooner than we expected, the results may be disastrous. While we feel more confident that ever with the good results provide by the probabilistic method, one has to take care of the design to make appropriate interpretation and application of the seismic hazard curve. For the structure of different kind, different kind of caution should be given. What’s more other issues like economic cost, technical feasibility etc. are also important factors to be gauged.

Chapter 5. Methods Used in Ilwis/Visual Basic Application

Three methods, simple ground motion assessment, bi-direction ground motion assessment and a simplified probabilistic method have been developed in the Ilwis/Visual Basic application for seismic hazard assessment. They can be used for difference situations, which have much to do with the available data and the objective of the users.

The first two methods are largely deterministic in nature, because it is up to the user to make an earthquake scenario. In the simple ground motion assessment, some seismicity information is provided for the user in order to make a judgment of the magnitude of a scenario earthquake. The distance from the epicentre is left to be decided by the user. In the bi-directional method there is no explicit information on seismicity. The assumption is that the user already knows well the bi-directional attenuation formula and the potential seismic source for his study. The magnitude indicated by the user will sometimes be related to probability given that it is deduced based on the seismicity statistics. The two deterministic methods are using attenuation formula to calculate the ground motion. The third method is a simplified probabilistic method, which is using an earthquake catalogue and a simple model of seismic sources. Some of the limitation resulted will be discussed later.

5.1. Simple ground motion assessment

This method provides a crude assessment using attenuation relationships to meet the need where there is no much data available. The schematic diagram of this method is shown in Fig 5.1. As it is shown, the requirement of input of the method is quite low and also is highly flexible if the user does not have good seismicity data at hand. Generally, there are two approaches to get the PGA results. User can start either with regional frequency-magnitude formula or with the seismicity information in global scale.

For an easy estimation, which is only a rough assessment for an earthquake zone, the expected magnitude associated with different return periods are listed for chosen area. The user can then use this information as input to calculate PGA using selected attenuation formulas.

But it is better that there is a magnitude-frequency relationship available, so that the choice on magnitude would be more sensible. As a test, two magnitude-frequency relationships are included in the Visual Basic interface. Thus magnitudes for different return periods can be evaluated.

Several attenuation relationships (Joyner & Boore, 1981; Fukushima & Tanaka, 1990; Campbell, 1981) are provided for selection, so this method can be used for a wide variety of areas with different seismogenic environment. The results from these attenuation formulas are PGAs.

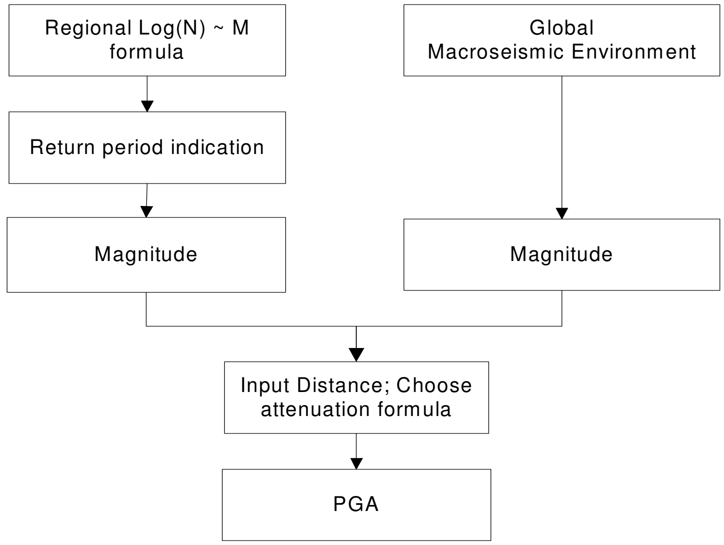

Figure 5.1 Schematic diagram of simple ground motion assessment

No clue on the distance from the epicentre is given, which is also impossible since the seismicity in different area cannot be able to handle in one way. The users should determine the location of the earthquake based on information available or his knowledge.

Fig 5.2 is the Visual Basic interface for simple ground motion assessment. On the upper left is the earthquake zone list, where once an area is selected some information on magnitude can be automatically shown in the lower right textbox. Beneath are the listbox for frequency-magnitude relationships and the automatic magnitude calculating for different return period using the frequency-magnitude relationships. Upper right hand is for the selection of attenuation relationships. In the middle of the right is the complex for PGA calculating which is also carried out automatically with the input.

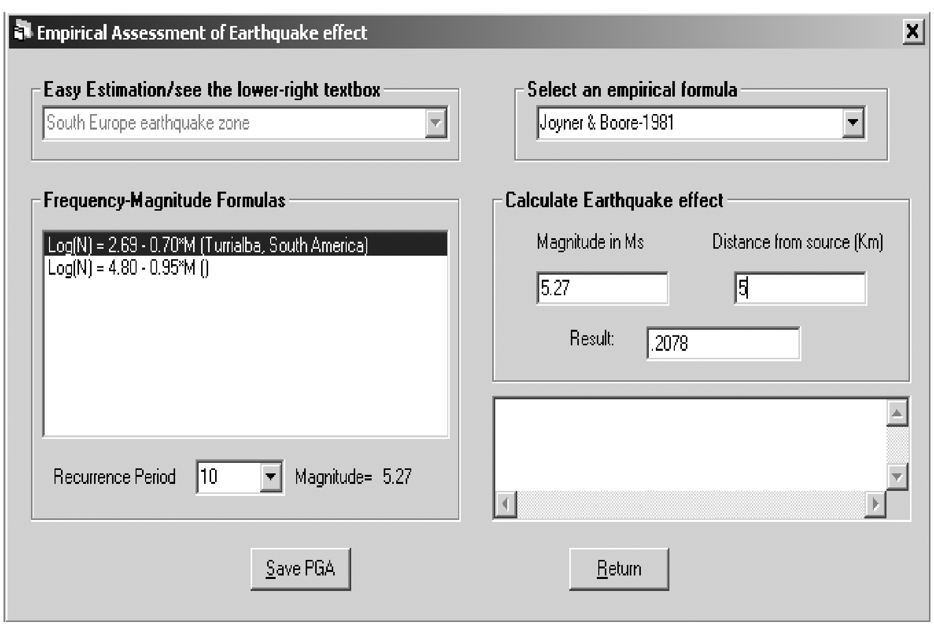

Fig 5.2 User interface for simple ground motion assessment

The “Save PGA” button is to store the PGA results in the mission file for later use.

The simple ground motion assessment does not require any Ilwis operation, it is all carried out within the Visual basic interface. This method is simple and it does not need much background knowledge. But since only very limited information is used, this method is only able to give a preliminary assessment of the seismic hazard. The high flexibility and simplicity also mean the results are general ones, and should not be used for practical studies, where local condition such as the soil and topography as well as the geological condition affect the ground motion.

5.2. Bi-directional method

It is widely observed that the ground motion attenuation is not at the same rate for the different directions from the epicentre. Except from the anisotropy of geological conditions, the earthquake mechanism and the strike of fault are of vital importantance.

If the earthquake is near the site of interest, the earthquake mechanism is usually an important factor affecting the ground motion attenuation. But if the earthquake occurred far away from the site of interest, earthquake mechanism would not be very important due to the long distance of wave propagation. Under most circumstances, fault type is an important factor that affects the ground motion attenuation.

Often, two directions determined by the fault or earthquake mechanism are used for the assessment of ground motion attenuation. They are the directions with the least and strongest ground motion attenuation and are called “axis”.

Many bi-directional models for ground motion attenuation are developed for a better prediction of ground motion. Bi-directional methods calculate ground motion with separate attenuation formulas for each of the two axes.

The elliptical model is the most widely used bi-directional model. It fits the seismic hazard distribution very well. The attenuation difference along and perpendicular to the fault can be incorporated with different parameters assigned.

It is much easier to apply the elliptical model within GIS. The method used in this study will be explained below.

The general form of ground attenuation for both axes in an elliptical model is well knows as:

$$I = C_1 + C_2 * M - C_3 Ln(R + C_4) \qquad (5\text{-}1)$$

Where R is the distance to epicentre, C_1 to C_4 are all constants, M is the magnitude. I is the intensity, but it can also be PGA.

Before any calculation, all the constants and the magnitude should be determined, therefore, except for R all others can be regarded as constants. Thus, formula for two axes x and y can be simplified as:

X axis: $I_x = a - b\ln(R_x + C)$ (5-2)

Y axis: $I_y = a - b\ln(R_y + C)$ (5-3)

The steps involved are:

1) To delineate two axes a and b separately and manually in two segment maps. The background area should be larger enough to contain at least the most active part of the fault. Then make two raster maps with the two segment maps. Usually axes a and b should be determined based on the fault strike or the known focal mechanism. If there is obvious directional difference in ground motion, the two axes should be long enough or cross the whole area of interest. But if the directional difference diminishes when it is far away from the epicentre, or the area covered is very large, then the axes should have a limited length in the map to reflect the fact that there would be less or no directional difference.

2) With the raster maps represent a and b axis, then carry out distance operation with Ilwis to get distance maps. If the distance in the bi-directional attenuation formula is not the physical distance, but a artificial distance based on certain modification of physical distance, then distance maps representing R_x and R_y should be further processed to be in consistence with the bi-directional attenuation formula.

3) In next step, calculate I_x and I_y separately using maps for R_x and R_y and the two attenuation formulas for a and b axes. In Ilwis, this would be easily accomplished with Ilwis expressions. The result in this step is the two maps representing I_x and I_y.

4) Finally, I can be calculated with using the two components I_x and I_y using the formula for vector adding in Cartesian coordinate system:

$$I = \sqrt{I_x^2 + I_y^2} \quad (5\text{-}4)$$

Therefore, bi-directional model for ground motion attenuation can be realized in a stepwise approach in Ilwis relatively easily. Fig 5.3 is the schematic illustration for bi-directional methods.

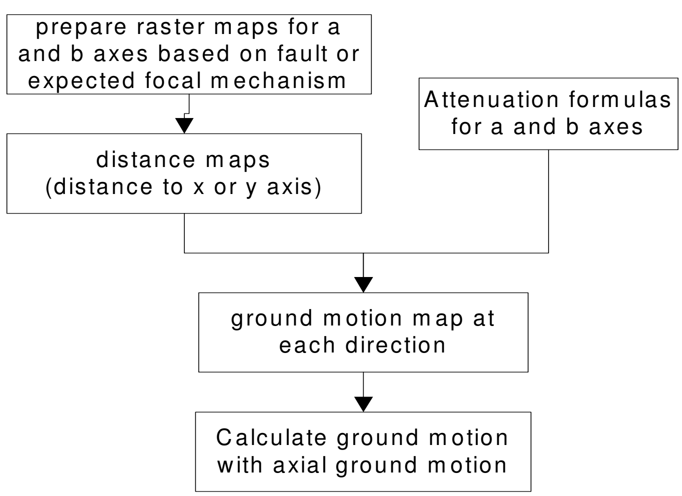

Fig 5.3 A schematic illustration of bi-directional method for ground motion calculation

Fig 5.4 is the Visual Basic interface designed for this method. From upper to the lower part, they are axes maps indication, bi-directional attenuation model options and parameters setting and name of output and intermediate maps. After all the input finished, click “Ok” button, all the operation can be carried out automatically in Ilwis.

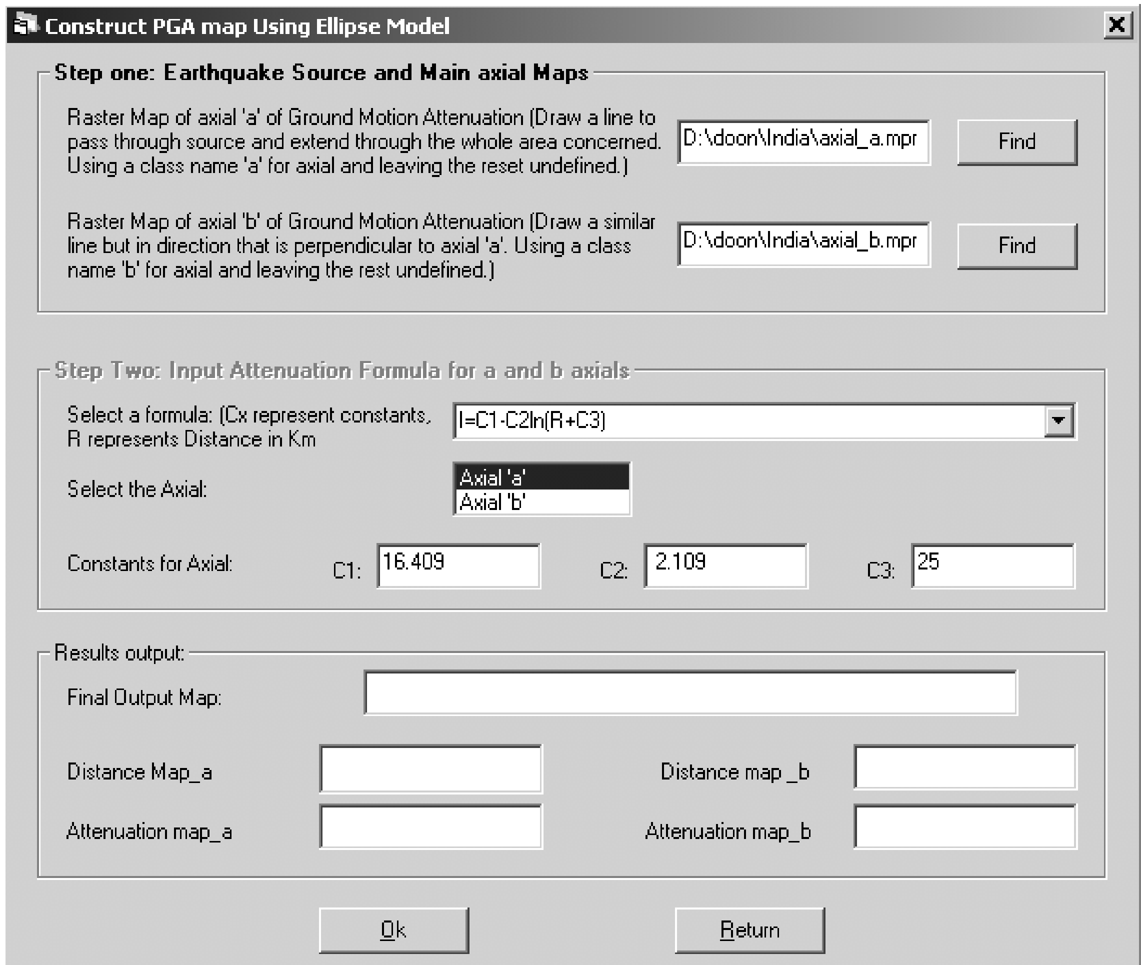

Figure 6

Figure 5.4 Visual Basic interface for bi-directional ground motion attenuation assessment

Fig 5.5 to Fig 5.7 are some of the results from an example operation using the interface. Fig 5.2 shows the ground motion attenuation axes determined upon the fault direction. The distance maps for both axes are not shown to avoid redundancy. Fig 5.3 is the result of intensity for two directions, I_a and I_b. The elliptical formulas used are those for West China (see formula 4-3, 4-4). The assumed magnitude is 7 in this example. So the simplified formula should be:

Long axial: $I = 16.409 - 2.109 Ln(R + 25)$ (5-5)

Short axial: $I = 12.482 - 1.494 Ln(R + 7)$ (5-6)

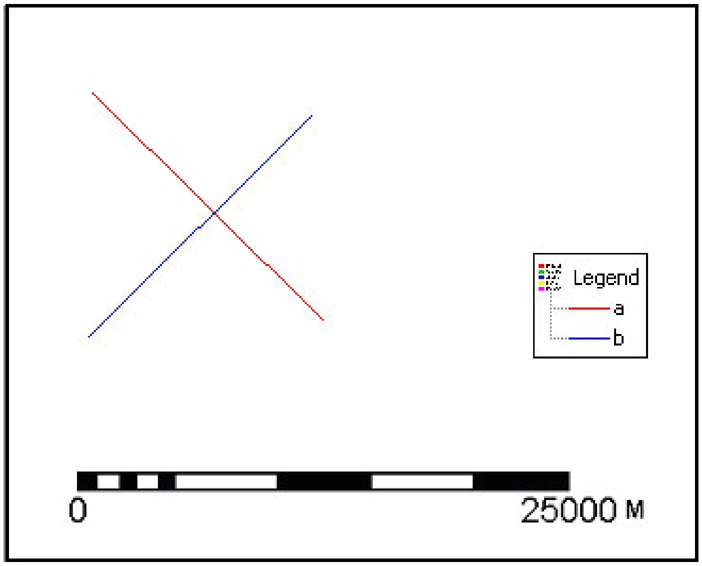

Fig 5.5 the axes for elliptical ground motion attenuation

The axes did not draw throughout the map in order to take into account that the directional difference will be less when it is farther from the epicentre. The values in Fig5.6 are continuous to keep the precision for following operations. The attenuation becomes more homogenous as it is far away from the epicentre.

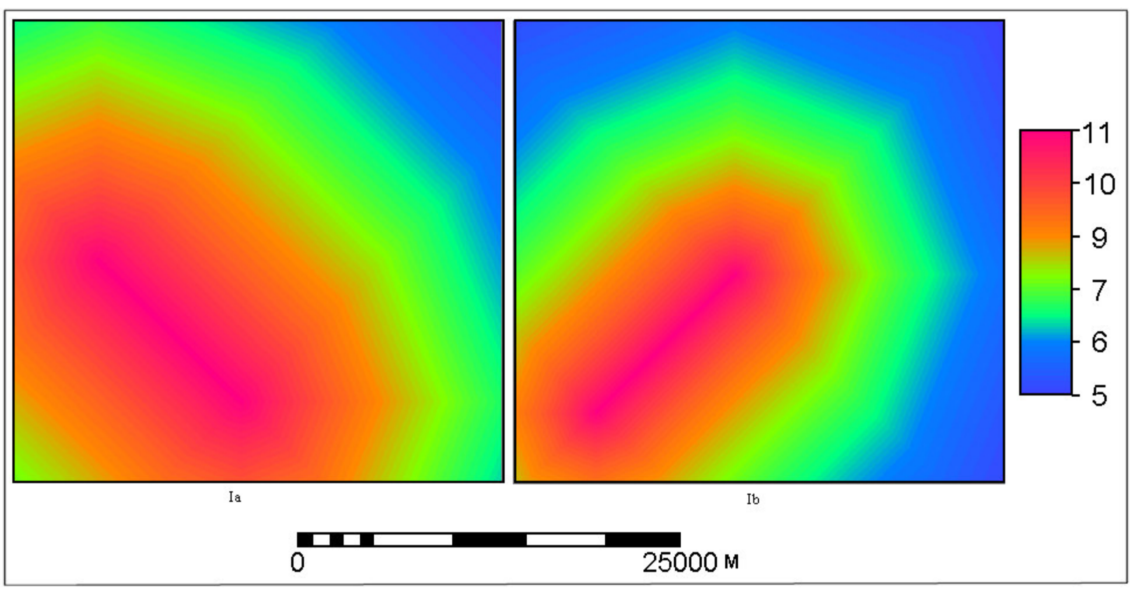

Fig 5.6 I_a and I_b

Fig 5.7 is the final map, where the values are rounded to be in accordance with the MMI scale values. It can be found that the shape of the ellipse inside the map is not very good. This is caused by the limitation of Ilwis, which uses an approximating method to calculate the distance for raster cells. The accumulation of the small amount of distance errors will cause significant “edge”. But it is not related to the method used for calculating ground motion, rather an inheritance from Ilwis operation. When it is far away from the epicentre, the shape of intensity isoseismic lines is nearly circular, which confirms the expectation.

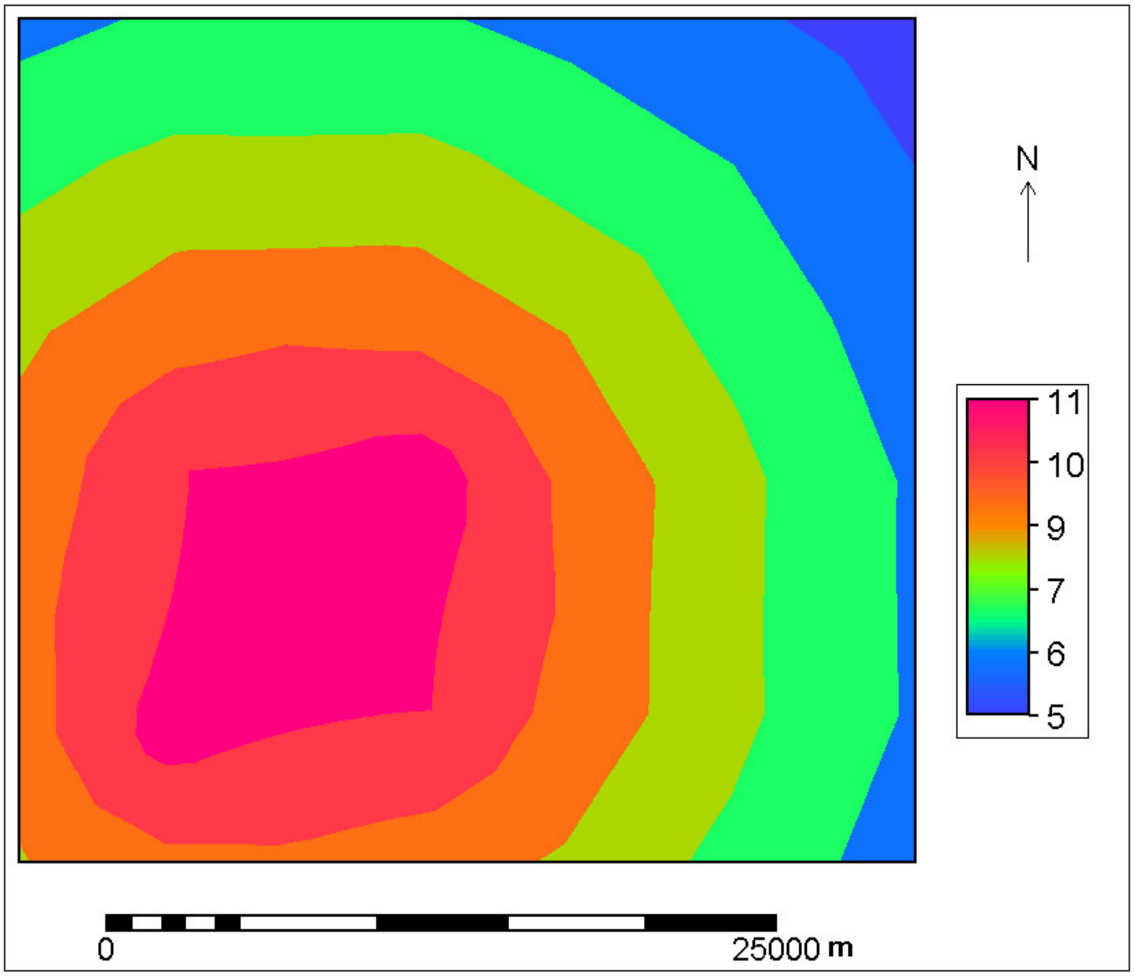

Fig 5.7 Final map for intensity

If it is necessary, the ground motion map produced by the bi-directional model such as elliptical model can also be refined using other maps such as the geological and topographic maps to incorporate more factors. A simple way is to use a factor map to do this, which is realized the Ilwis/Visual Basic application.

Maybe, the most interesting point in the above-mentioned method is how to use a Raster-based GIS to realize numerical methods in ground motion attenuation. Usually for an objective spatial function $G = f(x_x, x_2, \ldots)$, it is impossible to take all the spatial variables into consideration at a time in GIS. So the objective function should be replaced by several parameter equations to make sure that each of the equations can be solve at a time in GIS. After all of the parameter equations are solved, the final result can be obtained using the results of the parameter equations.

4.6 Simplified probabilistic method

The probabilistic method adopted in the study is a simplified version based on the general principles of probabilistic method. This is because it has to be feasible in GIS. And as a preliminary study, the technical difficulties to realize such a method should be moderate to come in terms with the planned time. With consideration to have a miniature of the probabilistic method while keeping the method practical, some simplifications are made. The mains steps for this method are:

1) *Calculation of frequency-magnitude relationship using an earthquake catalogue;*

There should be a good earthquake catalogue so that this step is possible. The earthquake catalogue with scarce records or large intervals of missing recording should not be used for this purpose because it cannot produce reasonable results.

The earthquake catalogue is assumed to be in Ilwis table form with certain format to have the unified name for domains such as years (named as "year", value domain) and magnitude (named as "Ms", value domain). This format is necessary to carry out operation automatically later.

The first step in the calculation is to read the frequency of magnitude from the catalogue table. A general rule applied to check the credibility of the earthquake catalogue is that the smaller the magnitude is, the larger the frequency should be. The magnitude conflicting with the rule will be neglected because it is largely a result of missing records. Then the logarithm of frequency is calculated so that the problem becomes a linear one, or

$$F_{\log} = a - bM \qquad (5\text{-}7)$$

Given Δ is the total residual, so

$$\Delta = \sum(\overline{F}_{\log} - (F_{\log})_i) = \sum(a - bM_i - (F_{\log})_i) \qquad (5\text{-}8)$$

Where $\overline{F}_{\log}$ is the mathematical expectation of logarithm of frequency for magnitude M_i, $(F_{\log})_i$ is the observed value of logarithm of frequency for magnitude M_i.

According to the least square method, which is a classic method for regression, to get the best fitting Δ should be the minimum value of all possibilities of a and b. To get such a minimum value, it requires:

$$\begin{cases} \dfrac{\partial \Delta}{\partial a} = 0 \\ \dfrac{\partial \Delta}{\partial b} = 0 \end{cases} \qquad (5\text{-}9)$$

So we have equations 5-10 and 5-11.

$$\frac{\partial \Delta}{\partial a} = \sum(a - bM_i - (F_{\log})_i) = 0 \qquad (5\text{-}10)$$

$$\frac{\partial \Delta}{\partial b} = \sum(a - bM_i - (F_{\log})_i)(-M_i) = \sum(-aM_i + bM_i^2 + (F_{\log})_i M_i) = 0 \qquad (5\text{-}11)$$

The final solutions for equation 5-10 and 5-11 are:

$$b = \frac{\sum M_i (F_{\log})_i}{\sum M_i^2} \quad , \; a = \overline{F}_{\log} - b * \overline{M} \tag{5-12}$$

Where $\overline{F}_{\log}$ and $\overline{M}$ are respectively the mean of $F_{\log}$ and M.

The correlation coefficient r is given by:

$$r = \frac{\sum M_i (F_{\log})_i}{\sqrt{\sum M_i^2}\sqrt{\sum (F_{\log})_i^2}} \tag{5-13}$$

If the earthquake catalogue used is reliable, experiences show that r is often large than 0.95 to indicate a high degree of correlation.

2) *Determining of maximum & minimum earthquake magnitude and maximum influential distance;*

The fitting formula for frequency-magnitude is only valid mathematically, there has to be a limitation to make the analysis sensible and reflect the reality. I used an informed subjective approach, in which the user will need to make a decision based on the information of the possibilities of occurrence of magnitudes within 50 years.

For a Poissonian process the exceedance probability of an event above M_i in T years is given by 5-14.

$$P_e(M > M_i) = 1 - \exp(-r_i T) \tag{5-14}$$

Where r_i is annual rate. Table 5.1 gives an idea of the exceedance probability in 50 years and associated annual rate and return period using the transformation of formula 5-14.

$$r_i = -\frac{Ln[1 - P_e(M > M_i)]}{T} \tag{5-14$'$}$$

Table 5.1 the exceedance probability and corresponding annual rate, return period

Exceedance Probability in 50 Years	Annual rate	Logarithm of annual rate	Return period
1%	0.00020101	-3.69679	4975
2%	0.00040405	-3.39356	2475
5%	0.00102587	-2.98891	975
10%	0.00210721	-2.67629	475
15%	0.00325038	-2.48807	308
20%	0.00446287	-2.35039	224
30%	0.0071335	-2.1467	140
40%	0.01021651	-1.9907	98
50%	0.01386294	-1.85814	72
60%	0.01832582	-1.73694	55
63.5%	0.02015716	-1.69557	50

Table 5.1 also explains sometimes the confusing expression heard, such as “exceedance probability of 10% in 50 years”, or “the return period is 475 years.” So we know they are actually the

same thing but in different terms of expression. In many nations the most often used exceedance probability in 50 years for seismic hazard at different levels are 2%, 10% and 63.5, and the return periods corresponding respectively are 2500 years (often roughly considered so), 475 years and 50 years. The 1% exceedance probability is not common in application, but sometimes may be used for structure of extreme importance or disastrous and it means a return period of roughly 5000 years.The largest event possible will be determined based on their exceedance probability in 50 years. Usually, an exceedance probability of 10% is enough.

On the other hand, there is need to set a limit on the smallest earthquake magnitude, because the calculating with the small earthquake not only affects the final results very little, but also there is nothing to be fear from such events. The most likely minimum earthquake should be within 2.5 to 4 depending on the distance from source and the need for seismic safety. If the seismic source is near the site and the seismic safety requirement is high, so a low value should be assigned. On the contrary, if the seismic source is far away, or the safety requirement is not very rigid for small events, then it should be a larger value.

The maximum distance of influence stems out of the same reason as that for the minimum earthquake magnitude. Calculating with a distance far away from the earthquake would be meaningless and so it should be shunned. But it has to be left as a matter of subject choice, which will largely rely on past earthquake investigations. A value proposed for conventional use is 200km, but it can be changed in the user interface to meet the different needs.

3) Calculating of probability associated with magnitude;

Magnitude associated probability can be determined using the frequency-magnitude formula. This results is only for annual rate, but later can be incorporated with other probabilities for the final results.

$$\int_{M_1}^{M_2} r_m dm = \int_{M_1}^{M_2} 10^{(a-bM)} dm = \frac{b \cdot 10^{(a-bM)}\Big|_{M_1}^{M_2}}{\ln 10}$$
$$= 0.4342945 \times b(10^{(a-bM_1)} - 10^{(a-bM_2)}) \qquad (5\text{-}15)$$

Where r_m is the annual rate of magnitude m, m_1 and m_2 are lower and upper limit for integration; "dm" expresses the variable of integration. Ln(10) is replaced with 0.4342945 for calculation. To reduce the onerous calculating, the magnitude range from minimum to maximum magnitude is divided into 20 intervals. And the mean of the intervals ($M_m = (M_1 + M_2)/2$) is used to calculating PGA in the attenuation formula. This, of course, causes some errors, but it is still acceptable. If the error needs to be reduced, the number of interval should be increased. In my study, it is thought that 20 is enough, since the range of magnitude is less than 5 (often the maximum earthquake is below 8, and the minimum is above 3, 8-3=5).

4) Calculating of probability associated with the distance;

The distance from the epicentre to the site is rather hard to be determined. This is due to the fact that not only the seismic source often remains obscure to some extent for its spatial inhomogeneity, but also the anisotropic and the tectonic features in the medium of propagation make that the purely physical distance cannot be linked directly to ground motion (Fig 5.8).

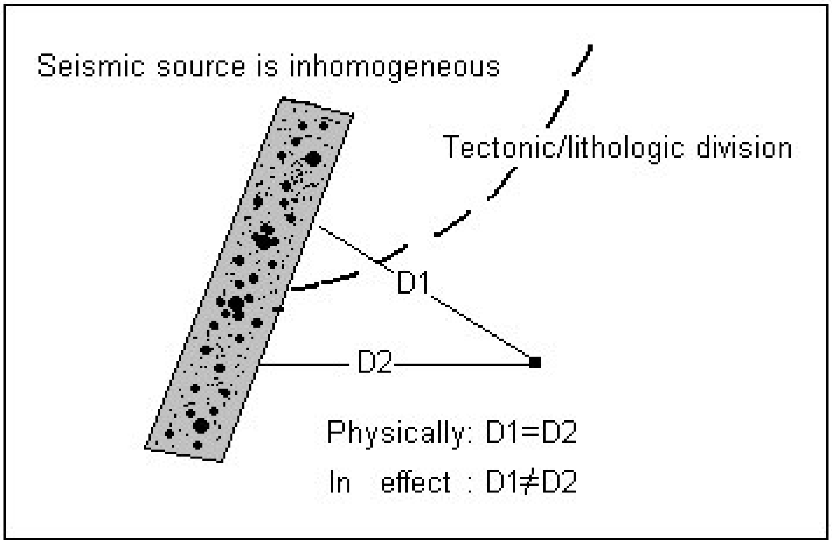

Figure 5.8 the inhomogeneity of seismic source and anisotropy of medium of wave propagation

In my study, a simple approach is used. The distance-associated probability is calculated based on assumption: 1) the seismic source is homogenous, and 2) the medium is isotropy.

Because there are numerous distance values, it is better to classify it several distance classes to reduce the calculation without causing too much error. Fig 5.9 shows the result of classification of the distance from the site of interest to maximum influential distance into 10 classes. Each of the distance classes will be represented by the middle value of the distance. So there would be only 10 possibilities to be considered in calculation.

The probability of each of the ten distances depends on the probability of the earthquake that will happen in each of the distance belts. Since the seismic source is considered as homogeneous, there is equal chance for an earthquake to happen at any point inside the seismic source. For this reason, the probability is actually geometric probability, which can be calculated with the area (formula 5-16):

$$P_d = \frac{A_c}{A_0} \tag{5-16}$$

Where P_d is the probability of a certain distance class, A_c is the overlap area between the distance class and the seismic source. A_0 is the area of seismic source.

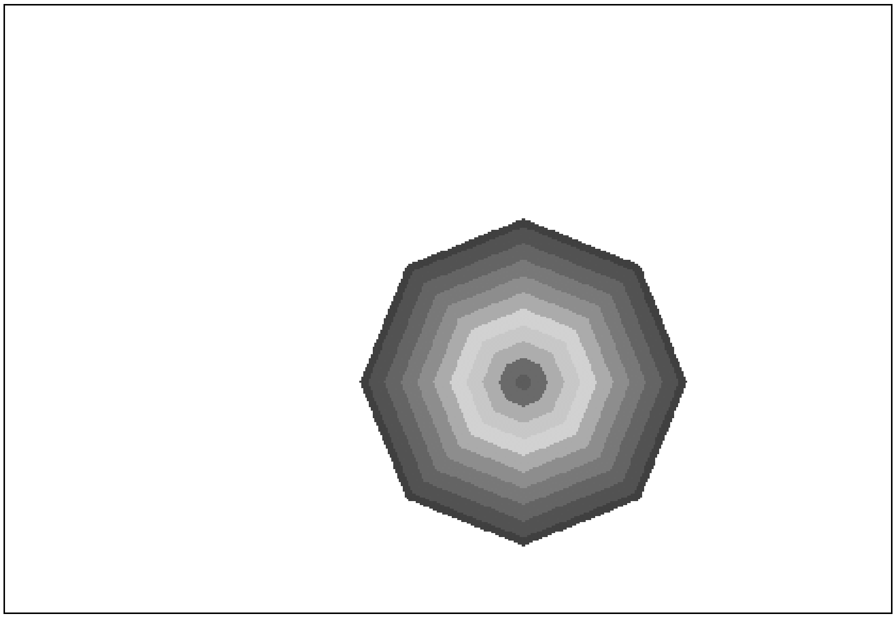

Figure 5.9 Classification of distance (below maximum influential distance) from site into 10 classes

Fig 5.10 shows the overlapping of distance classes with the seismic source.

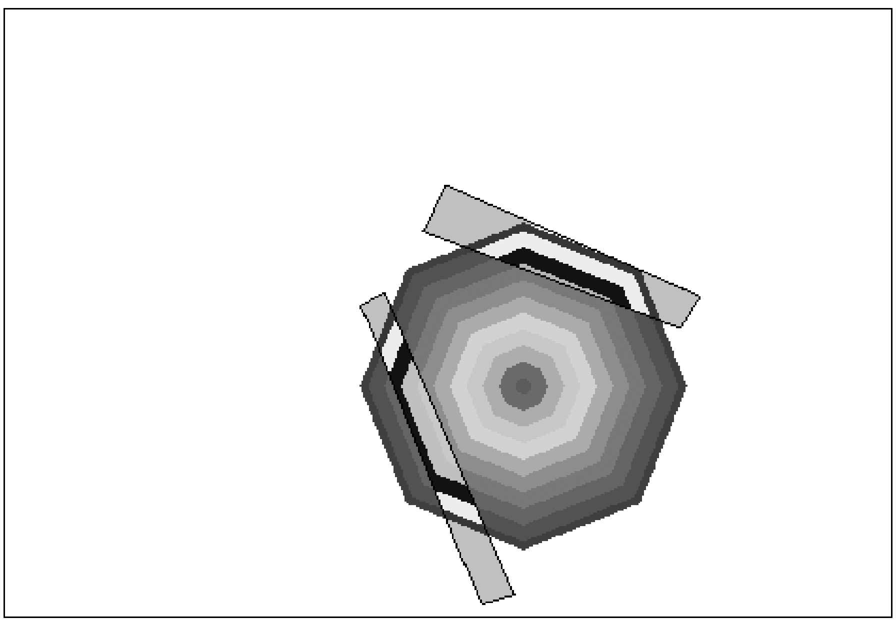

Figure 5.10 the overlapping between distance classes and seismic source determines the distance-associated probability

In Ilwis, this calculation can be carried out using two maps represent seismic source and distance classes.

Although, I did not try to make further effort to take into account the inhomogeneous seismic source model and anisotropy of medium due to time and data limits, some proposals are made here to improve the method.

To improve the seismic source model a weighted seismic source map can be used, which can be made by calculating the density of earthquake distribution. Fig 5.11 is an example to show the inhomogeneity of seismic source. The unit cell used is relatively large in this case, but it is still a better representation of the seismic source.

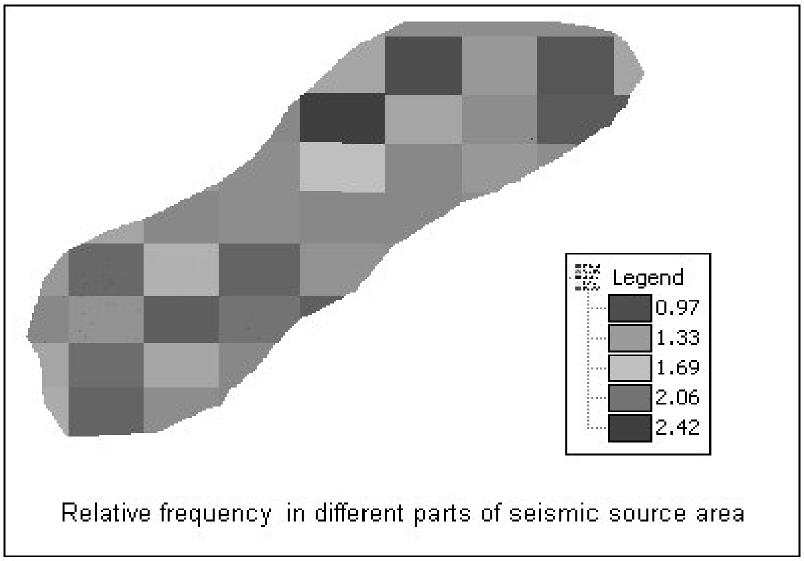

Figure 5.11 A representation of inhomogeneity of seismic source

As a result, the probability for each of the distance classes can be calculated using the expression:

$$P_d = \frac{\sum[(A_c)_i \cdot W_i]}{\sum A_j \cdot W_j} \tag{5-17}$$

Where P_d is the probability for certain distance class, $(A_c)_i$ is the area of overlap between the distance class and one seismic source cell *i*, W_i is the weight for $(A_c)_i$, A_j is the area of one seismic cell *j*, W_j is the weight of this cell. $\sum[(A_c)_i \cdot W_i]$ is the weighted overlapping area between certain distance class and seismic source. $\sum A_j \cdot W_j$ is the weight area of seismic source. A simple way to determine the weight is to use the distribution density of earthquakes in the past.

As it is well known, seismic sources are grouped into three types: point source, line source and planar source. I would think that it is better to treat all of the three in one way to reduce the complexity. Thus, whatever the type of seismic source is, all of the seismic sources will occupy certain area while they take different shapes. But in order to treat the mechanism of different types of seismic sources, different kind of attenuation relationship should be adopted in calculating (Fig 5.12).

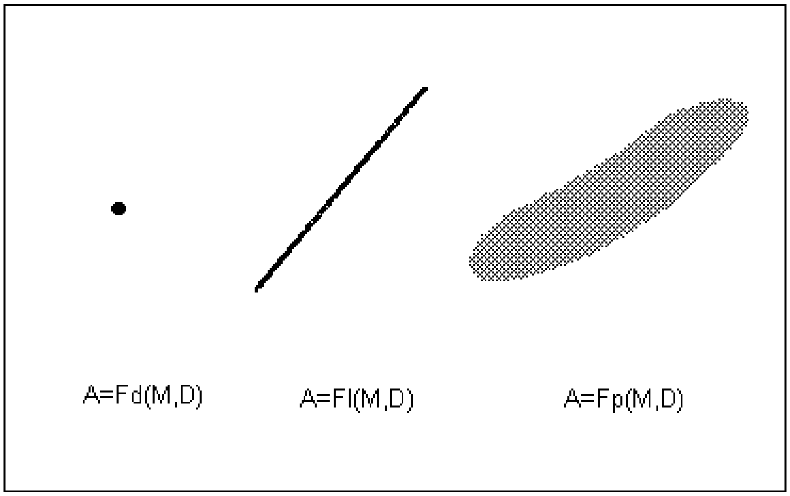

Fig 5.12 Treatment of different types of seismic sources

In Fig 5.12 different shapes of seismic sources represent their type. They all have area associated. But no detailed discussion is attempted in this study.

5) Calculating of probability associated with attenuation relationship.

Since detailed explanation is provided in section 6 of Chapter 4, there will be no repetition here. What is left is the integration of the normal distribution function.

The Normal distribution function(Fig 4.9 and 4.10) cannot be integrated in a usual way. The standard normal distribution accumulation table is the easiest way of doing it. The range of randomness of distribution variable lnPGA is divided into 60 intervals with half on the positive side and another half on the negative side from the mean, or put it in another way, the predicted lnPGA value. Except the first and the last interval of range of randomness, which are respectively assigned a value 0 and 1, all other interval has been equal divided with a range of 0.05. The range is also extended by 6 times to be in accordance with the accumulation normal distribution table, which has a total range of 6. The formula used to determine the exceedance probability is:

$$\begin{cases} 6(v_m - v) \le -3, & P_n = 0 \\ -3 \le 6(v_m - v) < 0, & P_n = P_k \quad ; k = Int(6\,|\,(v_m - v)\,|\,/\,0.05) + 1 \\ 6(v_m - v) = 0, & P_n = 0.5 \\ 0 < 6(v_m - v) < 3, & P_n = 1 - P_k \;; k = Int(6(v_m - v)/0.05) + 1 \\ 6(v_m - v) \ge 3, & P_n = 1 \end{cases} \qquad (5\text{-}18)$$

P_k is the k^{th} value in the table, $(v_m - v)$ is difference between the predicted lnPGA value (v) using Joyner–Boore (1981) attenuation formula with certain distance and magnitude and the lnPGA value to be evaluated. P_n is probability of n^{th} lnPGA to be evaluated under certain M and D. (Table 5.2 Accumulative normal distribution values)

Table 5.2 Accumulative normal distribution table

Nr.	Exceedance Probability	Nr.	Exceedance Probability	Nr.	Exceedance Probability
1	0.5	22	0.147	43	0.018
2	0.48	23	0.136	44	0.016
3	0.46	24	0.125	45	0.014
4	0.44	25	0.115	46	0.012
5	0.421	26	0.106	47	0.011
6	0.401	27	0.097	48	0.009
7	0.382	28	0.089	49	0.008
8	0.363	29	0.081	50	0.007
9	0.345	30	0.074	51	0.006
10	0.326	31	0.067	52	0.005
11	0.309	32	0.061	53	0.005
12	0.291	33	0.055	54	0.004
13	0.274	34	0.049	55	0.003
14	0.258	35	0.045	56	0.003
15	0.242	36	0.004	57	0.003
16	0.227	37	0.036	58	0.002
17	0.212	38	0.032	59	0.002
18	0.198	39	0.029	60	0.002
19	0.184	40	0.026	61	0.001
20	0.171	41	0.023		
21	0.159	42	0.02		

(Table 5.2 is only half of the normal distribution, but sine normal distribution is symmetric, the other half can be calculated correspondingly.)

6) *The drawing of the hazard curve.*

Twenty PGA levels are selected for calculating their exceedance probability. For each of the PGA levels a_n, the exceedance probability in one year can be calculated with formula 5-19.

$$P(PGA > a_n) = \sum_{k=1}^{10} \sum_{i}^{20} P_k \cdot P_i \cdot P_n(D_k, M_i, a_n) \qquad (5\text{-}19)$$

Where $P(PGA > a_n)$ is the exceedance probability for certain PGA level in one year, P_k is the probability of the distance class, P_i is the probability of each of the magnitude intervals, $P_n(D_k, M_i, a_n)$ is the exceedance probability of $PGA > a_n$ with distance D_k and magnitude M_i.

Finally, the exceedance probability for $PGA > a_n$ in 50 years can be calculated using formula 5-20.

$$P_{50}(PGA > a_n) = 1 - e^{(-50 * P(PGA > a_n)} \qquad (5\text{-}20)$$

With the 20 PGA a curve can be drawn by linking all the points together.

Table 5.3 shows the PGA levels and their corresponding natural logarithm. It was made in such a way to make the PGAs larger than 0.04g increasing with an increment of 0.04 until 0.6g. For the smaller PGAs, they are set to be half of previous ones, so that this coverage will cope with different situations.

Table 5.3 PGA levels and corresponding natural logarithm used in calculating

Nr.	PGA(g)	Ln(PGA)	Nr.	PGA(g)	Ln(PGA)
1	0.6	-0.5108256	11	0.2	-1.609438
2	0.56	-0.5798185	12	0.16	-1.832582
3	0.52	-0.6539265	13	0.12	-2.120264
4	0.48	-0.7339692	14	0.08	-2.525729
5	0.44	-0.8209805	15	0.04	-3.218876
6	0.4	-0.9162908	16	0.02	-3.912023
7	0.36	-1.021651	17	0.01	-4.60517
8	0.32	-1.139434	18	0.005	-5.298317
9	0.28	-1.272966	19	0.0025	-5.991465
10	0.24	-1.427116	20	0.00125	-6.684612

7) The overall integration of these steps is shown in Fig 5.13.

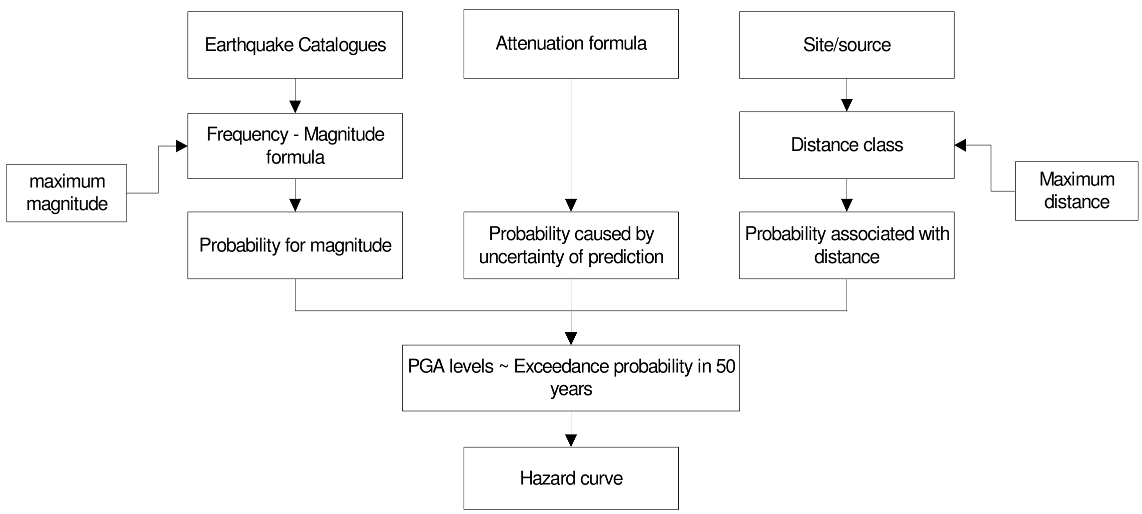

Figure 5.13 schematic diagram of probabilistic method for seismic hazard assessment

The user interface is presented in Fig 5.14. This user interface incorporates all the steps and also the display of the earthquake catalogue in different ways.

At the upper left frame, the content is for the input of the earthquake catalogue map and table. The point map for earthquakes is not necessary if the user does not want to show the map.

The upper right frame is for the display manipulation of the earthquake catalogue map so it can be displayed in different ways to give a better idea what it is. The parameters can be used are: magnitude, years, location and depth. Some logic and arithmetic operations can be performed using one of the parameters.

In the middle is the interface for calculating the frequency-magnitude relationship using the earthquake catalogue table. If the user wants to calculate within certain area, then a polygon map and a name the area should be given, otherwise, the results would be for the whole map area by default. In the text box to show the result, not only the frequency-magnitude formula is provided, the correlation coefficient is also calculated to give the user some idea of the credibility of the fitting. General speaking, since the number of magnitudes used is limited, there should be a higher correlation coefficient to make the formula credible. Table 5.4 is the critical vale for the correlation coefficient with different level of confidence. In the case of Fig 5.14, it is within 95% of confidence.

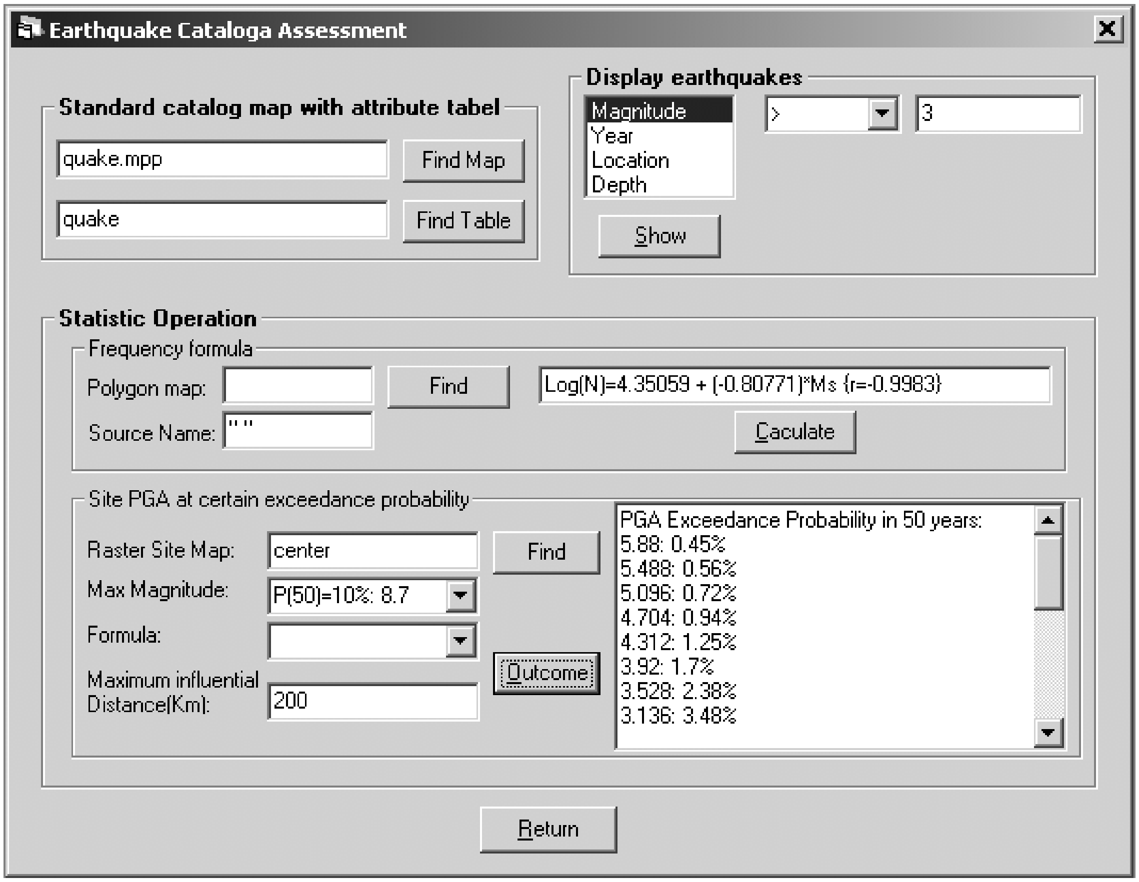

Figure 5.14 User interface for probabilistic PGA calculation

Table 5.4 Critical values for correlation coefficient at different confidence level

Degree of Freedom (Observations -2)	90% confidence	95% confidence	98% confidence
1	0.988	0.997	0.9995
2	0.900	0.950	0.980
3	0.805	0.878	0.934
4	0.729	0.811	0.882
5	0.669	0.754	0.833
6	0.622	0.707	0.789
7	0.582	0.666	0.750
8	0.549	0.632	0.716
9	0.521	0.602	0.685
10	0.497	0.576	0.658
11	0.476	0.553	0.634
12	0.458	0.532	0.612

The lower frame is for calculating the exceedance probability of different PGA levels. The maximum magnitude can be selected based on the exceedance probability within 50 years. The formula selection now is not available. The “outcome” button is to start calculating. “Return” is to close this window. The text box at the lower right hand shows the results. But as it is shown, the part on formula selection is not worked out now. A graph window is shown as Fig 5.15. The horizontal axis is PGA in cm/s^2. The vertical axis is the exceedance probability in percent.

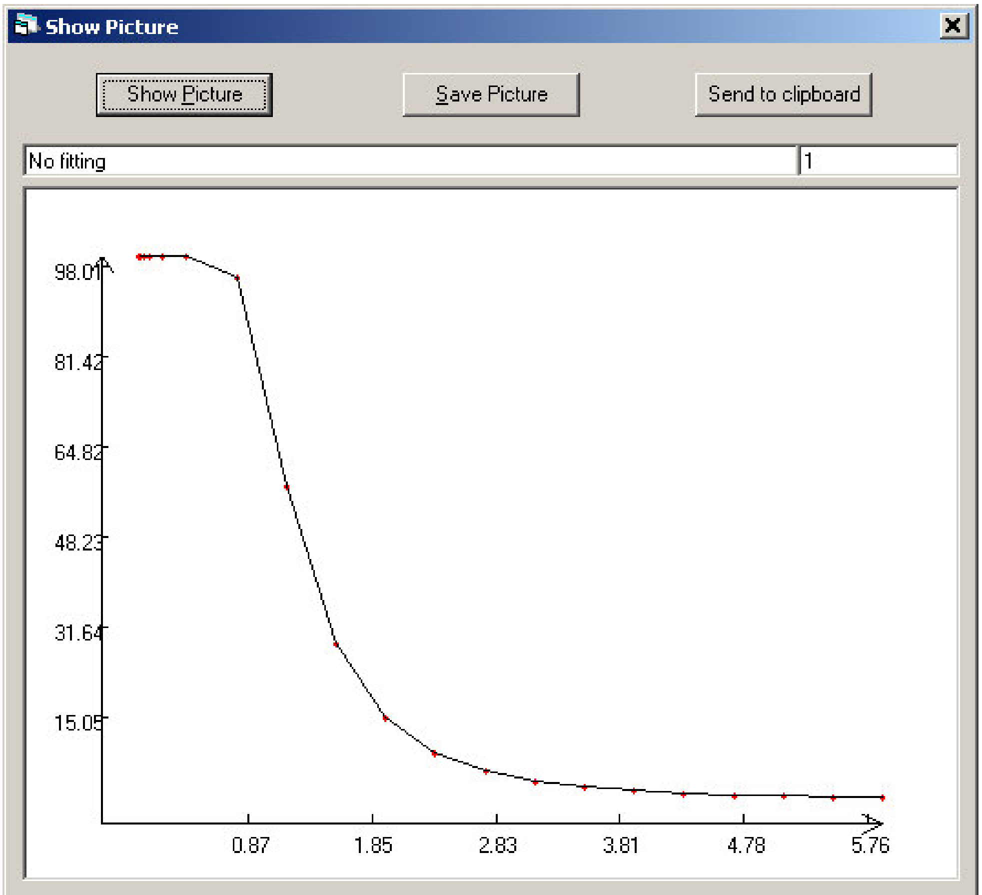

Fig 5.15 Hazard curved window

So far, due to time limitation, some of the works on software design are not finished. The incorporating of an advanced seismic source model and better manipulation of the graph window are not started yet, although in technical sense, they are both possible.

To sum up some of the points, 1) raster based GIS (Ilwis) combined with Visual Basic have certain advantages and flexibilities to realize the probabilistic method for ground motion assessment. 2) Some modifications on the probabilistic method using the numerical method should be modified for the raster-base GIS calculation.

Chapter 6. Ilwis/Visual Basic Application Design

6.1. Advantages of Ilwis/Visual Basic combination for seismic hazard assessment

With Ilwis alone, there is still a lot of both manual work and a higher lever of analytical requirement to carry out seismic hazard assessment. Due to various knowledge and procedures involved, it is hard to leave non-professional users to work out such things, so it is better to give some kind of assistance so that seismic hazard assessment can be done easily under such circumstances.

Ilwis provides scripts to enable automatic operation. But it is still a problem to understand what is input and what is output. Besides, Ilwis script do no have the interactive interface for user.

A better way is to design a user interface for Ilwis with Visual basic, so there are no much technical problems to be considered as long as there is proper input data available. A combination of Ilwis/Visual Basic application would serve the purpose well (Fig 6.1).

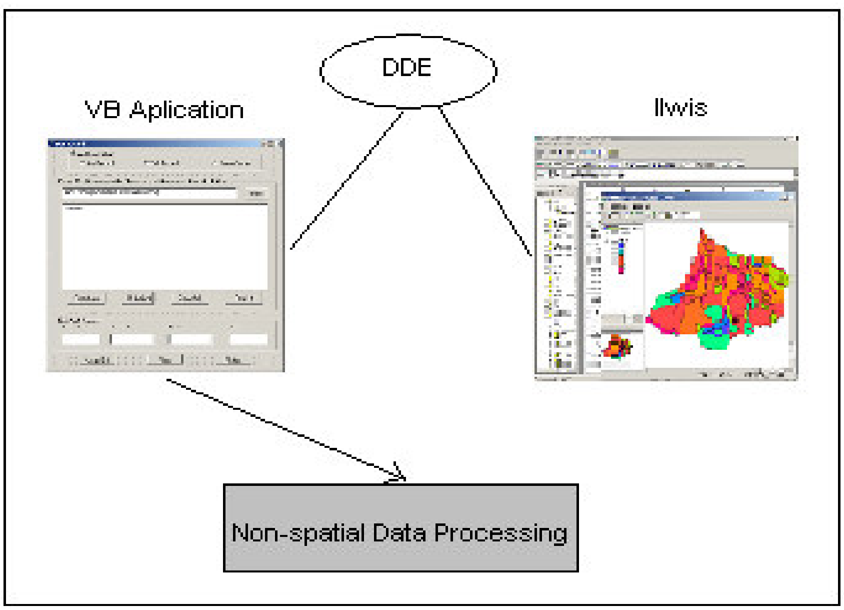

Figure 6.1 Combination of Ilwis/Visual Basic for seismic hazard assessment

There are some advantages of such an application:

1) Most of the GIS analysis, especially those of high professional requirement, can be done at a click of button from the Visual Basic interface. So it is more efficient;
2) The Visual Basic interface, if arranged properly, can help the user understand what he needs to do and how to do it without any specific effort to learn Earthquake Engineering;
3) It can be made more flexible to accommodating different circumstances caused by data availability and purpose of work;
4) Sometimes it is rather awkward to carry out certain numerical analysis in GIS on non-spatial data; but it can be accomplished much comfortably in Visual Basic modules using data through conversation with Ilwis while all other GIS-capable things can be done without any interference;
5) Use of a user-friendly interface can provide more information and in many ways for user to understand the problem well and keep the analysis under proper control.

In the following parts of Chapter 6, the problems on design of an Ilwis/Visual Basic application will be explained.

6.2. Introduction to DDE and Visual Basic DDE method

DDE is the abbreviation of Dynamic Data Exchange. It is a feature of Windows that allows two programs to share data or send commands directly to each other under the control of Windows DDE manager.

DDE can be thought of as a direct conversation between two application programs through the exchange of data. The application that provides some form of data (either text or graphics) to another application is called the "server" and the application that receives the data is called the "client". Many of the windows program support DDE, that is, they can be either DDE servers or client through certain grammar in programming.

DDE allows a client application to send commands to a server application. The types of DDE commands, if any, that a server program can accept will vary depending on the application. In order to establish a DDE conversation or, to put it in other way, DDE link, a DDE server application, a topic and at least one request item should be provided. After a DDE link with the server’s command processor, application can exchange data.

In Visual Basic there are following DDE link properties:

a) *LinkTopic:* To give the name of the DDE server wanting to communicate and which of the available ‘topics’ of the server that application wishes to use. The format is: application name| topic.
b) *LinkItem:* To *s*pecify the data to be sent to or return from conversation as defined by the LinkTopic property for that control.
c) *LinkMode*: To assign or receive type of link and activate the link followed. There are three types of links: vblinknone (value=0) No link; vblinkmanual (Value=1): Vblinkautomatic (value=2) .

d) *Linktimeout*: To set the maximum time waiting for server response. When –1 is given, the waiting would be the maximum allowed.

Also there are some DDE link methods and events:

a) *Linkexecute*: to send command strings to be executed by a source application. This will also give the privilege to manage other application from other application, which sometimes is very useful.
b) *Linkrequest*: to request data return from server application to the object that can contained the data (textbox, listbox …).
c) *Linkopen*: event triggered by starting a DDE link.
d) *Linkclose*: event triggered by close a DDE link.
e) *Linkerror*: event triggered by DDE link error.

6.3. Ilwis as a DDE server & types of topics

Ilwis support DDE as a server. The main functions of Ilwis as a DDE server are:

a) To executing the text (command, formula, expression) that is sent via DDE as if it were a script command;
b) To reply to the client by providing or calculating requested information;
c) To supply information at a mouse click in a map window to DDE clients that 'subscribed' to such information.

Thus, Ilwis can supply data or perform certain operation to another application through a DDE link.

Ilwis supports three topics:

- System: to execute Ilwis commands or expressions and also for request the server's properties. It is the only topic that responds to Execute method through which the Ilwis commands and expressions are passed.
- Calc: to request results of some calculation. Calc topic will only respond to the Linkrequest method and in this case the value of the Linkitem property is used to pass the expression.
- Coord: to 'subscribe' to information available at mouse click in a map window, or to request the latest version of the information. It will automatically respond upon clicks in a map window when the mode is set to automatic no request is required; when the mode is set to manual, the 'coord' topic will respond to the request method. In both cases, the only possible values for the linkitem property are .X, .Y, .XY and mapname.ext.

6.4. Structure of Ilwis/Visual Basic application

The structure of the VB program is based on two principles: the actual procedure of carrying out seismic hazard assessment and the division of work into modules that primarily operates independently. The first principle set limits on the sequences of the work to be done. So some of the steps must follow others, or some of the steps must be finished precedes others. The second principle helps to divide the work into different modules so that the programming will be easier.

The blueprint of the structure of the complete VB program is shown in Fig 7.2

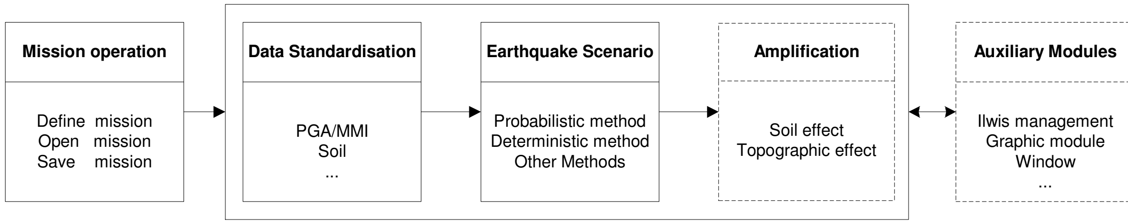

Figure 6.2 the structure of VB application

So mainly there are five basic components. The first component is the mission management that manages the whole process of seismic hazard assessment to assist user for a more efficient work and to save the troubles, too. The three components in the middle are based on the steps in seismic hazard assessment. They work on data standardization, bedrock PGA evaluation and amplification respectively. In a broad sense, the three components can also be regarded as a larger 'main processing' component because all of the works on seismic assessment are actually done here. The last component is a 'service component' that consists of several modules due to the various functions it performs. Most of the modules in the service component do not work alone; they often have some kind of interaction with one or more modules of the main processing component. Fig 6.3 shows the main window of the Visual Basic interface. Most of the menus correspond to each of the components. The yellow part is what has not been done yet. Another menu "Windows" is the Visual Basic function to show the child windows that are open within the main window.

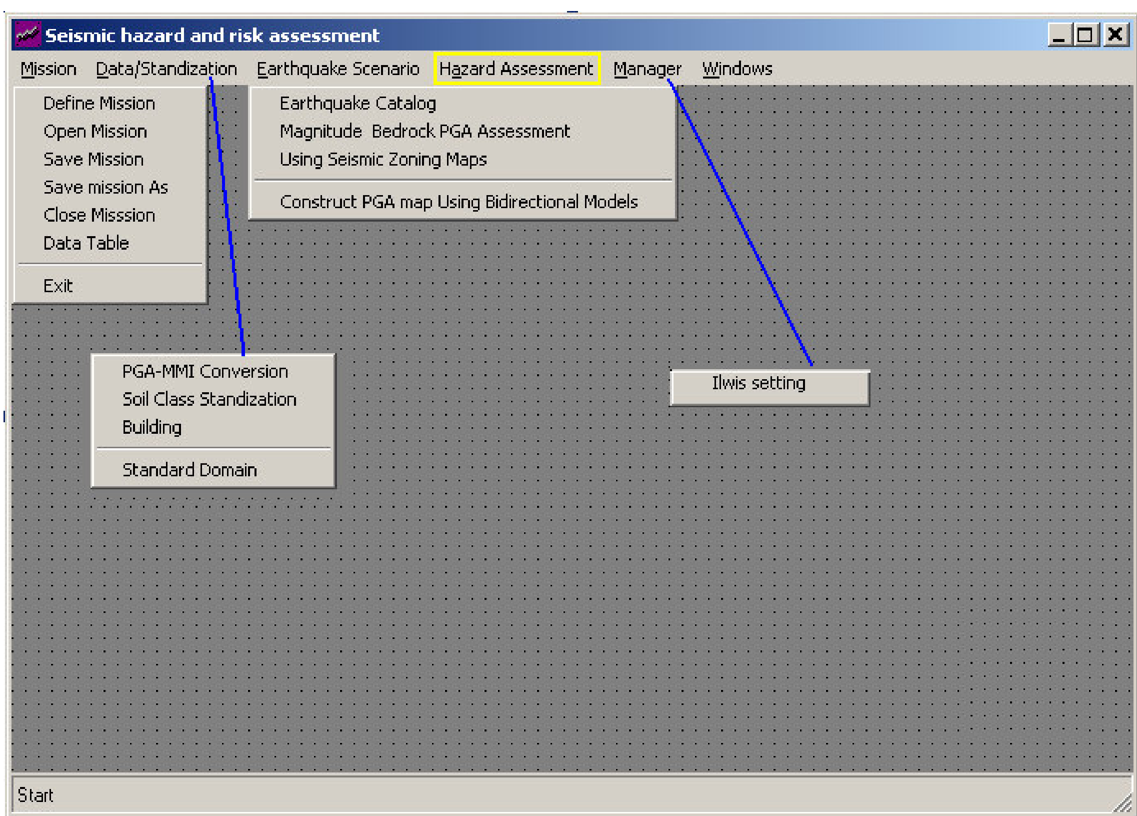

Fig 6.3 the main window of Visual Basic interface

All of the components have several modules in programming level with each module requires a specific data input and to finish its job. Whilst, it is worthy to mention that the simplified structure does not show all the communications among the modules, which are needed to finish a mission properly. But for a user, most of the details related to these communications are not necessarily relevant for his/her work to be done.

Unfortunately, two modules in the dashed line are not worked out due to time limit. So, actually, there are three modules in the Ilwis/Visual Basic application. More technical details will be explained below for these modules.

6.5 Concept of Mission

The work on seismic hazard assessment involves many steps. At the same time, these steps are related to one another. To enable the user to do such a work without too much reference to the specific knowledge related to seismic hazard assessment, the whole process must be arranged in a way that all what the user need to do is just to follow some steps and make some indication of input data or select of options. This is possible because now much of the work on seismic hazard assessment have some standard method recommended either by studies or by public codes. As far as programming is regarded, this means that parameters, options and other information of seismic hazard assessment should be managed by VB application instead by the user to avoid the technical challenges may be imposed otherwise.

Mission is a record file that records the important information on files, options etc. to make the seismic hazard assessment using GIS under the management of VB application. Thus the technical difficulty for users can be reduced as much as possible.

A mission is composed of several records, with each record corresponds to certain information of seismic hazard assessment using Ilwis GIS package. All the records have the same structure as defined by following codes in VB:

```
Public Type record
Item1 As String * 200
Item2 As String * 200
Item3 As String * 200
Item4 As String * 200
Item5 As String * 200
End Type
```

Obviously, this causes some space redundancy because of the fixed structure of the records. But the same reason makes the programming on mission much easier, and if necessary, new records can be added without much effort to change existing codes. All the records are stored in the mission file, which is actually a random record file in terms of VB.

Some of the information on records is listed in Table 6.1

Table 6.1 Information on some of the records

Record No. & content	Item	Information
1 (Mission information)	1	Name of mission
	2	Date and time
	3	Type of mission
	4	Working folder
	5	Valid records contained
2 (Mission progress)	1	Earthquake scenario
	2	Soil amplification
	3	Topographic amplification
	4	Free
	5	Free
3 (Bedrock PGA)	1	Type of analysis
	2	PGA/PGA file 1
	3	PGA/PGA file 2
	4	PGA/PGA file 3
	5	PGA/PGA file 4

The extension of mission is given as .inf, which stands for information. Since the mission file is actually a random record file, the operation such as open, save etc. can be easily handled by using the VB C*ommonDialog* control. Slightly different is the 'define' operation, in which a new mission file is created. The interface of defining a mission is shown as Fig 6.4.

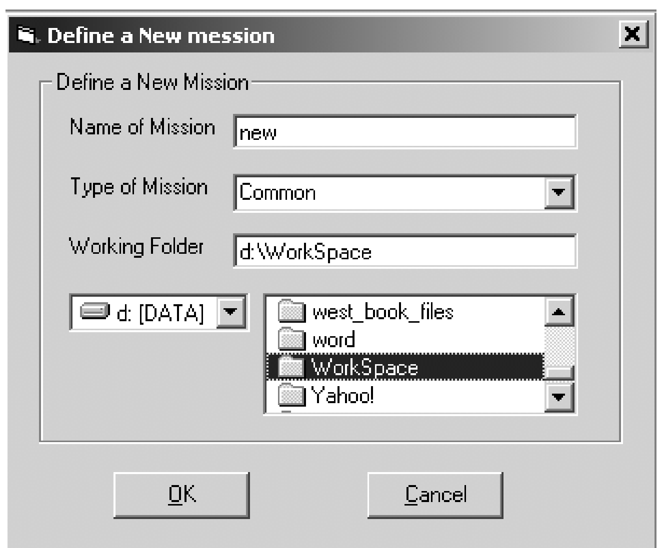

Figure 6.4 Interface of defining a new mission

As Fig 6.4 shows, to define a new mission, user needs to indicate the working folder where the mission file will be saved, a name for the mission, and also the type of the mission. There are two types of mission, common and advanced. In a common mission, the user will only be allowed to carry out the operation that is included in the application and without authority to change the configuration. This is to make sure that user at low-end will not make a mess of the application. The advanced type of mission is especially useful for advanced users, who know the seismic hazard assessment better and needs to incorporate some of their own study into the assessment. In an advanced mission, system configuration is open, and some of the models can be changed or added. But this is not fully implemented in software design.

Generally, the mission file is just like any other files and can be accepted by user without any trouble. Once a new mission being opened, then all the other information and operations can be handled properly by the VB application. And with the mission file, work on seismic hazard assessment can be made more smoothly and easily.

6.6. Automatic evoking calculation using change event

Sometimes, user expects that automatic operation can be done after inputting data rather than too much clicking. The change event, which is activated by change of content of the control, is very useful for this purpose. But the designated automatic operation should meet the three conditions: 1. The operations do not cost too much time, so that whenever the operation is activated unintentionally as any change of the content in input textbox will do, there would be little time cost. 2. Since the change event does not detect whether the input is finished or not, any input or delete of the texts in the textbox will activate the operation, it has to be sure that the operation with incomplete input will not cause the program to go wrong. 3. The extreme situation such as the empty or other invalid input should be checked to avoid the collapse of the program. An example to calculate PGA automatically is given below:

```
Private Sub txtdis_Change()
If txtdis <> "" Then

    Select Case cmbformula.ListIndex
    Case 0
          If txtdis < 0 Or txtdis > 500 Then
             txtpga = ""
             cmdsave.Enabled = False
             Exit Sub
          ElseIf txtMs.text <> "" Then
             d = Sqr(Val(txtdis) ^ 2 + 53.29)
             pga = -1.02 + 0.248 * Val(txtMs) - Log(d) / Log(10) - 0.00255 * d
             pga = 10 ^ (pga)
             txtpga = Format(pga, "#.####")
             cmdsave.Enabled = True
          Else
             txtpga.text = ""
          End If
   Case 1
          If txtdis = 0 Then Exit Sub
          If txtdis < 0.1 Or txtdis > 300 Then
             cmdsave.Enabled = False
             txtpga = ""
             Exit Sub
          ElseIf txtMs.text <> "" Then
             Ms = Val(txtMs)
             dd = Val(txtdis)
             d = Log(dd + 0.032 * 10 ^ (0.41 * Ms)) / Log(10) + 0.0034 * dd
             pga = 1.3 + 0.41 * Ms - d
             pga = 10 ^ (pga) / 1000
```

```
            txtpga = Format(pga, "#.####")
            cmdsave.Enabled = True
          Else
            txtpga.text = ""
          End If
    Case 2
          If txtdis < 0 Or txtdis > 500 Then
            cmdsave.Enabled = False
            txtpga = ""
            Exit Sub
          ElseIf txtMs.text <> "" Then
            Ms = Val(txtMs)
            dd = Val(txtdis)
            d = Log(dd + 0.0606 * Exp(0.7 * Ms))
            pga = -4.141 + 0.868 * Ms - 0.109 * d
            pga = 10 ^ (pga) / 100
            txtpga = Format(pga, "#.####")
            cmdsave.Enabled = True
          Else
            txtpga.text = ""
          End If
   End Select

  Else
    txtpga = ""
  End If
  End Sub
```

So in case that the textbox for distance is empty or the distance is out of range, no operation would be carried out. At the same time, the value of Magnitude is also check to make sure that the calculating can be carried out properly.

6.7. Ilwis command execution without and with a return value.

The types of Ilwis command execution used can be grouped into two classes: without and with a return value.

The command execution without a return value is to carry out the Ilwis operation with either a map or a table and the results will be either a map or some columns in a table. The link property used for this is ‘linkexecute’. An example with the table calculation is given below.

```
   txtout.LinkTopic = "Ilwis|system"
   txtout.LinkMode = 2
   txtout.LinkExecute "Tabcalc " & txttable & " " & txttable & ".num" & i1 & "=iff((ms >= " & i1 & ") And
(ms < " & k2 & "), 1,0)"
   txtout.LinkExecute "Tabcalc " & txttable & " " & txttable & ".sum" & i1 & "=sum(" & txttable & ".num"
& i1 & ")"
   txtout.LinkMode = 0
```

In this example, two operations on a table named by the string txttable were done. And the results will be stored in the table. Another example is for the map operation.

```
txturbanmap.LinkTopic = "Ilwis|system"
txturbanmap.LinkMode = 2
txturbanmap.LinkTimeout = 10
txturbanmap.LinkExecute "open " & txturbanmap
txturbanmap.LinkMode = 0
```

This example shows how to use the Ilwis command to open a map. Most Ilwis expression can be used in the same way.

Sometimes, it is necessary to get a value from Ilwis table or map. To get a value from Ilwis map, it need as interactive interface and with ‘coord’ topics. But this is not used so far. To extract a value from Ilwis table, it is better to use the ‘TBVALUE’ function with the ‘calc’ topic. The link property in this case is linkitem. An example for this is given below.

```
txtout.LinkTopic = "Ilwis|calc"
txtout.LinkMode = 2
txtout.LinkItem = "TBLVALUE(" & txttable & "," & lblq & "sum" & i1 & lbrq & ",2)"
txtout.LinkRequest
quakenum(i1 - 2) = Val(txtout)
txtout.LinkMode = 0
```

It can be found that linkitem need an operation that return a single value or a single string. Besides, linkitem need to use ‘linkrequest’ to get the date from Ilwis.

6.8. Quotation mark problem

In Ilwis, double quotation marks are used to indicate the expressions. But in Visual Basic expression, it uses the single quotation marks to indicate any quotation marks inside a Visual Basic expression. When this rule is applied, the outcome often goes wrong.

To solve the problem, two labels with caption “ and ” are created, and in the visual basic expression, the label would be quoted to get the quotation mark. An example is below:

```
txtout.Linkexecute  "mapA=iff(mapB=" & lblq & "city" & lbrq & "1,0)"
```

In the example, lglq and lbrq are respectively the label for the left quotation mark and right quotation mark.

Chapter 7. Conclusions

Although this study is tentative and cursory to some extent due to limited time, there are still some good points to make:

- GIS or numerical program alone cannot cope well with the whole process of seismic hazard assessment, because there are many and often-complex procedures involved, which may not be efficiently done with either of the two. The long-time cherished numerical programs are very competent in numerical calculation, but they are unable to process the spatial information to produce better quality and wide spatial coverage. On the other hand, although the GIS is quite useful to incorporate and manipulate the spatial information derived from seismogenic and geotechnical studies, it is too clumsy to carry out many operations without application designed for seismic hazard assessment.
- An Ilwis/Visual Basic application is more powerful in a sense that it provides both numerical calculation and specific spatial operation procedures, which can be done with simple input and mouse clicks. An Ilwis/Visual Basic application is versatile in input and output, and combined with the user interactive interface, Ilwis/Visual basic application is flexible, too.
- An Ilwis/Visual Basic application needs some standardization of the input data to enable some of the automatic operations. This standardization can be grouped into two types: data converting and reclassifying. The former can be realized with automatic operations through the user interface as long as there are empirical formulas can be used, while for the later it has to be done largely manually due to the various subjective and localized nature of names and representations of the data.
- Both deterministic and probabilistic methods for ground motion assessment can be performed by an Ilwis/Visual Basic application, but for deterministic methods, there are often more subjective decision that have to be made. For a deterministic method based solely on attenuation formulas, sometimes, there is no need for spatial operation indeed. One of these examples is given in this study. The bi-directional attenuation models such as the elliptical model are more useful as the isoseismic lines shows directional difference. But it needs certain spatial operation to be carried out. In Ilwis/Visual Basic the bi-directional model can be realized in a stepwise approach to incorporate the spatial information into the calculation.
- The probabilistic method for ground assessment is far more sophisticated than other method to incorporate most of the data available and provide seismic level ~ exceedance probability information. An Ilwis/Visual Basic application can carry out probabilistic with satisfying efficiency and accuracy. In realization, the probabilistic method should be divided into several parts to calculate the probability associated with magnitude, distance and attenuation formula separately before a final combination of the three. However, within GIS environment, some compromises have to be made for the highly sophisticated numerical method to reduce the complexity of GIS operation.

- A simplified method for probabilistic method in Ilwis/Visual Basic application for ground motion assessment is realized. This method is simple compared with the mainstream probabilistic method, but it is still useful to help to design an advanced one in the similar way.
- The results (Table 7.1, Fig 7.1) got with the simplified probabilistic method using the Nepal dataset of earthquake catalogue is smaller than that provided by GSHAP. This is within expectation, because the data used and the simplification of the probabilistic method. The seismic source model is not well defined in my study, which consequentially produces an average result of Nepal.

Table 7.1 Calculated exceedance probabilities (P_e) for PGA at different levels

Nr.	PGA	P_e (%)	Nr.	PGA	P_e (%)
1	5.88	0.14	11	1.96	5.35
2	5.488	0.18	12	1.568	10.76
3	5.096	0.23	13	1.176	25.04
4	4.704	0.3	14	0.784	66.03
5	4.321	0.41	15	0.392	99.97
6	3.92	0.56	16	0.196	100
7	3.528	0.8	17	0.098	100
8	3.136	1.17	18	0.049	100
9	2.744	1.81	19	0.024	100
10	2.352	3	20	0.012	100

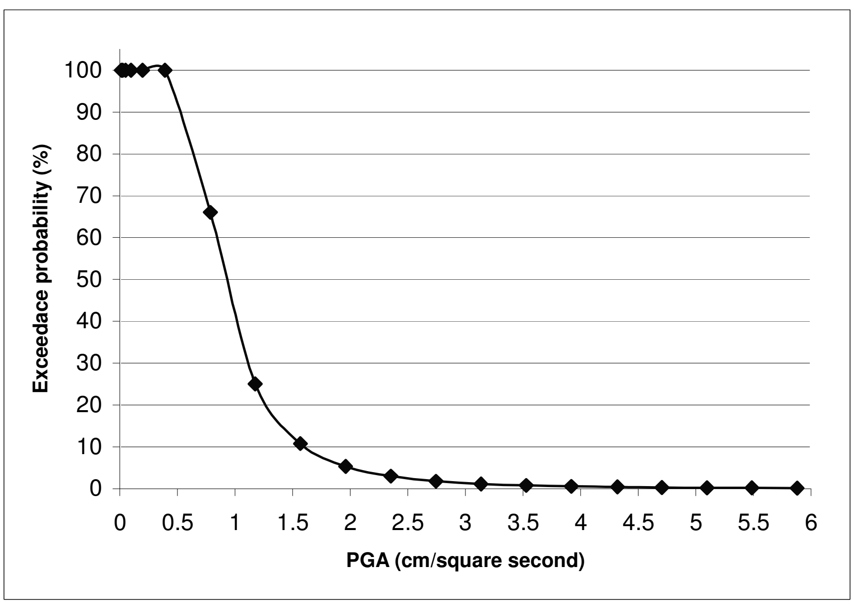

Fig 7.1 hazard curve plotted using data from Table 7.1

It can be found that PGA corresponds to exceedance probability of 10% is 1.7 cm/s^2, this is smaller than approximately 2.4 cm/s^2 from the GSHAP (1999).

- The Ilwis/Visual Basic application designed proves well the optimistic prospect of such a method to improve the seismic hazard assessment both spatially and in efficiency. However, the method in this study itself needs to be improved for practical purpose. Strikingly, the seismic source model and some procedures for calculating are obviously inadequate to satisfy the need of a practical case.
- The Ilwis/Visual Basic application as an user interface is generally much easier and efficient but it also has some defects. For example, the DDE method does not embed Ilwis within the application, though the user interface has a supportive role, the user should monitor the GIS operation at the same time. What's more, DDE enables only part of the functionality of Ilwis, other operations have to be done by the user manually. Hence, the Ilwis/Visual Basic does not work in an independent environment; the user still needs good skills to use Ilwis for his work.

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