GIS APPLICATIONS IN EARTHQUAKES ASSESSMENT

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ABSTRACT

Earthquakes are amongst the worst natural disasters on Earth. This paper deals, briefly, with earthquake as a natural hazard and how to minimize their effects using Geographic Information System. The paper starts with background of earthquakes, definition and effects. Then, some of the GIS applications in earthquake hazards are discussed and case studies are given from different countries and the paper closes with a conclusion.

1. INTRODUCTION

Earthquakes are one of the most devastating geohazards. Over 30,000 earthquakes are felt worldwide annually, 75 among which are considered significant earthquakes. Depending on number of factors including the magnitude, duration, the intensity and the population density, a significant earthquake may cause death to tens of thousands; and sometimes more as in 1976 Tangshan earthquake in China (about 240,000 deaths), and losses in billion of dollars, as in Kobe earthquake, Japan, January 1995 (losses estimated to be more than $100 billion) (Tarbuck).

GIS, Geographic Information System, is a computer-based system that is used to store and manipulate geographic information. This technique, which associates the attributes with its geographic location, has developed so rapidly over the past two decades that is has become an essential tool in geosciences. In geophysics, the GIS technique has found a wide range of applications since it is very important to represent the geophysical data in their geographic location.

The main objective of this paper is to briefly discuss earthquake as a natural hazard and how to minimize their effects using Geographic Information System. This paper starts with background of earthquakes, definition and effects. Then, the paper describes, briefly, why and how GIS is used in the assessment of earthquakes: *before*, *during* and *after* an event. After that, some of the GIS applications in earthquake hazards are mentioned through three different case studies from three different continents before closing with a conclusion.

2. BACKGROUND: EARTHQUAKES

Before discussing the GIS applications in earthquakes assessment, and in order to minimize the impact of earthquakes, once should know the some of the basic information about earthquakes that include: *definition*, *measurements* and *effects*.

2.1 Definition

An earthquake is a sudden vibration of the earth produced by a rapid release of accumulated strain energy that radiates in all direction from its source, *the focus*, in the form of seismic waves (Figure 1).

An earthquake may be accompanied with *foreshock* and/or *aftershocks*. A foreshock is a small earthquake that often precedes the main shock by days, or some cases, by as much as several years. An aftershock is a small earthquake that follows the main shock. Aftershocks can cause a considerable damage to the weakened structures (Tarbuck).

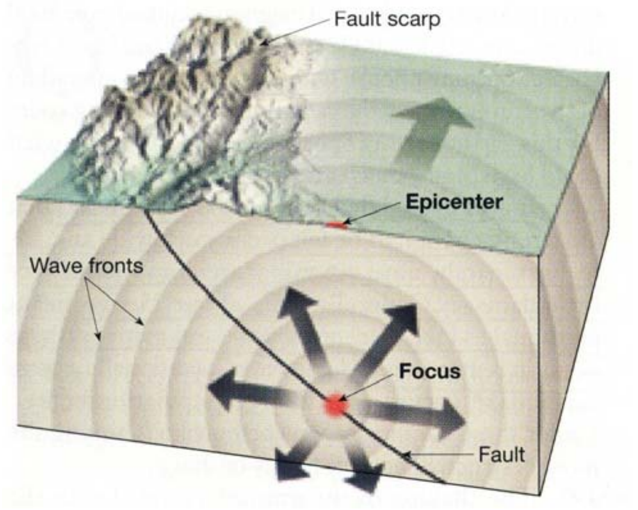


Figure 1: Illustration of Earthquake. The *Epicenter* is the surface location directly above the focus and the distance between the epicenter and the focus is called the *Focal depth* (Tarbuck).

2.2 Measurements

There are two main methods by which earthquakes can be measured: 1) Magnitude (Richter's Scale) and 2) Intensity (Modified Mercalli Intensity Scale).

2.2.1. Richter's Scale (Open Scale, Table 1)

A magnitude scale that measures the energy released at the source of the earthquake. The magnitude, also called *local magnitude* (M_L), is determined from measurements on seismographs (Δt and amplitude) and by using the following formula (see Figure 2):

$M_L = \log_{10} A/T + Q + C$, A is the max. amplitude in μm, T is period in sec, Q (Δ,h) a function of depth and epicenter, C is a constant (Bolt)**.**

2.2.2 Modified Mercalli Intensity Scale (Closed Scale, Table 1)

An intensity scale that consists of twelve grades and measures the strength of shaking produced by the earthquake at a certain location depending mainly on the damage caused to various types of structures.

There are other types of magnitude measures, such as, body-waves magnitude (M_b, for seismic waves having period T = 1 sec.) and surface-waves magnitude (M_s, T = 20 sec.). Also, there are other types of intensity measures, e.g. Rossi scale and Forel scale. Table 1 shows the relation between magnitude and the equivalent intensity (Bolt).

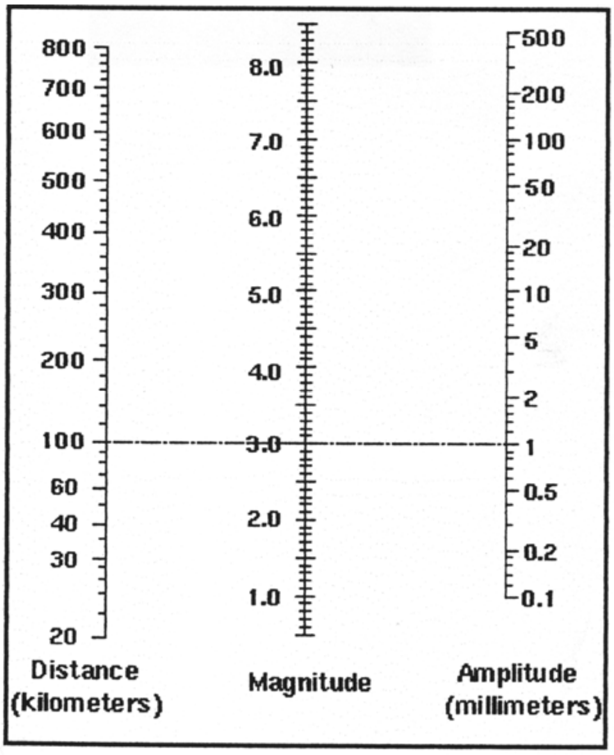


Figure 2: Richter's magnitude scale, called nomogram. There are three steps to determine the magnitude: 1) measuring the difference in arrival time between P and S waves and therefore the distance to the epicenter in km (using seismological tables), 2) measuring the maximum amplitude in mm, and 3) connect 1) and 2) through the magnitude scale by a straight line. In this nomogram, an earthquake at distance of 100 km and having maximum amplitude of 1 mm will result in magnitude of 3 according to Richter's scale. Note that an increase in the magnitude by 1 unit will result in increase in the amplitude by a factor of 10 **(Tarbuck & S:9)**.

Magnitude	Intensity	Description
1.0 - 3.0 Very Minor	**I**	**I. Not felt except by a very few under especially favorable conditions.**
3.0 - 3.9 Minor	**II - III**	**II. Felt only by a few persons at rest, especially on upper floors of buildings.** III. Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.

4.0 - 4.9 Light	**IV - V**	**IV. Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.** V. Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
5.0 - 5.9 Moderate	**VI - VII**	**VI. Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.** VII. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures.
4.0 - 6.9 Strong	**VIII - IX**	**VIII. Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, and heavy furniture overturned.** IX. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
7.0 and higher **Major, Great**	**X - XII**	**X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.** XI. Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly. XII. Damage total. Lines of sight and level are distorted. Objects thrown into the air.

Table 1: Magnitude and equivalent intensity (S:9).

2.3 Effects

The effects of any earthquake depend on a number of varying factors: 1) *Intrinsic* to the earthquake: its magnitude, type, location, duration and depth, 2) *Geologic* conditions: where effects are felt, distance from the event, path of the seismic waves, types of soil, water saturation of soil, and 3) *Societal* conditions: reacting to the earthquake, quality of construction, preparedness of populace, or time of day (e.g. rush hour) (S:9).

There are two classes of earthquake effects: *Direct*, and *Secondary*. Direct effects are solely those related to the deformation of the ground near the earthquake fault itself. Thus direct effects are limited to the area of the exposed fault *rupture*, e.g. *fissure* and *elastic rebounds* (*or fault displacements*. However, Most of the damage done by earthquakes is due to their secondary effects, those not directly caused by fault movement, but resulting instead from the propagation of seismic waves away from the fault rupture. Secondary effects result from the very temporary passage of seismic waves, but can occur over very large regions, causing wide-spread damage. Such effects include: *avalanches, ground settlement* and *the triggering of aftershocks* (S:9).

Below are brief explanations of some of the most common *seismic hazards* (hazard associated with potential earthquakes in a particular area):

a) Ground Shaking: a rapid horizontal movement.

b) Liquefaction: in water-saturated soil; the transformation of stable soil into a fluid that is often unable to support building or other structures (Figure 3) (Tarbuck).

Figure: 3 Effect of liquefaction during 1999 Izmit earthquake, Turkey (S:1).

c) Fire: during 1906 San Francisco earthquake, for example, the greatest damage was caused by fires when electrical and gas lines were severed. (Figure 4) (Tarbuck).

Figure 4: A raging fire at Turkey's largest oil refinery in the hard-hit Izmit, sparked by the devastating earthquake, was finally burning down three days later (S:6).

d) Flooding: a temporary condition of inundation of land adjacent to river channel or along shoreline of lake, sea or ocean. Below are some of the flooding events that are caused by earthquakes:

i. *Tsunami (seismic sea waves):* a rapidly moving ocean waves generated by earthquake activity, which is capable of inflicting heavy damage in coastal area (Figures 5 and 6). Tsunami can get as high as 30 meters (Tarbuck).

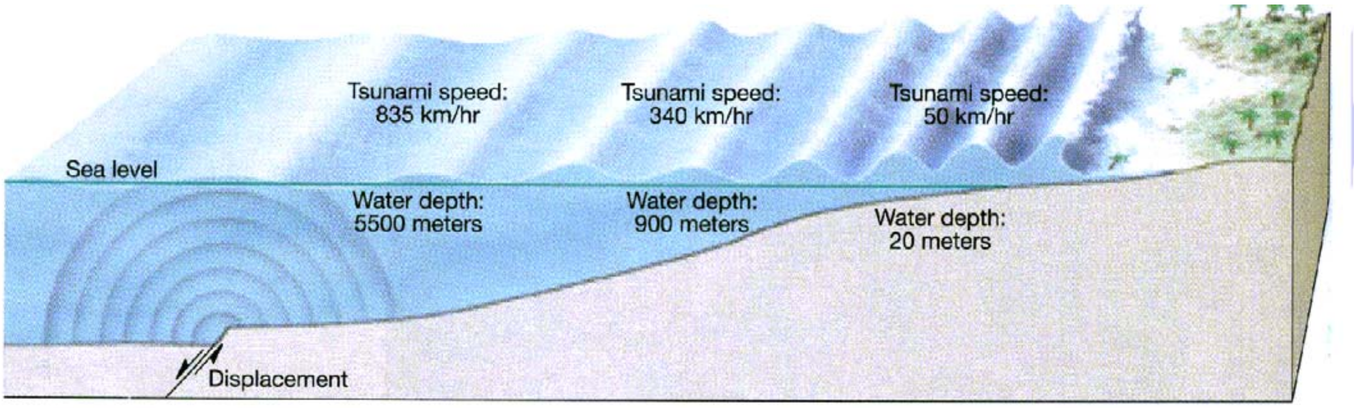


Figure 5: Schematic drawing of tsunami generated by displacement of the ocean floor (Tarbuck).

Figure 6: Debris scattered by a tsunami that struck, Aonae, Japan, in July 1993 (Tarbuck).

ii. Floods caused from *dam* and *levee failure* caused by earth vibrations (Tarbuck).

e) Seiches: rhythmic sloshing of water in lakes, reservoir and enclosed basins (Tarbuck).

f) Landslides and ground subsidence: caused by shaking and lurching ground. In 1964 Alaskan earthquake, for example, the greatest damage to structure was from landslides and ground subsidence triggered by the vibrations (Figure 7). The vibrations, also, caused the material to experience liquefaction (Tarbuck).

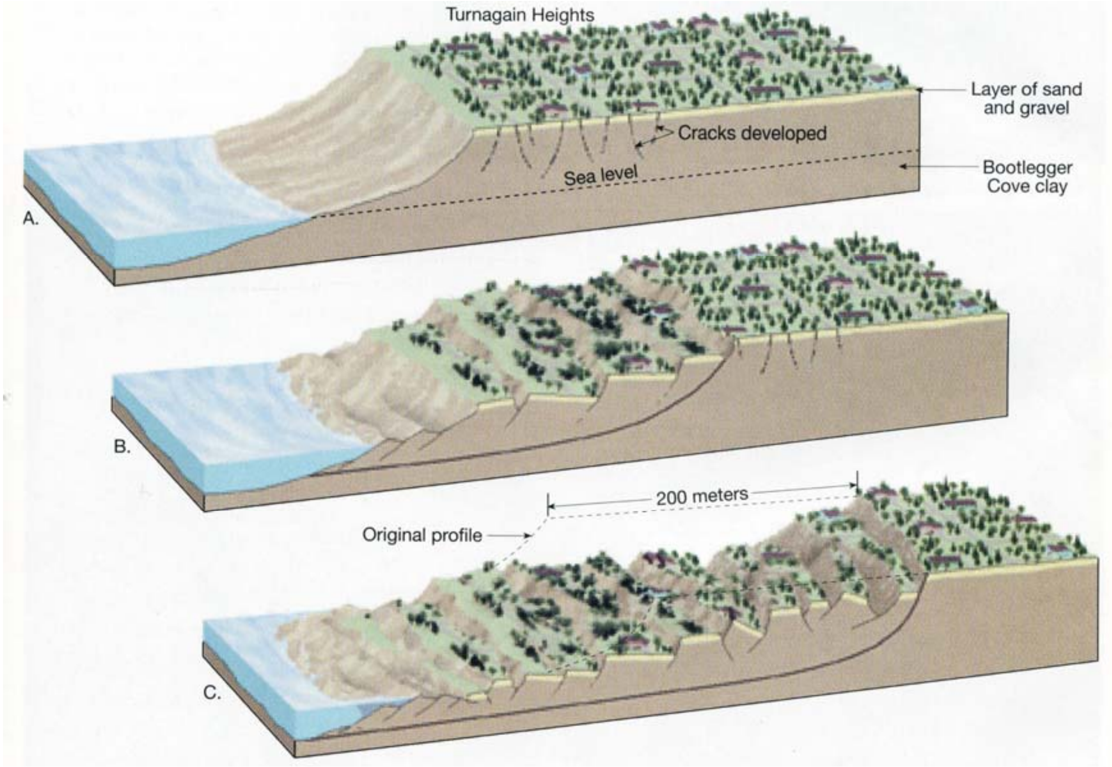
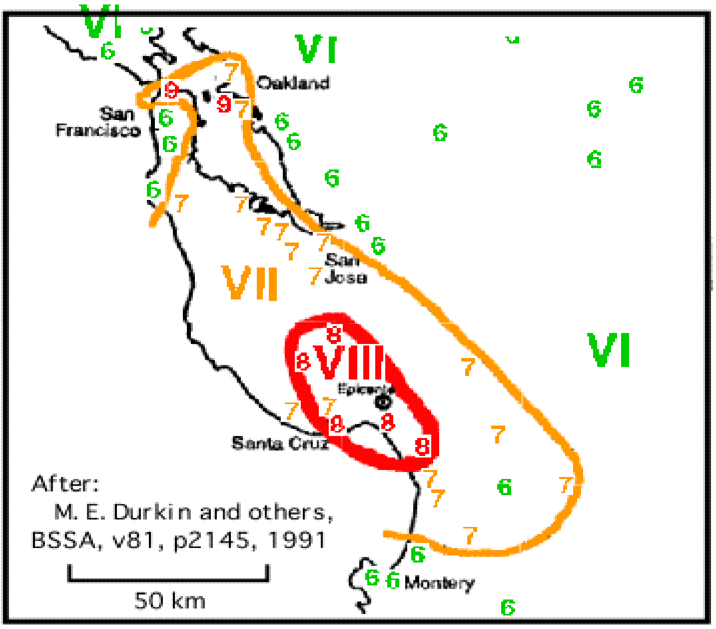


Figure 7: Turnagain Heights slide by the 1964 Alaskan earthquake. A. Cracks near the edge of the bluff caused by the vibration. B. Within seconds blocks of land began to slide toward the sea on a weak layer of clay. C. In less than five minutes, as much as 200 m of Turnagain Heights bluff area had been destroyed (Tarbuck).

3. GIS APPLICATIONS IN EQ ASSESSMENT

3.1 Why GIS?

GIS has provided a very efficient tool in the field of earthquake hazards assessment. Prior to GIS, seismologist used the *isoseismal maps* (Figure 8), earthquakes risk maps (Figure 9) and *seismicity maps* (Figure 10) in addition to other maps to study and predict earthquakes. Although mapping provides a very useful way of presenting information when compared with tables and texts, sometimes they would lack the meaningfulness without referring to the tables and texts instantly. It was not possible, before the introduction of GIS, to visualize different maps at the same time in an efficient way. Also, maps and attributes (e.g. the fault characteristics, ground acceleration and damage) have to be viewed separately, perhaps in a table, which makes it more difficult to study and predict earthquakes (Johnson).



After:
M. E. Durkin and others,
BSSA, v81, p2145, 1991

Figure 8: This map plots the Mercalli Intensity ratings of localities near the Oct. 17, 1989 Loma Prieta (World Series) earthquake. It is called isoseismal map, as one draws contour lines to enclose locations having higher intensities; the Arabic numbers represent the local observations (S:9).

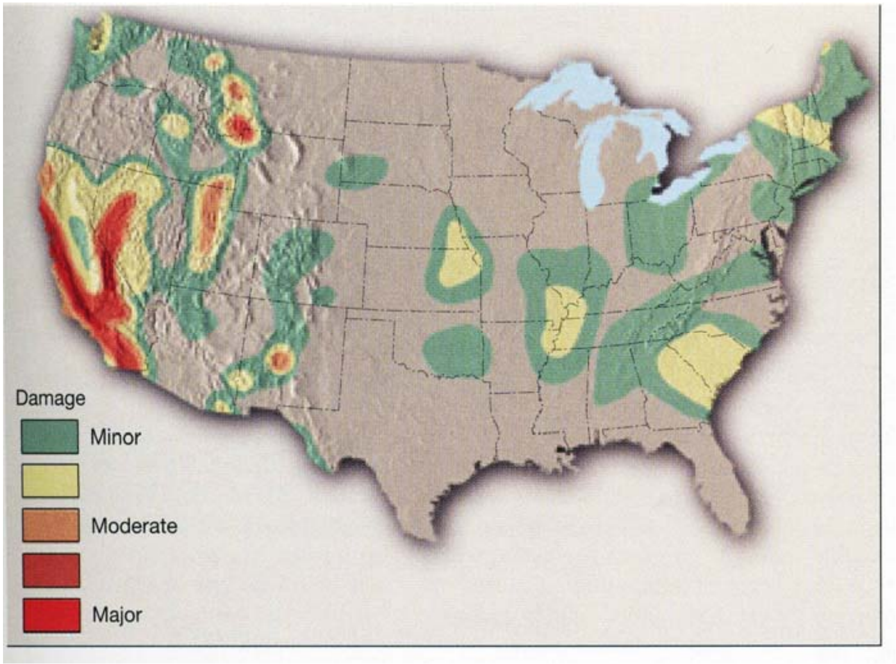


Figure 9: Earthquake risk map. This map shows the extent of earthquake damage that is likely to occur at least once every 50 years period. Again, it can be used in planning and insurance purposes (Tarbuck).

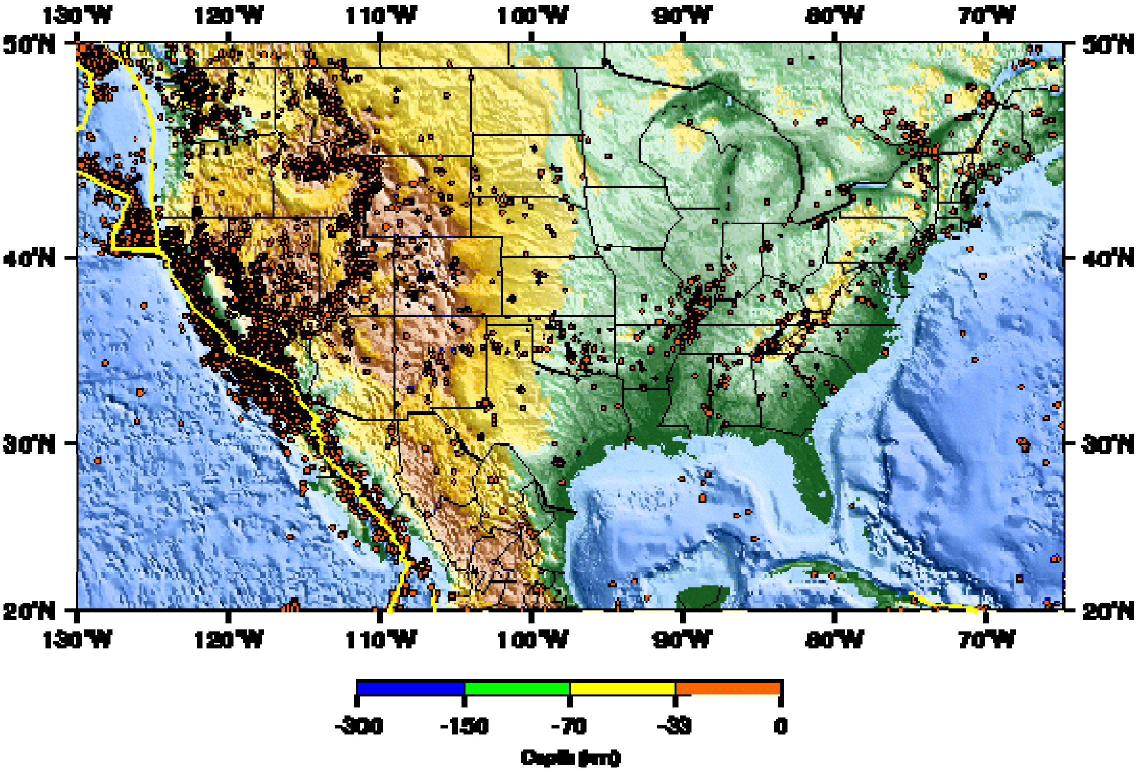


Figure 10: Seismicity of the US (1977-1997) (S:9).

With the use of GIS, different maps (layers), such as infrastructures and faults maps can be viewed simultaneously as well as the attributes such as faults characteristics and earthquakes magnitude (Figure 11).

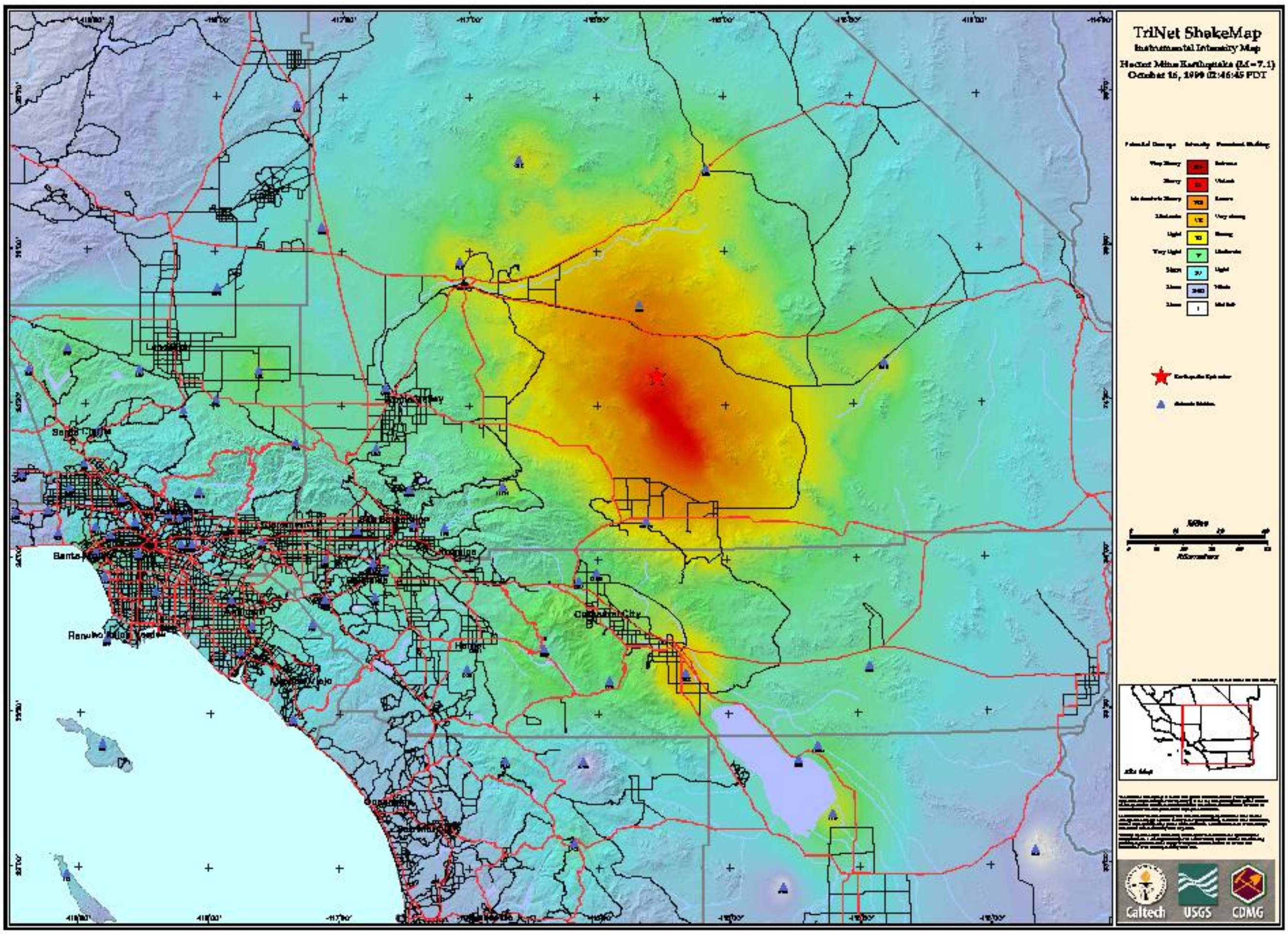


Figure 11: A GIS view of shake map. Note how many things can represented in a single view (S:1).

In the field of seismology, GIS has been used in all three phases: *1) management-planning*, *2) mitigation-preparedness* and *3) response-recovery.* Planning involves identifying the seismic hazards, risk and possible consequences of an emergency. A process that is called ***Hazard Zoning***, i.e. identifying, geographically, the zones that are more susceptible to seismic hazards on maps (Johnson).

The output of the hazard zoning process is presented in maps that are utilized in the mitigation and preparedness activities that start after the damage is evaluated, e.g. mapping and analyzing the relation of faults to existing infrastructure highlights areas vulnerable to earthquakes. These areas, identified in the hazard zoning maps, become the focus of the mitigation efforts, which may come in different measures such as stringent building codes and retrofitting existing structures. Preparedness may be achieved through several activities such as mapping evacuation routes and public education (Johnson).

During an earthquake, quick mobilizing and targeting response effort can help in reducing the secondary damage from fires, gas leak and water supply contamination. Finally, recovery, in both short term and long term, can be better coordinated through GIS by prioritizing damage repairs and careful analysis of infrastructure and hazards before rebuilding can create more sustainable communities (Johnson).

In addition to all of these, GIS is very important in coordinating the efforts of participating agencies. Not only does GIS improve communication between responders, it can help alert and inform residents of affected areas. It gives emergency responders personnel the tools for data integration (specially when dealing with very large data), analysis, and communication that can make a critical difference in dealing with earthquake hazards. Even though it is true that earthquake cannot be prevented or predicted with great certainty, such emergency management activities, enhanced through the use of GIS, limit the lost of life and property when earthquakes happen (Johnson).

3.2 How GIS is Used?

There are several steps toward a proper utilization of GIS in seismology. Here, general steps will be mentioned briefly and it should be emphasized that different steps may be applied in different circumstances depending on the objective of the study.

The first step toward an efficient use of GIS in earthquakes assessment is to identify the source of the problem, which is the source of the seismic activity, mainly *faults* (Figure 12). After locating the source of the seismic activity, then data collection (seismic data) is the next step. Part of the data may be available from historic records and others have to be collected continuously through *seismographs*, devices that are used to record the seismic activity. These seismographs are linked, instantaneously, to a computer system using a combination of *GPS*, Global Positioning System, and *landlines* (Gooding).

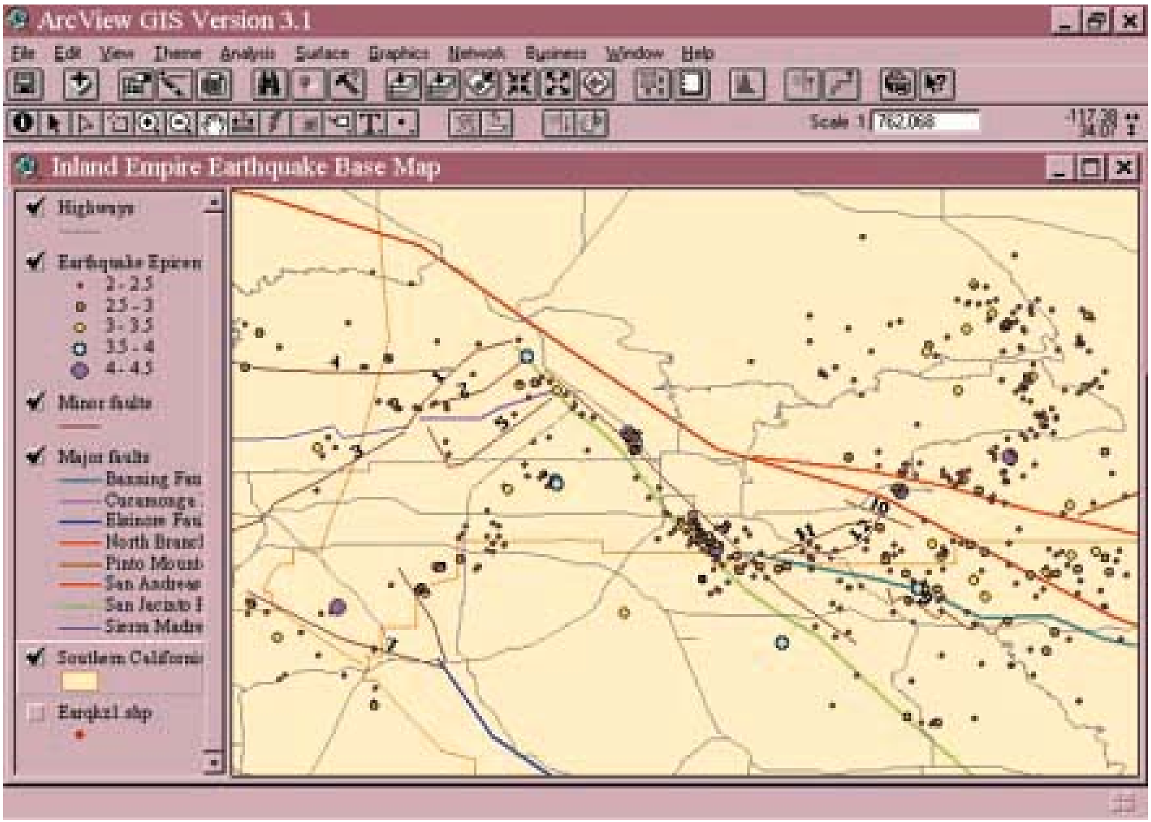


Figure 12: A GIS view of the biggest concentration of faults in the valley and mountainous region surrounding the San Andreas Fault zone and the San Jacinto fault zone (Gooding & S:1).

After managing the seismic data issue, comes the step of creating or obtaining the maps. In general, maps are available through specialized agencies in digital format, e.g. USGS in United States. However, one should decides what maps should be used, which can be inferred from the objective of the study, e.g. topographic maps, faults maps, population maps …etc. For instant, the geographic data that comes with ArcView GIS can be used to create base map (Gooding).

Once the data is collected and the maps are created, one should define the parameters involved in the study (project), e.g. maximum and minimum magnitude, and convert these parameters into the proper format (shapefile). For instant, MS Excel may be used to create earthquake data table and then saving the data as a dBASE file that is useable by GIS. This is the process of creating the project *database.* It is of vital importance to ensure the consistency of the data, e.g. units of longitude and latitude. After the database is created, table(s) may be used to create an event theme and earthquakes may be classified by their magnitude using the graduated symbols available through the theme legend editor (in ArcView GIS) (Gooding).

Additional steps may be added, again depending on the objective of the study, like creating 3D, contour and triangular irregular network (TIN) themes (Figure 13). By this, the final step has been reached, which is to analyze and interpret the maps and the data after they have been organized and presented in very useful and simple way (Gooding).

Figure 13: A GIS view of triangulated irregular network (TIN) created from the earthquake point theme. Faults and earthquake epicenters are visible on the surface. Areas in yellows and reds indicate shallower epicenter depths. Blue areas indicate deeper epicenters (Gooding & S:1).

3.3 Case Studies

Three case studies are presented here: one that shows the application of GIS in estimating the probable maximum losses after the*1989 Newcastle Earthquake, Australia.* The second case shows the implementation of GIS in the development of an earthquake risk assessment framework from the *Island of Cyprus.* The last case study is from the *Bay Area, CA, USA* where GIS has been used in addition to other methods in *Mapping the Big One.*

3.3.1 <u>Case Study 1:</u> 1989 Newcastle Earthquake, Australia

Even though Australia lays in a low seismic zone, in 1989, an earthquake of magnitude of 5.6 caused: 12 fatalities, 160 injuries and 1,124 million insured damage. Research to estimate *Probable Maximum Losses* (PML) to the insurance industry has been conducted by Natural Hazard Research Center (NHRC), Sydney. Over 40,000 claims where reported and GIS was used to link each claim to Modified Mercalli (MM) map (Fig. 14). GIS was very helpful in making it easier to better understand the spatial data, e.g. spatial location of buildings in relation to the length of streets that cross MM boundaries (Figure 15) (Hunter).

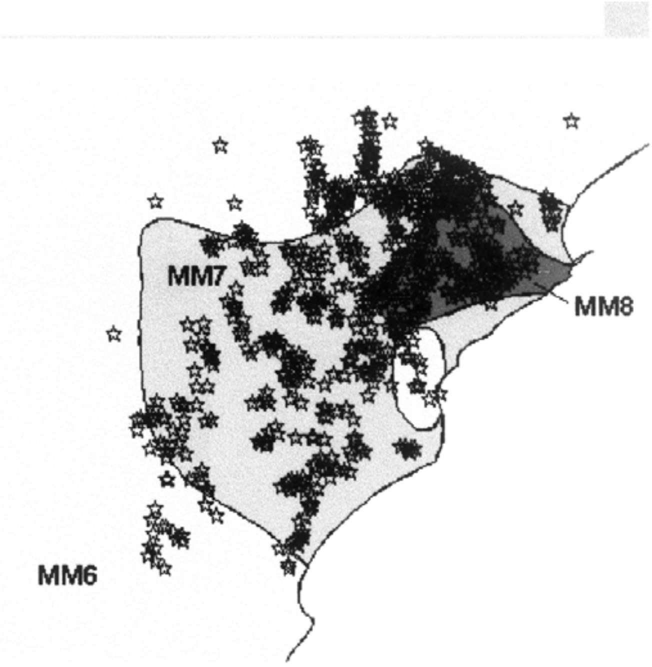
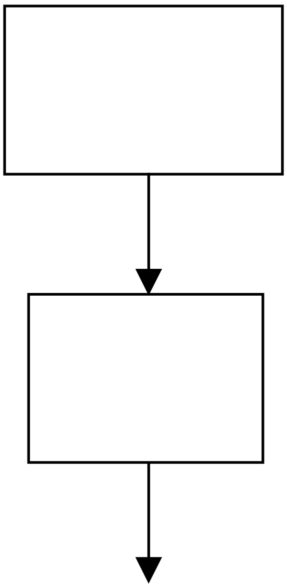


Figure 14: Map of claim location and MM values of the areas affected by Newcastle Earthquake (Hunter).

Input



Output

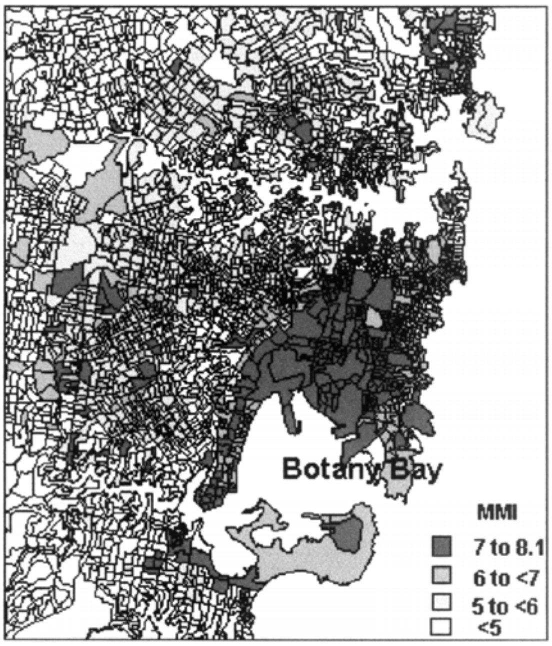
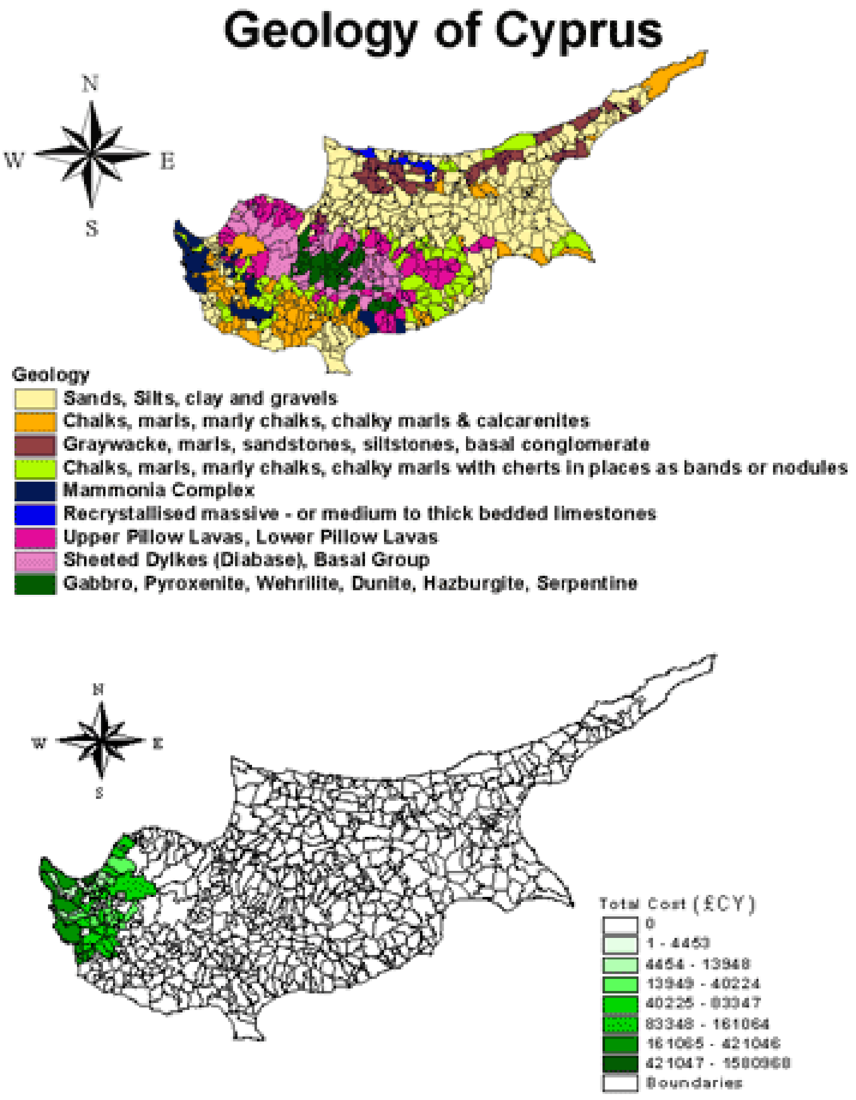


Figure 15: Estimated MM values for an earthquake of magnitude 5.6 originated at depth of 12 km. This can be used as a base map and other details, e.g. building construction and population, may be overlaid for the purpose of assessing the seismic risk associated with areas of interest. (Hunter).

3.3.2 Case Study 2: Island of Cyprus.

GIS was used in the Developments of Earthquake Risk Assessment framework using computer simulation. Input Parameters included, but not limited to, population, buildings, and hydrogeology. One important assumption were made that past earthquakes of certain magnitude would reoccur in the same region in a defined period of time. The adopted solutions include strengthening of existing buildings, demolition of weak buildings, level of aseismic measures to be taken and land use planning and relocation of population (Figure 16) (Kythreoti et al).

Figure 16: Geology of Cyprus (top), and Intensity Map (bottom) (Kythreoti et al).



Estimation of damage cost based on the total dwelling stock, the predicted intensities and the mean damage ratios; caused by the earthquake which occur on the 23rd of February 1995 with Ms=5.7

3.3.3 Case Study 3: Mapping the Big One, Bay Area, CA, USA.

GIS has been used by ABAG, Association of Bay Area Governments, to produce comprehensive maps of seismic hazard zones in order to identify areas prone to ground failure and minimizing damage of earthquakes. The program is funded by Department of Interior, USGS and National Science Foundation. The input data include data from seismographs and GPS. The output is presented on maps containing fault traces, shaking, dam failure…etc. Solutions implemented include programs to strengthen housing, land use and zoning controls, disaster response planning, infrastructure and lifeline requirements (Figure 17) (Ward).

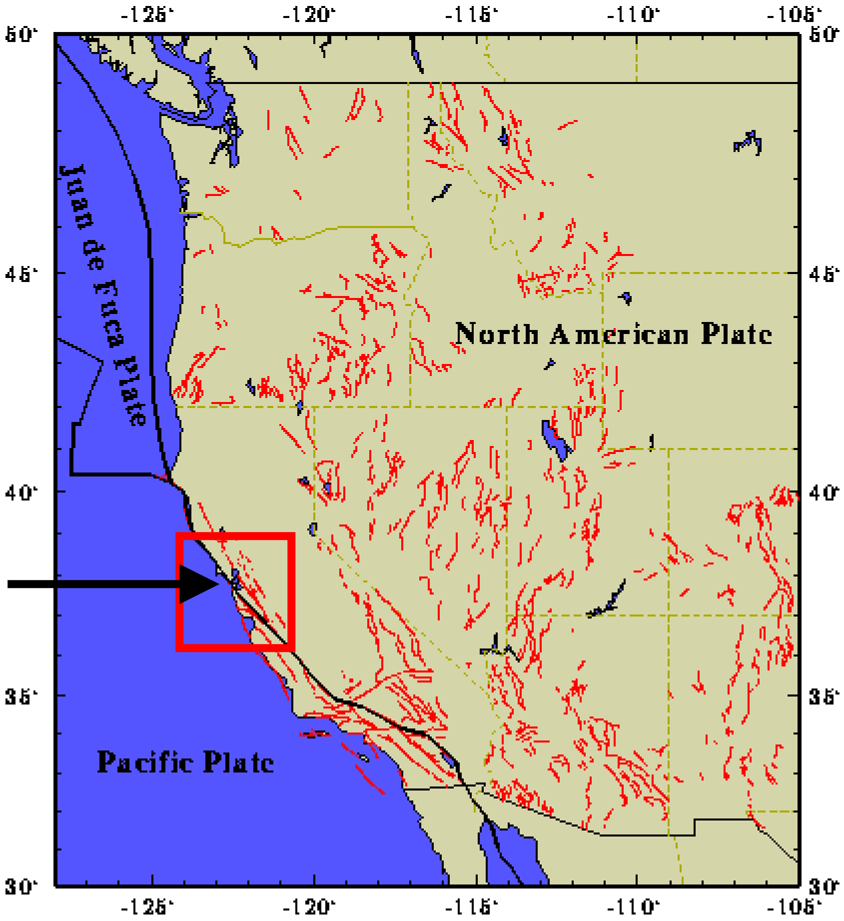


Figure 17: A GIS map showing the distribution of faults in the West Coast area of USA. Note the major fault, i.e. San Andreas Fault that passes through the Bay Area (S:1).

4. CONCLUSION

Emergency response related to earthquakes is one area that could benefit greatly from a coupling of GIS and short-term earthquake prediction. Having quick access to areas that were affected most by an event, such as travel routes and gas lines, the effect on these infrastructures could be significantly reduced. Another important benefit is the early-warning system, which could provide enough time to shut down nuclear reactors and close at risk gas lines and therefore minimize along fault potential damage. GIS could feasibly handle this task with the proper input. GIS gives emergency responders personnel the tools for data integration (specially when dealing with very large data), analysis, and communication that can make a critical difference in dealing with earthquake hazards.

It can be concluded that earthquakes problem is a multidisciplinary problem that should be talked by: Geophysicists, Geologists, Engineers and Planners, and Socioeconomic. Scientific understanding of earthquakes is of great importance, and it requires a big budgetary resources. As the population increases, expanding urban development and construction works move toward areas susceptible to earthquakes. It’s recommended, when dealing with seismic hazards, that GIS is used in conjunction with other techniques, such as GPS, Remote Sensing and engineering solutions. Also, all types of seismic data, real time and historical data, should be used in data integration so that a comprehensive database is achieved for short-term and long-term earthquakes monitoring and prediction systems.

With a greater understanding of the causes and effects of earthquakes, and by increasing the awareness of earthquake hazards, all together with the up to date state of the art technologies including, and not limited to, the utilization of Geographic Information System, it becomes possible to reduce damage and loss of life from this destructive phenomenon.

“Even though earthquake cannot be prevented, emergency management activities, enhanced through the use of GIS, can limit the lost of life and property when earthquakes happen.”

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