URBAN SEISMIC HAZARD MAPPING USING SPATIAL DATABASE MANAGEMENT TOOLS

UNITED STATES GEOLOGICAL SURVEY
NATIONAL EARTHQUAKE HAZARD REDUCTION PROGRAM

PREPARED BY:
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MAY 30, 1995

Research supported by the U.S. Geological Survey (USGS), Department of the Interior, under USGS award number 1434-94-G-2408. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

ABSTRACT

The work carried out under this grant award is outlined in considerable detail in the final report. The different seismic planning data sources are carefully described along with how they fit together to form a package for use by natural hazard planners. The report contains details about the digital data layers and how together they form a nucleus of a geographic information system for seismic mitigation and planning. The main thrust of the project, however, was towards bringing such a system to the desktop for ex ante use during the planning stage, not ex post after a seismic plan has already been determined.

Thus the major contribution of the project is not the final report itself but the ArcView application contained on the accompanying diskette. The report identifies hardware/software requirements and suggestions about its use.

CHAPTER 1:

INTRODUCTION

This project, "Urban Seismic Hazard Mapping using Spatial Database Management Tools", was funded in order to investigate the potential for using geographic information systems (GIS) to identify, plan for mitigation, and to regulate seismically hazardous areas. A main thrust of the project was to look at ways this information can be used within the land use planning process. Applications of this project are relevant to disaster response and recovery planning, hazard mitigation, and land use planning within the context of Washington's 1990-91 Growth Management Act.

On January 17, 1994, the west coast of the United States experienced a large earthquake centered in Northridge, California. Images and descriptions of the Northridge earthquake and related destruction brought a new sense of purpose and urgency to hazard identification and reinforced the importance of relating hazards to planning practice. In particular, the need for advanced spatially referenced databases for emergency recovery and for reconstruction was made very clear.

EARTHQUAKE HAZARDS AND RISKS

One of the primary objectives of this project was to identify available data that could be used in hazard identification. A brief discussion of hazards presented by an earthquake seems in order.

Events associated with an earthquake can be sorted into two general categories for further consideration: **hazards** and **risks**. (French and Isaacson, 1984)

Hazards are typically considered as physical characteristics of the landscape that are altered when an earthquake strikes. **Geologic hazards** indicate characteristics of the earth's surface that make particular areas more or less prone to geologic alterations during a seismic event, such as ground shaking, liquefaction or landslides. **Physical hazards** indicate characteristics of the built environment that are more or less resistant to the force of an earthquake. Examples of physical hazards include unreinforced masonry buildings, and other types of buildings constructed prior to seismic safety regulations.

We consider **risks** to be *social or demographic* characteristics of the landscape that are directly or indirectly threatened by a geologic or physical hazard. Equipped with a community profile describing the population, race, age, average household size, income, etc., an emergency manager or mitigation planner is in a much better position to make quick, critical decisions in the preparedness, response, recovery and mitigation stages of the disaster, and to be able to plan more carefully for individual needs.

In this project our operating premise was that a spatial database management tool, namely ESRI's ArcView, is a cost-effective and relatively easy way to store and query data about both geologic and physical hazards as well as risk. Our contribution is a tool that is useful in assessing all three of these elements, both individually and in relation to one another.

CHAPTER 2:

DATA RESOURCES

The objective of the project was to design a spatial database that could be used to identify and relate different aspects of earthquake hazard. Five types of data were used in this project: geographic, geologic, lifelines, housing data and population information. Other supplementary data types that could be used to enhance this project are discussed below.

Source data often vary in detail and scale. This project required combining datasets with various scales, including state, county, city, tract and blockgroup. The common denominator of the data was the city level. Because geological and geographical data was available, the city of Seattle was chosen as a case study for this project. We had the full cooperation of the City's Planning Department for needed data layers. City planning staff, most especially Cliff Marks, were enormously helpful in facilitating the early stage of the project.

The data considered within this project can be sorted into the following categories:

- **Base Data** - basic land forms, water bodies, cities, census geography, roads and rails. (Data Layers that compose the "base map" for the analysis.)

- **Primary Data** - liquefaction zones, landslide sites, historic intensity, demographic and social characteristics. (Data Layers that are "applied" to the base map in the analysis.)

- **Supplemental Data** - elevation / topography, satellite imagery, etc. (Suggested additional data layers added primarily for relief and reference)

Table 1 (Appendix B) shows the data types and sources for each of the overlays used in this project.

BASE DATA

Base data for this project was obtained from the following source:

1990 Washington State Redistricting Database. Compiled by the Washington Redistricting Commission and administered by the Washington State Energy Office, this database contains political and demographic information for every county in Washington. It is composed of "cleaned" TIGER/Line files of Census geography (i.e. County, Major Civil Division, Place, Tract, Blockgroup and Block), legislative districts, major and minor roads, Public Land Survey geography (Township, Range and Section), and major water features. The base data provided by this source includes the location of roads and rails. Roads are sorted into major (freeways and highways) and minor (arterials and collectors) categories.

This database provided several of the base layers, and is a good resource to be tapped in constructing similar models elsewhere in Washington.[1]

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[1] This database was selected for convenience and ease of use. It should be pointed out that identical data can be obtained for any state by transforming either the 1990 or 1992 TIGER/Line files to GIS data layers.

PRIMARY DATA

Primary data for this project was obtained from the following sources:

City of Seattle Comprehensive Plan and Seismic Hazards Study. The City of Seattle compiled a report entitled "Seismic Hazards in Seattle" under a NEHRP grant in 1992. (Marks, et. al., 1992) In their report liquefaction zones, locations of previous quake-related landslides, and future landslide-prone areas are identified. This information is also present in the City's 1994 comprehensive plan and accompanying Environmental Impact Statement. (City of Seattle, 1994) The ARC/INFO coverages used in the analysis of liquefaction and landslide hazards were provided by the City's Planning Department GIS Technician with the assistance of the seismic hazards project manager.

Liquefaction refers to the tendency of highly saturated soils to become fluid when subjected to ground shaking. It is among the most prevalent causes of earthquake damage, and has been associated with most major earthquakes in the past 30 years. (Jaffe, *et al.*, 1981) Soil disturbance caused by ground shaking causes physical properties of a soil to change rapidly. Sudden fluidity alters a soil's bearing capacity, reducing its ability to support foundations or other loads. Liquefaction problems are most prevalent among water-saturated sands, silts, and other compacted soils.

There are several consequences associated with liquefaction. Liquefied soil may move or oscillate with displacements that are large enough to rupture pipelines, move bridge pilings, or split buildings. Light objects underground may float toward the surface, while heavy objects may sink. (Madin and Mabey, 1993b) Soils subject to liquefaction can be identified, and their thickness and influence on the severity of earthquake damage can be determined at a given site. Sands, silts, and compacted soils are good indicators of the potential for liquefaction. For liquefaction data collection, an ordinal scale indicating the potential for liquefaction to occur is desirable. (French and Isaacson, 1984) Such a scale can protect the validity of the liquefaction portion of a multiple hazards analysis. Unfortunately, the data received about liquefaction in Seattle is binary in nature. Sites are identified as being either prone to liquefaction (liquefaction = 1), or not prone (liquefaction = 0).

Areas underlain with sands or silts and subject to intense ground shaking pose more liquefaction hazard than areas underlain with sands or silts and subject to less intense ground shaking. The location of past and existing wetlands, and depth to groundwater are also good indicators of liquefaction potential. Because liquefaction hazards are greatest where groundwater is near the surface, developments placed on filled wetlands or in areas of high groundwater may be subject to liquefaction. (Jaffe, *et al.*, 1981) Commercial and Industrial districts located in filled areas near bays are also extremely subject to liquefaction. For this reason, much of the Duwamish industrial area in the City of Seattle has been designated a liquefaction hazard area. (Marks, *et al.*, 1992)

Ground shaking can also trigger slope failure following an earthquake. A landslide is a downward and outward movement of unstable slope materials, including rock, soils, artificial fills and vegetation. Seismically-induced landslides occur when ground shaking and/or subsidence causes existing landslides to move or new landslides to form. Known landslide sites are therefore relevant to the consideration of potential earthquake hazards. Slope stability and soil thickness can be used together to indicate the relative potential for slide activity among both existing slides and landslide-prone areas.

The potential for a landslide to form depends upon the presence of water in soil, the stress placed upon soil by structures and landforms, and the gradient of the unstable slope in question. (Laprade, 1993) Ground shaking or settlement associated with an earthquake will often increase the stress on soils covering a steep unstable slope, causing it to fail. Slopes can also fail if they are undermined by coastal or stream erosion.

The Puget Sound region presents landslide hazards because it is a glacial landscape. A layer of glacial till is underlain by a layer of outwash sands. Both of these layers lie directly above impervious clay. In areas of high precipitation, the contact points between outwash sands and clay are critical. Water can pass freely through both the till and sand, but is forced to move laterally across the top of the clay layer until it reaches a hillside. This buildup of groundwater above clay layers following heavy precipitation increases the stress placed on a slope and contributes to its failure -- with or without predicated seismic force. Thus, regulating development activity in areas where outwash sands contact impervious clays would be a good mitigation measure for reducing seismic landslide hazards. In many cases such bluff areas will be highly valued for residential use because of the views they afford.

Slopes subject to landslides can usually be identified by determining a slope gradient and acquiring and applying data about surrounding soils and hydrology. Stressed slopes often show signs of gradual subsidence and cracking that are indicative of their weak, non-cohesive nature. (Jaffe, *et al.*, 1981) Most jurisdictions in Washington are completing landslide hazard maps as a result of the Growth Management Act (GMA) Sensitive and Critical Areas requirement. Similar maps have been completed for California communities for several years as a result of the General Plan requirement to complete a Seismic Safety Element.

The landslide data provided by the City is stored as binary data. Sites are identified as being either existing slides (landslide = 1), or not (landslide = 0). Both of these data layers were composed using a geologic map of Seattle as a part of the "Seismic Hazards in Seattle" project.

<u>1990 U.S. Census of Population and Housing STF-1 and STF-3A</u>. Using data stored on CD-ROM from the Census, we compiled spreadsheets of pertinent variables and linked these with the census geography layers described previously as base data. Initially, the data was combined for all of King County, Washington. A spatial overlay was performed using the ARC/INFO *clip* function to isolate the data for only the City of Seattle.

Both Population and Housing data was obtained for the City of Seattle. Population data was obtained primarily to help **risk**, as described previously. Housing data was obtained both to define risk, as well as to provide an indicator of **physical hazard**, namely age of structures as defined by the variable *H25A. Median year structure built.*

We used census data as an indicator of housing age and construction integrity, as shown below.

Population Data	**Housing Data**
P3. 100 Percent count of persons	H3A. Percent of housing units in sample
P3A. Percent of persons in sample	H20. Units in structure
P5. Households	H23. Source of water
P6. Urban and rural	H24. Sewage disposal
P7. Sex	H25. Year structure built

- P8. Race
- P10. Persons of Hispanic origin
- P13. Age
- P16. Persons in household
- P49. Means of transportation to work
- P50. Travel time to work
- P54. School enrollment, type of school
- P80A. Median household income in 1989
- H25A. Median year structure built
- H30. House heating fuel
- H61. Value
- H61A. Median Value
- H64. Plumbing facilities

Most studies of this type use a slightly more rigorous method and data source to provide structure characteristics. (e.g. Perkins, 1992) Assessor's data would be more reliable than census characteristics to provide structure data. In only one known instance, Portland Oregon, (Uba, 1994) have there been adequate resources to carry out intensive structure surveys.

To increase the accuracy of our census data "proxy" for structure integrity, we have sorted the median year structure built variable into four categories dictated by successive updates to the Seattle Building Code relating to seismic reinforcement. This will be described in more detail in a subsequent part of this report.

Historic Intensity Measures for 1949 and 1965 Earthquakes. Researchers commonly assume that damage from future earthquakes will occur in the same locations as past earthquakes. Thus, historic earthquake intensity makes a good predictor of future physical hazard. The magnitude of the earthquake, the distance to the earthquake fault, and the geologic materials underlying the site are the principal factors affecting the intensity of an earthquake at a given location. Earthquake intensity should be differentiated from earthquake magnitude. While magnitude is a measurement of recorded ground motion, intensity is a proxy measure for ground shaking at a particular site. It is determined from reported damage, and is biased by human perception of the event.

Intensity is commonly measured using the Modified Mercalli Intensity scale (MMI) -- an ordinal scale ranging from 1 to 12, with higher values indicating increased levels of earthquake damage. MMI surveys are often conducted by mail or newspaper insert following high magnitude earthquakes. As a result, MMI data are often skewed in favor of population density. An MMI sample is far from a stratified random sample. This makes decisions on the use of MMI data in hazard mapping and land use planning applications quite difficult. MMI data do provide an estimation of ground shaking. However, that estimation is 1) derived from damage assessment, 2) influenced by varying personal perceptions of property damage, and 3) subject to sampling error. There are serious questions about both validity and reliability of MMI data. However, MMI data is often the only measure available due to the lack of seismic data for many historic earthquakes and the limited data available for recent earthquakes.

Results of two such surveys -- one administered following the 1949 magnitude 7.1 earthquake, the other following the 1965 magnitude 6.5 earthquake -- were provided by Tony Qamar, former State of Washington seismologist. This data was converted from latitude-longitude coordinates of damage sites to a coordinate system compatible with the other data being assembled, the State Plane Coordinate System for Washington, North Zone.

Water Service Lifelines. Data describing water service lines in Seattle was provided by the Seattle Engineering Department. This data was to include attributes describing the diameter of water pipes, construction material, and approximate date of construction. Unfortunately, these critical attributes were not included with the pipeline geography furnished to the project. Moreover, to minimize the size of the data required for this project, water supply data was only collected for a study area in Southeast Seattle. Nevertheless, what was furnished has been incorporated into the spatial database in two ways: as a data layer itself and also as the pipelines that are within landslide and liquefaction areas (*watslide* and *watsliq*, respectively.)

The water supply data provides an example of infrastructure **lifelines**. Failure of electric, water, or transportation facilities following a major earthquake can have a significant negative effect on a community's emergency and recovery efforts. In response to potential system failures resulting from earthquakes, lifeline earthquake engineering has developed as a significant field of specialization within the civil engineering discipline.

The Federal Emergency Management Agency (FEMA) and National Institute for Standards and Technology (NIST) have invested considerable resources in the development of a methodology for identifying and setting design and construction standards for lifelines. NIST (1992) defines lifelines as "... the public works and utilities systems that support most human activities: individual, family, economic, political, and cultural. Lifeline systems comprise electrical power, gas and liquid fuels, telecommunications, transportation, and water supply and sewers." (Pg. I-1 ...emphasis added.)

The lifeline engineering community defines lifelines in terms of *systems*. Using a systems approach, each of the above infrastructure categories is broken down into *elements* and *components*. For example, within the transportation system, highways are recognized as elements, and bridges are recognized as components within a highway.

A lifeline vulnerability study in progress for the Portland metropolitan area (Uba and Savage, 1994) provides an example of a general approach used for planning purposes. A general picture of the region's entire infrastructure is used to identify critical points in lifeline systems and critical facilities within hazard zones. The method requires a composite hazard map, much like that required for the risk assessment methodology described previously. GIS digital maps for each of the identified lifeline systems and critical facilities are then spatially overlaid on the hazard maps, yielding descriptive reports of infrastructure elements and components within various hazard zones, rather than estimates of dollar losses. The findings of this lifeline analysis are presented as amounts of lifeline infrastructure or community facility located in hazard zones.[2] This type of information is useful to emergency planners responsible for administrating hazard mitigation in local jurisdictions, as it provides convincing visual evidence of the relationship between potentially weak infrastructure and potentially hazardous areas. (Uba, 1994)

Lifeline studies are worthwhile tools for planners. Most of the work in this area has been performed by civil engineers, and is very technical -- for example, the structural response characteristics of various construction materials to ground shaking. However, since infrastructure is a primary determinant of growth, the study of lifelines should be part of the planning process. One of the planning studies reviewed in this work performs a lifeline vulnerability analysis following completion of a hazard map. (Uba and Savage, 1994) GIS has been increasingly used as a method for locating

2 The findings are presented, for example, in terms of percentages of sewer lines located in Zone A (Greatest Hazard), B, C, or D (Least Hazard) resp. Combining of different hazards into a composite hazard is somewhat controversial but will not be pursued here.

vulnerable infrastructure lifelines and critical facilities in conjunction with an earthquake scenario event. Shinozuka, *et al.* (1992) performed an analysis that identifies bridges at risk during earthquake scenarios. Multiple regression was used to estimate the level of damage for each bridge as a function of ground motion attenuation, structural characteristics of the bridge(s), and geologic site conditions. Their study demonstrates how statistical methods used in risk assessment can be combined with GIS technology to produce sophisticated loss models for infrastructure facilities.

Careful planning for the extension of sewers, roads, and water lines can be particularly effective mechanisms for guiding future development away from hazardous areas. In many cases, these lifelines will traverse hazardous areas to provide service to certain areas of a community. Infrastructure, critical facilities siting, and capital planning all play very important roles in growth management planning. Geographic information systems, if employed for such planning can reveal significant insights into areas that should be avoided.

SUPPLEMENTAL DATA

Additional data could be used to provide easier comprehension and readability in the analysis. The following data sources could provide reference points and visual relief that will enhance the analysis. Neither enhancement has been performed to date in this project, but we suggest using either or both procedures to add context to the analyzed data.

<u>United States Geologic Survey Digital Elevation Model (DEM)</u>. By obtaining and constructing DEMs for the study area, ARC/INFO's Triangulated Irregula Network (TIN) module could construct three dimensional surfaces over which the base and primary data layers could be draped, providing a more realistic representation of relative earthquake hazards (ESRI, Inc., 1993b.) This technique would be particularly useful in the analysis of landslide hazards and would provide valuable insight toward defining levels of liquefaction hazard.

<u>SPOT Multispectral or Panchromatic Satellite Image(s)</u>. By obtaining and importing digital satellite images of the study area, one can add reference points such as buildings, roads and landforms to the analyzed data. The SPOT satellite system provides the best spatial (ground) resolution currently on the market. A SPOT satellite is equipped with two identical high-resolution-visible (HRV) sensors capable of producing 10m resolution panchromatic (black and white) images or 20m resolution multispectral (color infrared) images of a 60km by 60km area. SPOT satellites pass over a point on the earth's surface once every 26 days. (ERDAS, Inc., 1994) The images can be used as a background for the base data and draped over the DEM described above to provide additional context for the analysis.

DEVELOPMENT OF THE SEISMIC HAZARD MAPPING DATA LAYERS

It is important at this stage to note that the data sources indicated above are the same data sources used in the ArcView 2 application described in the sequel. Future users of this application should have little difficulty obtaining many of these data elements, as TIGER/Line files, Census STF-1 and STF-3A CD-ROMs, and USGS DEMs are all public data and can be obtained either from a Federal Repository Library, or the federal agencies themselves (at a slight cost.)

The other data sources are harder to obtain. Good sources for liquefaction and landslide data may include a local city or county planning department, a regional planning agency, or a local university's planning and/or geology departments. MMI surveys are best obtained from a local university's seismology laboratory. In our application, the MMI points may be replaced with other point-based data, such as ground rupture locations or earthquake epicenters. Water or sewer data can usually be obtained from the utility department or a County or City Engineering Department.

In some cases, data can be imported directly into ArcView. Other times, a layer may need to be "constructed," either by relating a spreadsheet or database to the geographic coordinates of the base layer, or by manually digitizing the data points into a new layer.

These data sources provide the backbone that drives the hazard mapping application described in the next chapter. Table 1, Appendix B, contains a brief summary of all of the data layers used in the project.

CHAPTER 3:

SEISMIC HAZARD MAPPING

The purpose of this project was never to map areas of potential seismic hazard in Seattle; to a large extent that had already been done, though possibly somewhat inadequately in certain respects. Our purpose was to show how the ensemble of mapped data could be assembled into a desktop mapping system and how then it could be used to facilitate the planning for and mitigation of seismic hazards *ex ante*. Once the database described in Chapter 2 was assembled, we applied geoprocessing to incorporate the data about hazardous areas in Seattle into a desktop mapping package.

We used ARC/INFO's *identity* and *union* functions to perform spatial overlays using the four data sets in our possession that we had identified as significant to hazard mapping: liquefaction, landslide existence or potential, seismic historic MMI (1949 and 1965), and median year structure built. It soon became apparent, however, that there were large areas of the city where there would be no apparent hazard of *any* type whatsoever. Assuming that a subduction zone earthquake in the Puget Sound area would have *some* effect on every point in the landscape, we decided to test a raster-based GIS approach that would better indicate areas of *relative* hazard within the City.

We developed indices of "relative hazard" of several types using a "relative" approach to earthquake hazard identification using raster GIS methods similar to the methods that have been employed in Portland (Mabey and Madin, 1993), San Francisco (Perkins, 1987; Perkins, 1992), Santa Barbara County (Santa Barbara County, 1993) , and San Luis Obispo, California. (French and Isaacson, 1984). The goal of a relative hazard mapping approach is to define homogeneous hazard areas, and compare them one to another to determine relative suitability for development. (Henderson, 1994)

Following our review of several of these so-called "relative hazard" methods, we returned to our original intention to construct a desktop seismic hazard "view" for the Seattle area using the more traditional vector-type, rather than grid-type, data layers. The software that we adopted for this purpose was ArcView 2, a spatial display and query desktop package by ESRI, the developers of ARC/INFO. The elements contained in the "view" are described below; they are all derived from ARC/INFO coverages.

This section of the report describes how the above data can be organized into ArcView themes that can be used to view urban seismic hazards, to display the areas of greatest earthquake hazard, and thus to plan for and/or mitigate those hazards in areas of high risk. The report contains as an integral part a diskette with the data and a "pre-packaged" ArcView of the data which we intent to use to show how ArcView is an ideal platform for the identification and display of the locations of infrastructure lifelines that are exposed to earthquake hazards.

As used in ArcView, "themes" are mapped attributes of the data layers (coverages). Thus one data layer or coverage with dozens or scores of columns of attributes could contribute to any particular ArcView dozens or scores of mapped thematic information. For example, five mapped themes listed below (Total Housing Units, Total Population, Residential Density, Median Year Housing, and Median Property Value) are contained in *one* ARC/INFO coverage, studybg (study area by blockgroup).

ArcView Themes

The following are the mapped themes that have been employed in the demonstration ArcView. The attribute that is mapped and its corresponding ARC/INFO coverage is indicated .

Theme	Description	Coverage	Attribute(s)
Liquefaction Zones	Seattle	sliqzone	polygons
Known Landslides	Seattle	sslide	polygons
Arterials	streets, study area	stdyrds2	lines
Water Service LL	Seattle	watnet	lines
Watsliq.shp	Water/Liquefaction Shapefile	watnet, liquefaction	outlines
Watslide.shp	Water/landslide Shapefile	watnet, sslides	outlines
Village	Seattle Urban Villages	village	Shade
MMI 1949	1949 Seattle M7.1 earthquake	sea49	MMI values
MMI 1965	1965 Seattle M6.5 earthquake	sea65	MMI values
Freeways & Hwys.	Seattle road network	seards1	lines
Water bodies	Puget Sound, lakes	seahydro	polygons
Seattle	City boundaries	seattle	lines
Total Housing Units	Seattle, by census tracts	seatract	polygons
Total Population	Seattle, by census tracts	seatract	polygons
Total Housing Units	Study area, by blockgroup	studybg	polygons
Total Population	Study area, by blockgroup	studybg	polygons
Residential Density	Study area, by blockgroup	studybg	polygons
Median Year Housing	Study area, by blockgroup	studybg	polygons
Median Property Value	Study area, by blockgroup	studybg	polygons

Four of the primary data layers described in Chapter 2 were selected as being most indicative of earthquake hazards: liquefaction, landslide existence or potential, historic MMI (1949 and 1965), and Median year structure built. These were selected based upon data availability (as described in Chapter 2), and upon the data selections of precedent studies (as described above).

"Liquefaction Zones" theme shows the spatial location of liquefaction zones across the Seattle area. Areas of significant liquefaction potential can be identified in the Duwamish industrial area, as well as in the Rainier Valley, particularly in one of the urban village areas targeted for greater residential and commercial densities.

"Known Landslides" displays the distribution of known landslides across the Seattle area. Many of these locations are steep slopes that overlook water bodies.

"Median Year of Housing Construction" presents a thematic map of the 1990 Census variable H25A. Median year structure built, by blockgroup. The data are classified into four categories reflecting successive seismic updates of the Seattle Building Code in 1946, 1953, and 1964.

ArcView Hazard Mapping Application

Introduction to ArcView

ArcView is best described as "viewing" software used to access spatial databases. It is produced by Environmental Systems Research Institute (ESRI, Inc.) of Redlands, California. The software is configured for use on PC-compatibles, Macintoshes, and UNIX workstations. This application is designed to run on PC-compatible machines running ArcView version 2.0. A minimal configuration is a 386/25 with 8MB RAM, 20 MB disposable disk storage (for data, the executable code, and for virtual memory requirements), Windows 3.1, and VGA monitor. A superior configuration is a Pentium 90 with 32 MB RAM and a high resolution, 17" monitor with SVGA graphics (1024x768).

ArcView uses ARC/INFO coverages as a foundation for displaying and querying spatial data. In addition, the latest release of ArcView (v. 2.0) allows the user to perform several essential GIS operations, such as projection, table relationships, and spatial overlay. This report provides only the information necessary to successfully navigate through the seismic hazard map application. For more detailed instructions on the use of ArcView, the user is referred to the ArcView "users guide."

In order to use the sample application enclosed with this report, you will need to have ArcView 2 installed on your PC. Before beginning, you should verify that both the "ArcView" and "Import" icons appear in your ArcView program group.[3] Highlight the "Import" icon and then click on Properties in the Program Manager to determine the location of the import.exe file; you will need to know it later.

Before copying any of the files from the floppy disk, you should first use DOS or the Windows: File Manager (Main) to create a new directory (c:\seishaz) on your hard disk (c:) where all of the data files and the ArcView project *seishaz.apr* file will subsequently be located.

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[3] If the "Import" icon does not appear in the program group, you will need to ascertain the location of the *import.exe* file; it most likely will be found in the c:\win32app\arcview\bin directory. If it cannot be located, it may be necessary to re-install the software from the program disks or CD-ROM.

Installing the Application

All of the utilities and data needed for the application are carried in one 1.44 MB diskette. Using DOS or the Windows File Manager, copy all files on the enclosed diskettes into your c:\seishaz directory. The disks contain all of the files you will need to run the application in ArcView. You should verify that your c:\seishaz contains the following files:

pkunzip.exe (the utility for decompressing the seismic.zip file)
seismic.zip (the compressed ARC/INFO coverages in export format and other files)
dataimp.bat (a batch file that may require editing for importing the ARC/INFO export files)

Exit Windows, if necessary, and navigate to the c:\seishaz directory on your hard drive. From the DOS prompt, type "c:\seishaz\pkunzip seismic.zip". This will execute a file called pkunzip which will unpack all of the needed data layers as ARC/INFO export files (covname.e00 files) from the seismic.zip file. The pkunzip.exe file is a standard decompression file that comes with ArcView and many other software installation utilities. You may wish to verify that the export files have been created.

The next step is to convert all of the export files into coverages using ArcView's import utility. This file is called import.exe and will ordinarily be found in the same directory as the executable code. By default this file may be found in the c:\win32app\arcview\bin directory. If not, carry out a file search to locate the directory where import.exe resides. This directory must be the one referenced in the dataimp.bat file that will have been copied; display the text contents of the dataimp.bat file to confirm that the import.exe utility will operate on all of the export files to create the ARC/INFO coverages in the c:\seishaz directory. The path to the location of the import.exe file must be identical for each line in the dataimp.bat file. It may prove easier to edit the dataimp.bat file in a spreadsheet than in a text editor where a space delimited, text file of three columns can be readily edited and saved using Lotus, Excel, or any other standard spreadsheet. Once the dataimp.bat file has been edited and saved it should be carefully inspect to determine that each row in the file has the following appearance:

c:\arcview.20c\arcview\bin\import c:\seishaz\sea65 c:\seishaz\sea65

There will be as many of these as there are export files to be converted.

When the DOS prompt returns, type win to restart Windows and double-click the ArcView program group and ArcView icon to initiate ArcView.

Executing the Application

Open the ArcView project "seishaz" (c:\seishaz\seishaz.apr). You may need to select this directory; if preferred, it can be the working directory associated with the ArcView icon which will make the directory the default seletion.

You will note that the project contains the following objects:

- Views: (Digital Maps) - Seattle View
- Tables: (Attribute Tables) Table names

- Charts: (Derived from Attribute Tables) - Length of Waterpipes in Landslide Areas
- Layouts: (Output Designed from Views, Tables, and Charts) - Layout1

We will use these objects to view seismic hazards in Seattle, to display the areas of greatest seismic risk, and to identify the locations of water lifelines exposed to seismic hazards. Users may start using the demonstration ArcView by carrying out the following tasks.

Viewing Seismic Hazards

Use the table of contents to turn on/off themes for liquefaction, landslides, and historic Mercalli intensities. Use the zoom tools to zoom in and out of the view. Notice that some themes do not necessarily "turn on" even when clicked; they may be controlled by minimal and maximal scale factors that are set in the Display portion of the Dialog icon. For example, when the scale is set by zooming to the Study Area, the scale will be 1:32,738 whose denominator is less than 50,000 that is set by default for this theme. This means that for any scale *larger* than 1:50,000 the theme will be displayed when "turned on" Conversely, at smaller scales it will be "off" even when "turned on".

Identifying Seismic Risk

Use the table of contents to "turn on" themes for population density, median income, and total population. Use the "Information" tool to select census tracts or blockgroups and to view their census characteristics. "Open" the corresponding tables for blockgroups to display all attributes for selected records. "Turn on" themes for liquefaction, landslides, and historic Mercalli intensity to superimpose them on the census layers. Use the zoom tools to zoom in and out of the view.

Look at the relationship between liquefaction zones and areas of proposed intense urban development. This can be seen by turning on the "Village" and "Liquefaction" themes where the shading of the latter permits a visual "join" between the two themes. Use the "theme on theme" overlay tool to select and display all urban villages that intersect with liquefaction zones. ("Village" should first be made active, i.e. highlighted; then from the Theme menu the selection can be performed by identifying "intersect" with "Liquefaction".)

Assessing Lifeline Vulnerability

"Highlight" the study area by clicking next to its name. Use the "zoom to mapextent tool" to zoom to the study area and automatically trigger the waterlines theme (theme by scale discussed above). Display the attribute tables for the water lines. Use the table of contents to focus on liquefaction, landslides, and historic intensity in the study area.

Commentary

An earthquake measuring 7.1 on the Richter scale shook the Puget Sound area in 1949. Following the quake, a Mercalli survey was conducted, producing the data used in this project. The 1949 MMI data clusters in the urban centers of Seattle, Tacoma and Everett, reflecting survey location bias. Similarly, in 1965, an earthquake measuring 6.5 on the Richter scale struck the area. Mercalli intensities for that earthquake are shown in Figure 5 and summarized in the Appendix. Again, the 1965 MMI data cluster in the area's urban centers, as well as the West Seattle area.

Decisions on meaningful use of the MMI data were difficult. Since the data provide personal perceptions of earthquake damage, there are serious questions about both its validity and reliability. Within the advisory committee (see Appendix A), we discussed concerns about the MMI data for both dates. Issues were raised regarding the predominance of West Seattle data, especially since many chimneys in that area were constructed using higher concentrations of sand than chimneys in other areas, and with post-earthquake reconstruction, the damage might be less. The data is based upon a mail survey,and those who were most affected would be most likely to return the survey. However, as fixed-point phenomena, the MMI data were judged to be reasonably valid.

Geographic distribution of MMI data was problematic, as data points were limited to established urban areas and clustered within these areas in a manner that prevented meaningful comparison between neighborhoods. Comparison of the MMI data with liquefaction zones shows no apparent clustering of intensity occurs with respect to existing liquefaction areas, most notably in the Rainier Valley. (See Figure 5.) The data appears to be clustered in the areas of heaviest damage, with serious "gaps" arising in areas with similar secondary attributes. (e.g. liquefaction potential, age of housing, etc.) Still, MMI is a valid indicator of where past damage has occurred. Future earthquakes will likely increase the data and the validity of its application in this process.

The study team asked the advisory committee about the idea of using ARC/INFO's Triangulated Irregular Network (TIN) module to transform the MMI point data into vector data similar for elevation contours. (ESRI, Inc., 1993b). Such mapping of earthquake intensity has been performed and incorporated into models calibrated to the 1989 Loma Prieda earthquake. (Perkins, 1992, pg. 20, and Stover, et. al., 1990) However, given data clustering and the lack of correlation with secondary attributes, we chose not to transform these data points into isoseismic contours. Rather, we maintained both data files as point coverages and incorporated them into the hazard mapping application. Further research into methods for generating isoseismic contours may convince us that generating the contours would be valuable for our modeling effort; for the time being, we feel that point data is best given the intended target audience for the product. If the USGS develops maps of such contours in the future, communities may readily download them into their own seismic GIS.

CHAPTER 4:

CONCLUSION: FUTURE DIRECTIONS

This report summarizes efforts completed using spatial database management tools to map seismic hazards in the Seattle, Washington area. The merits of this work lie in the ability to demonstrate the relatively facile use of existing data to inform planners and decision makers, and the ability of relatively inexpensive software available to local governments to manipulate and display the results quickly and accurately. With the above two considerations in mind, we propose the following activities as possible future applications for this project.

Hazard Modeling and Mapping

Previous versions of ArcView lacked both the ability to display certain types of data and the ability to execute complex scripts to perform analysis using the parent program ARC/INFO. These shortcomings have been remedied version 2 of ArcView, and the scripting capability has been expanded dramatically with the addition of Avenue, a programming protocol that will accompanies ArcView. The addition of Avenue provides the user the ability to develop custom applications for use with specific data sets. It makes possible the creation of a series of menu-driven applications that relate specifically to the seismic hazard phenomenon. The 2.0 version of ArcView was not distributed in time for the project team to carry out customization of ArcView menus that would make the existing ArcView demonstration more readily comprehensible to the untrained user.

Furthermore, this approach may be applied to other natural hazards present in the Pacific Northwest. Primary research should focus on floods, volcanoes and wildfires. Taken in the context of the Washington Growth Management Act of 1990, this extension could fill the void left by non-conclusive definitions of "critical areas" under the Act as they pertain to natural hazards.

Spatial Data Clearinghouse

A priority of the study team was the creation of a spatial data clearinghouse. Such a facility, housed within the University of Washington's Center for Sustainable Settlements, would collect and distribute GIS data from federal agencies, state agencies and local jurisdictions. The initial focus of the center would be to nurture an on-going relationship with the Federal Emergency Management Agency (FEMA) to provide interchange of hazard-related data sets including floodplains, seismic data, satellite images, etc. Over time, the focus would incorporate growth management-related data from local jurisdictions, in the effort to bring hazard mitigation planning within the purview of the growth management process in Washington. The University of Washington Department of Urban Design and Planning already has data on critical areas in the Puget Sound region, provided by King, Snoqualmie, and Pierce Counties, and many satellite images and much aerial photography collected over a span of nearly 25 years.

With Internet access such a clearinghouse could provide valuable service to local governments by compiling and distributing "data packages" custom-designed for jurisdictions. By packaging the data using the ARC export format, it is possible to quickly distribute data to governments using ArcView and other GIS software for their planning needs.

APPENDIX A:

PROJECT ADVISORY COMMITTEE

Mr. Clifford Marks from the City of Seattle's Planning Department acted as the professional advisor to this project. Meetings and conversations with Mr. Marks throughout the project helped to shape the final product.

An advisory committee composed of experts in earthquake hazard identification and mitigation was formed to provide oversight and review of the project. The members serving on the advisory committee were:

Jim Mullen -- City of Seattle, Department of Emergency Services
Cliff Marks -- City of Seattle, Planning Department
Patricia Bolton -- Battelle Research
Linda Noson -- Ratti, Swenson, Perbix & Clark / Dames and Moore
Bob Frietag -- Federal Emergency Management Agency (FEMA)

The members met to review and critique the prototype. A demonstration of the ArcView-based system showed both usefulness and applicability. The demonstration consisted of a discussion of the underlying approach and its application, a product demonstration, discussion of strengths and weaknesses of the data, and possible future directions for this project.

APPENDIX B:

Table 1. Data Dictionary

Coverage Name	Coverage Type	Description	Data Source
blockgroup	polygon	census blockgroups with demographic information	Washington Redistricting File (WRF)
city	vector	cities within King County (KC)	KC
county	vector	KC boundary	WRF
hydro	vector & polygon	streams, lakes, and Puget Sound	WRF
kerosion	polygon	KC erosion hazard areas from Comprehensive Plan	KC
kflood	polygon	KC flood hazard areas from Comprehensive Plan	KC
kparks	polygon	KC parks from Comprehensive Plan	KC
kseismic	polygon	KC seismic hazard areas from Comprehensive Plan	KC
kslide	polygon	KC landslide hazard areas from Comprehensive Plan	KC
llnz	text	converts latitude and longitude to north zone projection	Jeff Henderson (JH)
llutm	text	converss latitude and longitude to UTMS	JH
log	text	Arc/Info record of your commands	
medhugr		median year housing built grid (median year housing built from the census blockgroup coverage was isolated and gridded)	WRF, JH and John Davies (JD) additions
mmi49gr	grid	point coverage of the MMI survey in 1949 converted to 325' by 325' grid cells	UW Geophysics, JH
mmi65gr	grid	point coverage of the MMI survey in 1965 converted to 325' by 325' grid cells	UW Geophysics, JH
outgrid	grid	result of hazard "index" calculation	JH, JD
outpoly	polygon	outgrid in polygon format	JH, JD
pls	vector?	Public Land Survey: KC township and range sections	WRF
rails	vector	major rail lines	WRF
readme.grids	text	description of grids	JH, JD

Coverage Name	Coverage Type	Description	Data Source
blockgroup	polygon	census blockgroups with demographic information	Washington Redistricting File (WRF)
rechyr	grid	reclassified housing year grid (pre-1946 = 10, 1946-1953 = 6, 1953-1964 = 3, post-1964 = 0)	JH
remap2.rm	text	remap file for housing ranges above	JH
roads1	vector	major highways and freeways (no addresses)	WRF
roads2	vector	arterials and minor roads (no addresses)	WRF
s49m71	point	MMI readings for 1949 earthquake of magnitude 7.1 on Richter scale	UW Geophysics
s49mmi.csv	ASCII	comma delimited ASCII files containing a unique number and MMI for 1949 earthquake	UW Geophysics
s65m65	point	MMI readings for 1965 earthquake of magnitude 6.5 on Richter scale	UW Geophysics
s65mmi.csv	ASCII	comma delimited ASCII files containing a unique number and MMI for 1965 earthquake	UW Geophysics
seabg	polygon	census blockgroup coverage clipped for Seattle	WRF, JH,RK
seattle	vector	city reselected for seattle	WRF, JH
sliqgrid	grid	Seattle liquefaction grid (1 = liquefaction, 0 = no liquefaction)	City of Seattle
sliqzones	polygon	polygon version of sliqgrid	City of Seattle, JH
sparks	polygon	Seattle parks	City of Seattle
sslgr	grid	Seattle landslide grid (9 = landslide, 0 = no landslide)	City of Seattle
sslide	polygon	sslgr converted to polygon coverage	City of Seattle, JH
ssteep_b	polygon	Seattle steep slopes south (below) of Ship Canal	City of Seattle
ssteep_t	polygon	Seattle steep slopes north (top) of Ship Canal	City of Seattle
sznz.prg	text	projection file: Washington (WA) plane south zone feet to WA plane north zone feet	JH
tract	polygon	census tract geography with attributes	WRF
utmnz.prj	text	conversion from UTM to WA north zone projection	JH
village	vector	Seattle urban village boundaries	City of Seattle

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