



GIS based Earthquake Risk-Vulnerability Analysis and Post-quake Relief Planning

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ABSTRACT

Earthquake associated risk poses obstacle to developmental process as well as threat to the livelihood of the resident population, especially in metropolitan cities in developing countries. In order to mitigate and manage the natural disasters, there is an urgent need to adopt various techniques and tools like GIS to design and develop a procedure that will enable the city administrators and responsible disaster management personnel to evaluate earthquake severity and potential impact on the facilities, and suggested associated levels of post-earthquake monitoring response for different magnitude earthquakes occurring within certain distances from the urban amenities and facilities. Hence this proto-type using ArcGIS have been focused on three major components, i.e., Hazard Mapping, Risk Analysis and Post-quake relief planning. Vulnerability analysis was derived from population and estimated building property while Post-quake relief planning focus on quake-hit areas and compared with available general amenities and services such as hospitals, police stations, fire stations etc. Macro level analyses are being attempted with sample Gujarat Data sets and micro level with Ahmedabad data sets to demonstrate the potential.

1. INTRODUCTION

Earthquakes have long been feared as one of nature's most devastating natural hazards. Earthquakes continue to remind us that nature still can strike without warning and, after only a few seconds, leave casualties and damage in their wake. Although earthquakes cannot be prevented, current science and engineering provide tools that can be used to reduce their damage. Science can now identify, with considerable accuracy, where earthquakes are likely to occur and what forces they will generate. Engineering provides design and construction techniques so that buildings and other structures that can survive the tremendous forces of earthquakes. Therefore, it is important that all the stake-holders viz., Government, Administrators, citizens and local community take appropriate preventive measures to protect lives and property. In order to enable / aid the local government/administrators in their effort to manage disasters, an attempt has been made to present how Geospatial technologies can be integrated and visualized various scenarios of Earthquake Disaster Mitigation & Management at various levels and scales of maps which have three basic goals directly related to the mitigation of hazards caused by earthquake viz.,

- i. Mitigating the possible consequences of earthquakes,
- ii. Anticipating the possible nature and scope of the emergency response needed



- iii. Developing plans for Post-relief operations and recovery.

2. THE TYPICAL CYCLE OF NATURAL DISASTERS

Natural Disaster management professionals have established that most disasters follow a well-established cycle of processes. The emotional and psychological response of the victims also follow a set of well-recognized stages as they experience and cope with the crisis. An understanding and sensitivity to this helps alleviate human suffering and design appropriate loss and risk mitigation strategies.

Stages in Natural Disaster Mitigation and Management Cycle		
Disaster Stage	Time from the event*	Stake-holders
Rescue	Week	Affected communities, volunteers, Central, State and local governments, Armed and paramilitary Forces, Specialized rescue agencies, Print and Electronic Media
Relief	Weeks-month	Central, State and local Governments, Utilities, NGOs, Donor agencies, Print and Electronic Media
Reconstruction & Rehabilitation	Months-years	Communities, Central & State Governments, Donor agencies, Contractors, Finance & Development Agencies, Technical support agencies, NGOs
Mitigation planning	All time efforts	Communities, State Government and Local administration, NGOs, Technical support agencies
Preparedness	All time efforts	Communities, Local administration, NGOs

Source: UNDRO, 1990; TARU, 1993, 1997, 1999, 2000
 Note: Time estimates based on Uttarkashi (1991), Latur (1993), Jabalpur (1997) and Chamoli (1999), Bhuj (2001) Earthquakes in India

2.1 Advantages of GIS analysis and visualization

GIS lets you organize, manage, and distribute geographic information culled from various databases while maintaining data integrity and focusing on project direction. GIS integrates extremely diverse data, various tools, and different ideas and people into common frameworks for analysis, cooperation and decision making. The advent in GIS Technology & scientific approaches could be integrated with established disaster management systems to facilitate disaster preparedness, mitigation, rehabilitation & reconstruction or even rescue operations. Such a work involves the use of spatial analysis technologies in quantifying earthquake and environmental hazards. This GIS based approach in hazard mapping, Risk Analysis and Vulnerability assessment at macro to micro levels has been designed as a technology demonstration proto-type project for a wide range of audiences, people, companies, institutions and governments at all levels who have a direct or indirect stake



holders of the society including property and real estate owners/managers/agents, the insurance industry, mortgage lenders, investors, city planners, emergency managers, relief organizations.

3. APPROACH AND METHODOLOGY

The development of GIS system is based on seismological factors, mitigation planning process, post-relief planning and rehabilitation process. The major tasks involved in development of GIS system involves are detailed out in our approach and methodology. To generate this information, the methodology includes:

- Classification systems for assembling information on the building stock, the components of utility lifelines (roads, hospitals, police-stations, petrol/gas stations etc) and related socio- economic data sets;
- Methods for evaluating damage and calculating various losses; and
- Databases containing information useable for calculations and as default (built-in) data.

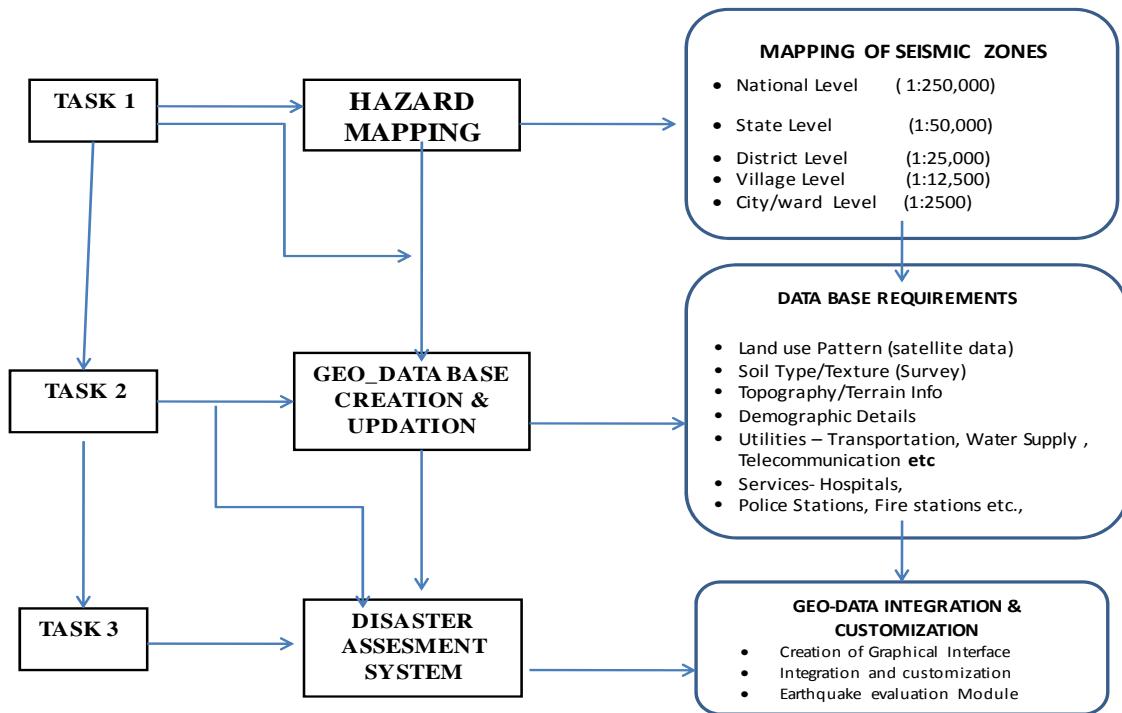
Data base design, creation and integration from Geo databases

The system study is an important step in developing enterprise-wide GIS applications. Initially, standards are set that essentially constitutes the meta-data for the GIS. They assist in defining the configuration, content and purpose of the proposed GIS system and are used to manage the enterprise GIS development and operations. The system involves the design of the geo database in line with user needs assessment, workflow and system requirements of the municipalities. The data for the GIS system are available in the form of digital maps, aerial photographs, satellite imagery, field survey and cadastral maps.



Map India 2010

19 - 21 January at Epicentre, Gurgaon, India



METHODOLOGY OF EARTHQUAKE RISK ANALYSIS & VULNERABILITY ANALYSIS SYSTEM



The following are the three tasks that define the enterprise systems study at a macro level that can be scalable and integrated if need be with:

- User needs studies or assessments
- Data identification – existing data and additional data requirement
- Establish technical standards for governance in terms of co-ordinate systems, data models and data interchange formats accuracy etc.

Major elements of user needs study include:

- (a) Detailed organizational analysis of hazard management division, their functions & processes
- (b) System analysis of information flows within and among departments
- (c) Definition of GIS requirements in terms of user applications, databases and data requirements.

4. Geo-data base files content description

SNO	MAP DESCRIPTION	SCALE
1.	INDIA EARTHQUAKES (NATMO)	1:6,000,000
2.	INDIA NATURAL HAZARDS (NATMO)	1:6,000,000
3.	INDIA SOILS (NATMO)	1:6,000,000
4.	INDIA SOIL TEXTURE (NATMO)	1:6,000,000
5.	STATE LAND USE (NATIONAL ATLAS OF INDIA)	1:1,000,000
6.	PHYSIOGRAPHY / HYDROGEOLOGY	1: 250000
7.	CITY URBAN LAND USE (NATIONAL ATLAS OF INDIA)	1:25,000

PROJECTIONS ETC:

PROJECTION	GEOGRAPHIC
DATUM	WGS84
SPHEROID	WGS84
UNITS	METERS
LONGITUDE OF CENTRAL MERIDIAN	72
LATITUDE OF STANDARD PARALLEL	24



4.1 ARCINFO COVERAGES & ARCVIEW THEMES:

SNO	COVERAGE	FEATURE CLASS	ARCVIEW THEMES
INDIA			
1.	INDIAPROJECT	POLY	INDIA
2.	MAGPROJ	POLY	EPICENTRES
3.	SEISMICZONE	POLY	SEISMICZONES
GUJARAT			
4.	GUJBNDPROJ	POLY	DIST_BND
5.	DISTPROJ	POLY	DIST_BND
6.	HEADQTRSPROJ	POINT	HEAD QUARTERS
7.	LANDUSEPROJ	POLY	LAND , SOIL ,SOIL TEXTURE
8.	RAILPROJ	LINE	RAILWAYS
9.	RIVERPROJ	LINE	RIVERS
10.	PLACEPROJ	ANNO	TOWNS_POPULATION
11.	IND_SITE_PROJ	POINT	INDIA
12.	ROADSPROJ	LINE	ROADS
13.	PORTPROJ	POINT	PORT
14.	RELIGIOUSPROJ	POINT	RELIGIOUS
15.	OTHERSITEPROJ	POINT	TOWNS_POPULATION
AHMADABAD			
16.	LANDUSE	POLY	LANDUSE
17.	ROADS	LINE	ROADS
18.	RAILWAYS	LINE	RAILWAYS
19.	CORP_BND	POLY	BOUNDARIES
20.	PLANUNIT_BND	POLY	BOUNDARIES
21.	OLDCITY_BND	POLY	BOUNDARIES
22.	WATERBODIES	POLY/ARC	WATERBODY
23-28	EVENTS, SCHOOL , POLICE STATION, FIRESTATION , HOTEL, HOSPITAL are stored as Points		



5. Application overview:

Identification of Application Modules involves identification of application modules that address seismic hazard management functions, thereby formulation of attribute data requirement and database design. The following table describes the GIS solutions at different stages of hazard. Application Development phase involves the actual execution of work that include preparation of base map, database generation (data entry, updating of digitized map and integration of map data and attribute data) system integration and query shell development through various stages viz., (a) Customize the database for easy user interface (b) Manage work flows and Model diverse systems and (c) Incorporate satellite / other data for geographic analysis and display. An overview of the structure adopted for application modules development is described under following heads.

- a) Seismic Hazard Identification,
- b) Potential risk analysis,
- c) Vulnerability Analysis
- d) Post quake relief planning.

Potential risk analysis addresses questions like what would happen if a magnitude 7 earthquake were to occur on the "x" Fault, how much would be the exposure in terms of man-made and natural resources for the state. Vulnerability Analysis looks at the geographic and temporal distribution/variation of population and estimated building property value. Population and building stock at microzone level are used as sample portfolios for analysis. This has an extension facility to plan and monitor services for relief and rehabilitation. In the Planning for post quake Relief and Rehabilitation sub-module, the quake-hit areas are compared with available general services such as hospitals, police stations, fire stations, and trucks to arrive at decisions to facilitate their services, to find the shortest path and to monitor the services at use.

5.1 Seismic Hazard Identification Module:

Hazard Analysis is an essential part of risk assessment. Earthquake hazard identification refers to: (1) how frequent and severe have earthquakes happened in the past, (2) where are the seismically active zones are located with respect to our population centers, (3) what is the relative seismicity.

5.2 Seismicity Maps:

Seismicity Maps are part of the Hazard Analysis Module. E-DIMS uses India earthquake catalogs that were downloaded from the Indian Meteorological Department Website. The catalogs include earthquakes that occurred since 1800. The map annotations show the date (GMT), time (GMT), longitude/latitude, magnitude (scale), reference catalog and any other attached notes.



Map India 2010

19 - 21 January at Epicentre, Gurgaon, India

5.3 Potential Risk Zones Module

Fault Maps are part of the Potential Risk Zones Module (shown for the region of Kerala). The fault data originally includes the fault zones, fault classification, lengths, rupture mechanism, slip rates, rank, magnitude recurrence model, maximum and minimum magnitudes, moment rates, characteristic rates & return intervals for maximum magnitudes, down dip width, depths of top and bottom fault plane edges, rake, dip angle, azimuth, number of points, polyline longitude/latitude coordinates and notes for the faults). The map annotations list only a small subset of those parameters. The fault polylines shown on the fault maps are the top edges of the faults' 3D planes. Faults are superimposed on Kerala's administrative map for orientation.

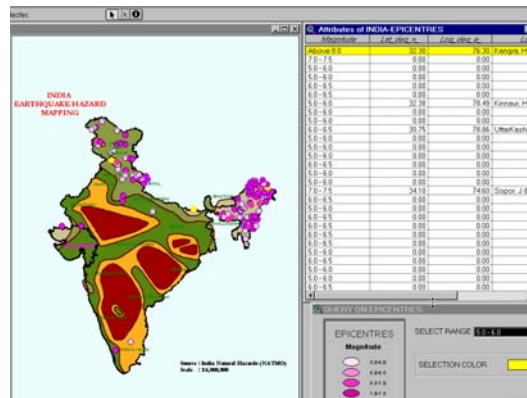
- The Management System which would use the above maps and databases shall be used by the state / district / local administration not only for the risk analysis and vulnerability assessment, but also for organizing response operations.
- In addition, the system would have a great functional value for the resource and development planning of the district.

POTENTIAL RISK ZONES

HAZARD MAPPING		Target Groups	POTENTIAL RISK ZONES		Target Groups
<p>What it does?</p> <ul style="list-style-type: none"> • seismic zones <ul style="list-style-type: none"> - region-wise - state-wise • seismicity map <ul style="list-style-type: none"> - macro-level planning - past occurrences data 	<p>What we need?</p> <ul style="list-style-type: none"> • Map (National/state) • Seismic zones • past earthquakes, intensity, epicenter lat/long, 	<ul style="list-style-type: none"> •Emergency Managers •Relief organizations •Insurance Companies 	<p>What it does?</p> <ul style="list-style-type: none"> • Hazard - evaluation of regional faults • Vulnerability - earthquake scenarios • Exposure - potential impact on the infrastructure facilities 	<p>What we need?</p> <ul style="list-style-type: none"> • Maps (region/city) • fault zones, fault classification, lengths, etc. 	<ul style="list-style-type: none"> •Regional planners •real estate agents •administrative officers •Relief organizations •Insurance Companies

EMERGENCY MANAGEMENT

<p>What it does?</p> <ul style="list-style-type: none"> • Information on loss • Where & how of rescue operations • Post-earthquake monitoring response 	<p>What we need?</p> <ul style="list-style-type: none"> • Landuse map • parcel and zoning map • facilities, infrastructure • demography, property value 	<p>Target Groups</p> <ul style="list-style-type: none"> •Real estate agents •City planners •Investors •Relief organizations •Insurance Companies
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Property Analysis is part of the Exposure Analysis and a preface to the Loss Analysis Module. Property value refers to estimated building property values in Indian Rupees. It does not include the infrastructure and non-building structures like highways, railroad, bridges, etc. It includes buildings' structural, non-structural and content values combined, but exclude land. For homes (dwellings), relevant structures are included in the property value.

- The Module deals with nearly all aspects of the built environment, and with a wide range of different types of losses (structural & non-structural, population, infrastructure etc.).
- The technology to execute this would be ESRI's GIS software ArcView to provide easy-to-use Graphical User Interface.

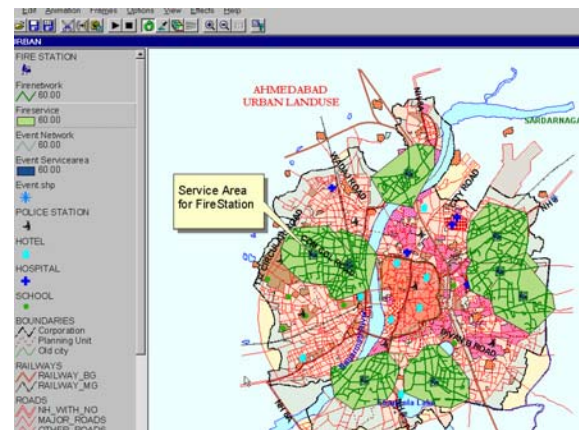
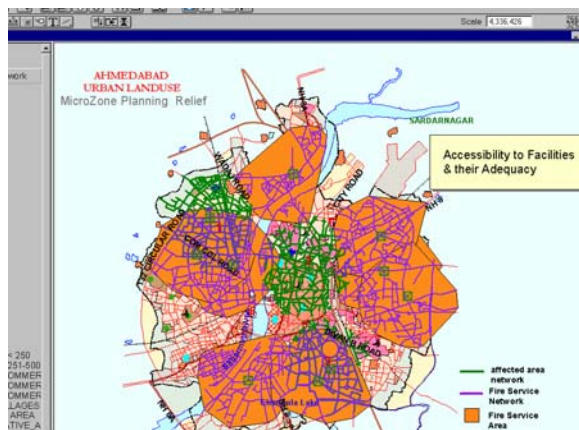
6. Important Considerations: Analysis Based on Default Information

The basic level of analysis would use only the default databases built into the methodology for information on building square footage and value, population characteristics, costs of building repair, and certain basic economic data.

- The effects of possible liquefaction and landslides are ignored. Direct economic and social losses associated with the general building stock and essential facilities are computed.
- Default data for transportation and utility lifelines shall be included, thus these lifelines are considered in the basic level of analysis.

6.1 Analysis with User-Supplied Inventory

Results from an analysis using only default inventory can be improved greatly with a minimum amount of locally developed input. This is generally the intended level of implementation.





However, there could be no standard analysis with user-supplied data and hence, no minimum or standard amount of input. Such an effort might involve:

- Development of maps of soil conditions affecting ground shaking, liquefaction and landslide potential. These maps would be used for evaluation of the effects of these local conditions upon damage and losses.
- Use of locally available data or estimates concerning the square footage of buildings in different occupancy classes.
- Use of local expertise to modify, primarily by judgment, the databases concerning percentages of model building types associated with different occupancy classes.
- Preparation of a detailed inventory for all essential facilities.
- Collection of detailed inventory and cost data to improve evaluation of losses and lack of function in various transportation and utility lifelines.
- Use of locally available data concerning construction costs or other economic parameters.
- Collections of data, such as number of fire trucks, for evaluation of the probable extent of areas affected by fires.
- Development of inundation maps.
- Gathering of information concerning high potential loss facilities and facilities housing hazardous materials.
- Synthesis of data for modeling the economy of the study region used in calculation of indirect economic impacts.

7. Query shell development and Interface

The design and standardization of query shell is an integral part of GIS development. This would enable access level controls, user friendly menus & interfaces. This takes into consideration the privileges given for personnel at various levels of management and day-to-day operations and at the time of disaster. The interface shall be designed to reflect the existing processes, which the disaster management staff is accustomed to. This would enhance smooth transition from the current system of works to data automation.

8. POSSIBLE END-SOLUTIONS USING DISASTER MANAGEMENT SYSTEMS:

Description	Output	Scale
Maps of seismic hazards	<ul style="list-style-type: none"> • Information on seismic features, seismic zonation, etc. • Intensities of ground shaking for each census tract • Contour maps of intensities of ground shaking 	1:250,000
Landsliding probability*	<ul style="list-style-type: none"> • Characterization of damage to general building stock • Structural and nonstructural damage probabilities by census tract, building type and occupancy class. 	1:8000
Transportation and utility lifelines	<ul style="list-style-type: none"> • Damage probabilities for various times-earthquake • All pipeline systems: the estimated leaks and breaks • Water , Electric power : estimate of service outages • Damage probabilities/ Loss of beds in hospitals 	1:4000



Map India 2010

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High potential loss (HPL) facilities	<ul style="list-style-type: none"> • Locations of dams • Locations of other identified HPLs 	1:50,000
Fire following earthquake	<ul style="list-style-type: none"> • Number of ignitions by census tract • Percentage of burned area by census tract 	1:12500 1:2500
Inundated areas	<ul style="list-style-type: none"> • Exposed population-Value of general building stock 	1:50000
Debris	<ul style="list-style-type: none"> • Total debris generated by weight and type of material 	1:2500
Social losses	<ul style="list-style-type: none"> • Number of displaced households • Number of people requiring temporary shelter • Casualties in four categories of severity 	1:2500
Losses related to building stock	<ul style="list-style-type: none"> • Structural and nonstructural cost of repair/replacement • Business inventory/ income loss / Relocation costs 	1:2500

9. CONCLUSION

Uncertainties are inherent in any such loss estimation methodology. They arise in part from incomplete scientific knowledge concerning earthquakes and their effect on buildings and facilities, and in part from the approximations and simplifications necessary for comprehensive analyses. The range of uncertainty - possibly a factor of two or more - is best evaluated by conducting multiple analyses, varying certain of the input parameters to which losses are most sensitive. The disasters cannot be prevented but the effective use of Geospatial technology based application initiatives can help us in being prepared and respond effectively to disasters and thereby reducing the extent of damage.

10. ACKNOWLEDGEMENTS

The Geo-data base creation in this earthquake disaster information management system was done as a part of the proto-type technology demonstration work during 2002-03 at Pentasoft Technologies Ltd. Contribution by GIS Team members Rekha, Sheerin, Vasanth, Srikala and Muralis team are gratefully acknowledged