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Earthquake Control using Geographical Information and Building Damage-Estimation Models

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Abstract: Natural disasters are the consequences that result from natural processes, and they include hurricanes, volcanic eruptions, earthquakes, landslides, floods, other geological processes and human activities. To reduce the effect of such disasters, governments formulate an effective system, i.e. disaster management. The available data from infrastructures, lifeline systems, roads, health clinics etc. helps the management to provide better decision making. In this regard, the role of Geographical Information System (GIS) is vital to collect, stow, analyze, model and present a bulk data quantity. The present case study based on Chennai summarizes several steps to develop a web-based GIS that manages and responds to earthquakes. A key problem to implement this sort of system is the unavailability of a specific model to evaluate the extent of damages occurred soon after the occurrence of earthquakes. This work intends to construct a Building Damage-Estimation Model (BDEM) for the optimization of the response period and loss occurring due to earthquakes. It also introduces energy dissipation and active control devices to build earthquake-resistant structures.

Keywords: earthquakes, disaster management, geographical information system, building damage estimation model

1 Introduction

An abrupt and violent ground shake is termed as earthquake. Human vulnerability results in economic, structural and life losses owing to the absence of right emergency control [1]. Such losses depend upon the human ability in supporting, resisting or recovering quickly from the disasters. This shows that natural hazards are common in vulnerable areas and occur mostly with human involvement [2,3]. The extent of loss can probably rely upon hazard type, stretching from wildfire to impact events, that threatens buildings and ends civilization accordingly. Certain direct impacts of natural hazards include tsunamis from earthquakes, famines and diseases from drought and property and human loss due to floods. Hazards damage physical events or human activities causing social, financial and ecological disruptions, and they also involve latent conditions representing future threats too in addition to life injuries [4,5,6]. As discussed earlier, the origin of hazards can be natural (physical, atmospheric, hydro and bio-hazards) or man-made (resources depletion and technological hazards). The origins and impacts of threats can be in single, sequential or joint form. Hazards are categorized by their locality, intensity, recurrence rate and probability. Earthquakes become a part of the world and their frequency rate tends to be high [7]. Hence disaster management is mandatory in man-made environment rather than natural surroundings. It is classified as planning, alleviation, preparation (pre-events), response and recuperation (post-events) phases, which are related in terms of time, function and skills [8,9]. The responsibility of the governments is to enable disaster management at municipal, district, state and national levels. Since disasters are spatial, each phase depends on information from different sources. By evaluating and displaying spatial information layers, GIS assists every aspect of disaster management.

Chennai is the most populous capital city and has the largest cultural, political, economic and educational hubs in Tamil Nadu, and it is prone to natural disasters often [10]. Although, Tamil Nadu government continues to perform various prevention plans to lessen the seismic reparations, several vulnerable features still exist with

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respect to the diversity of spatial structures. As a result, a sudden earthquake is likely to expose Chennai to the risk of deaths, injuries and destructions in infrastructures and environment [11,12]. Earthquakes causing gigantic vibration in the Earth's crust lead to severe ground problems, and they become a health hazard to be worried over [13]. Therefore an immediate plan has to be established for response phase aiming to mitigate human and physical losses [14]. Collecting the necessary information via government sections and other establishments to be used as inputs in GIS benefits the concerned management to negotiate better decisions immediately [15,16]. This paper describes GIS to measure earthquake damages and to have quicker disaster response. As a way of testing the scheme, a case study was directed in a district of Chennai.

2 Tools and methods

GIS design for the distribution of geospatial data on web sources enables easy accessing of any disaster details whenever required. Hence BDEM-based GIS is built to manage seismic disasters. As a way to assist plans and preventive measures for disaster management, database information and methods are used. Web sources can be applied to develop tools and systems to get GIS software and satellite pictures. To enable faster response time and recovery, systematic contingency plan offers a better approach. BDEM estimates the degree and size of destruction caused by earthquake as a mean to support GIS-based earthquake management, and thus the managers benefit to provide rapid response. The history of civilization has been affected to an extreme level due to life and economic loss caused by natural disasters. Natural disasters' risk in urban regions tends to be high since cities are more densely populated and more concentrated with economic assets.

3 Earthquake damage measurement using GIS

Sumatra-Andaman under-seaquake (December 2004) is the fourth largest since the beginning of 20th century. Its epicenter corresponded to west coast of Sumatra, Thailand, Indonesia and Sri Lanka and it took over the lives of around 275,000. In Chennai, Tsunami washed the people who were around the beach. It also led to the shutting down of Kalpakkam nuclear power station as the seawater rushed to it, though people were saved as no leakage was radiated or reactor was damaged. And the sea waves in Kanyakumari took away some of the life of pilgrims. Keeping in mind of all these indescribable nature, Anna University of Tamil Nadu develops a GIS for earthquake response. The intention of this proposed research is also to structure a GIS to manage earthquake response phase such that it facilitates effective decision making during or after the occurrence of quakes. Figure 1 shows the GIS-based earthquake damage measurement.

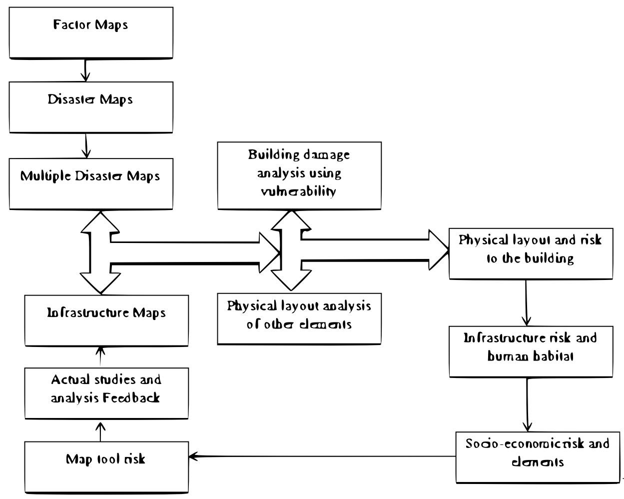

Fig. 1: Earthquake damage measurement using GIS

3.1 Earthquake contingency plan

Severe earthquakes may lead to total city collapse as cities are developed without any attentiveness for earthquakes. Past information clearly depicts that high intense quakes or slighter shaking occurred recently may be the warning to build effective countermeasure. Therefore a well-planned system (contingency plan) is a necessary one for optimum and effective preparation, immediate response and speedy restoration, in which well utilization of resources can be initiated to meet the requirements. A clustering mechanism has been used in United Nations to promote its humanitarian response actions, thus to provide a coordinated and complete emergency response, where it proves its efficiency and reliability in responding to disasters. It has been used to act in response after Indian ocean quake and Tsunami in Tamil Nadu (2004). It is planned to use the same mechanism in Chennai also in case of any such threat occurs again. Figure 2 shows the magnitude of quake range in Chennai. This strategy, under national earthquake contingency planning, groups every reaction events by nine applicable operative function clusters in terms of work similarity and disaster time directives of diverse establishments.

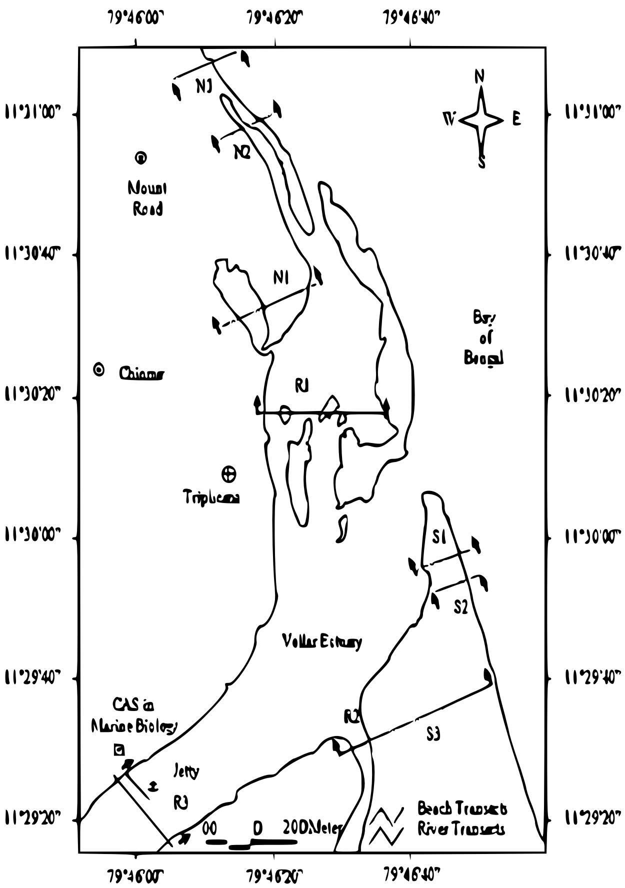

Fig. 2: Magnitude range of earthquake 2004 in Chennai region for our case study

3.2 Web-based data sharing system

It is determined that Spatial Data Infrastructure (SDI) overcomes certain challenges like limitations in data sharing by which there would be no hindrance in data accessing for technical staffs in disaster managing departments, and thus technologies and data management standards can be well established. In disaster managements, spatial information and allied mechanisms have key roles for productive cooperative decision-making system. SDI aids to develop risk assessments and relocation plans, and supports to establish disaster control plans by reducing damages. Utilization of SDI helps to develop web accessing of spatial data and it includes stakeholders, primarily the organizations in disaster management to produce, update and maintain the essential spatial datasets for earthquake response. Sharing and exchanging such information allows a greater part of disaster management community to access the datasets. This collaborative setting works on the basis of partnership concepts in spatial data generation and sharing. Figure 4 shows the earthquake damage ratio of five floor structure. A total of 572 islands forms the Andaman and the Nicobar, where 38 islands are occupied. The islands are situated in the northern epicenter of earthquake. The recorded earthquake magnitude ranged between 9.1 and 9.3. Some of the worst hit Indian regions were the states of Tamil Nadu, Pondicherry and the Andaman and Nicobar Islands. Report show that the waves reached 15 meters high. The death cases recorded were 812, and about 7000 are still missing. India stood third with highest death rate. Tsunami affected the Indian fishing groups, and Nagapatnam was severely affected. It also leads to the damage of many fishing requirements with the loss account to over US$ 123 million. Accessibility of accurate spatial data at right time is necessary for decision making. Accordingly, distribution of geospatial data on a network helps in easy accessing about earthquake disaster management to the managers. Hence in addition to a standalone GIS, a network-based GIS is also mandatory. So a web-based GIS is developed to manage response phase of earthquake disaster management. It involves a user (client) who can contact a server for any kind of data. Disaster management database is shown in Table 1.

Table 1: Disaster management database

S.No	System mode	GIS operation configurations
1	Hardware	Computer, Laptops, Mobile, GPS
2	Software	Arc View, Arcgis 10.1(Desktop Software)
3	Data used	Landscape, Survey, Transportations, Services, Bathymetry, Hydrology, Geology,Landmarks, Managerial Boundaries,Tidal Data, Orthophotograph, GCP, Land Scan

4 Building Damage-Estimation Modelling (BDEM)

BDEM is a tool used for civil engineers to analyze building constructions and cost estimation. By implementing the BDEM system, the earthquake-related hazards can be calculated by considering the building methodologies and by determining casualties and building damages and losses, termed as Potential Earth Science Hazards (PESH). Ground shake is the ultimate cause of these sorts of indescribable losses. It is revealed that, one of the main earthquake disasters occurred in Tehran is due to the unavailability of prediction rate beforehand. In BDEM, mathematical relations are employed using environmental data as inputs, which also comprises structural and real earthquake characteristic data to be imported in BDEM.

4.1 Ground motion and building frequencies

Time, amplitude (displacement, velocity and acceleration) and frequency are the important parameters of the ground motion.

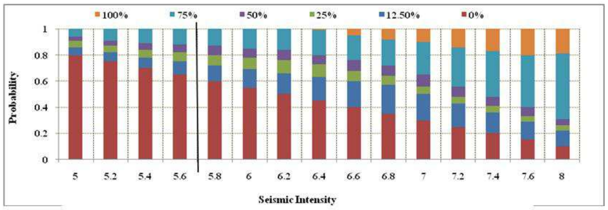

Fig. 3: Seismic intensity and severe damage ratio

Table 2 shows the damage ratio and mean value for all severity rankings, and in Figure 3, the association between seismic force and damage ratio is showed. Table 3 shows the link between frequency f and period T. BDEM categories buildings into safe, evacuated and destructed buildings as in Figure 4.

Table 2: Severe damage ratio range and mean value for all severity ranks

Severity rank	severe damage ratio (D) (%)	Average
1	0	0.0
2	$0<D<13$	6.3
3	$13 \leqq D<25$	18.8
4	$25 \leqq D<50$	38
5	$50 \leqq D<100$	75
6	100	100

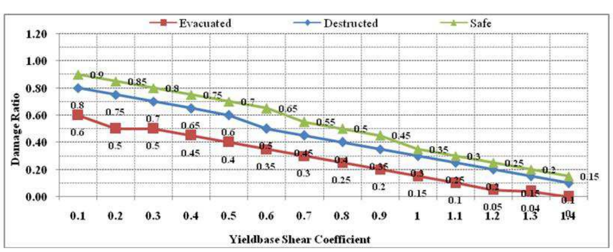

Fig. 4: Earthquake damage ratio of five floor structure

Table 3: Building heights and observed natural period (T)

Building height	Typical natural period (T)
2 Storey	0.2 Seconds
5 Storey	0.5 Seconds
10 Storey	1.0 Seconds
20 Storey4	2.0 Seconds
30 Storey5	3.0 Seconds
50 Storey6	5.0 Seconds

5 Results and discussion

5.1 Seismic resistant building design

Application of seismic dampers in building structures like diagonal braces controls seismic damages and improves their durability by absorbing the transmitted seismic energy. These dampers find application in vehicles as well to absorb hydraulic shocks. Seismic dampers suitable for energy dissipation devices are:

1. Viscous dampers, where silicone fluid absorbs the energy moving between piston cylinder setup.
2. Friction dampers, where friction surfaces absorb the energy.
3. Yielding dampers, in which metallic elements absorbs the energy.
4. Viscoelastic dampers (VED), where control solid shearing absorbs the energy.

5.1.1 Fluid damper design construction

Fluid damper as in Figure 5 comprises an inox piston with bronze orifice head and is full of silicone oil. The use of passages in the piston head alters the damper fluid flow which in turn alters the resistance features of the damper. The construction columns with dampers experience slight horizontal movement and thus the resulting damage is considerably less during earthquakes. Friction-VED (F-VED) has the merits of both frictional and viscoelastic energy dissipation models. Buildings with high damping capacity extensively help to reduce seismic energy entering them.

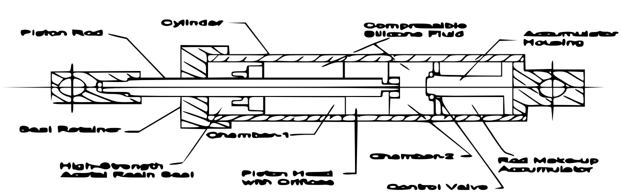

Fig. 5: Design construction of a fluid damper

5.1.2 Active control device system for earthquake resistance

Structural functions work against earthquakes and controls the vibrations. The installed sensors within and exterior to the structure transmit information to the computer attached with the structure. This system provides decision based on intelligence thereby its own building attributes are amended in a regular manner. Figure 6 depicts the fundamental pattern of an active control unit of 12 floor building. The main components of this system are:

1. Sensors to assess the external excitations and structural responses.
2. Actuators for the required control forces.
3. Computer to determine the control forces based on the observed excitations and structural responses.

Accordingly active systems should possess an external energy input in order to drive the actuators. In contrast, this is not necessary in passive systems, where the efficiency is based on system tunings to the required excitations and structural behaviors. Hence, these passive structures are efficient for the tuned vibration modes alone. Active systems are widely applicable as the control forces work in accordance with the actual excitations and structural behaviors.

They are open looped when only the external excitations are assessed, and is termed as closed loop, when building response is fed as input. Sometimes when both excitation and response are utilized, it is said to be an open-closed loop structure. Figure 7 exhibits the closed-loop control with two main inputs. Step 1 is used to monitor the electric field of earth. Step 7 is used to generate tidal and lithospheric oscillations theoretically.

Steps 7 and 8 generate the most probable occurrence time data for a strong earthquake. At step 2, processing of seismic precursory electrical signals from step 1 takes place, and correlation of these signals occurs at step 9 using step 8. The earthquake epicenter area is determined at step 3 through step 2. From the faster response assessment, cumulative energy stored in the seismic region as a time function can be calculated using an input from step 4. Calculation of seismic history of regional and epicenter areas is already performed. Step 5 shows the lithospheric and seismic energy flow model using inputs from steps 10 and 4. Meanwhile step 6 calculates the earthquake magnitude. Step 10 provides the result with earthquake occurrence time. The key inputs correspond to seismic, electric and precursory signals at specific times to which max-min oscillating and lithospheric stress loads are attained. The parametric factors for a successful earthquake prediction such as time, location and magnitude are determined from our results.

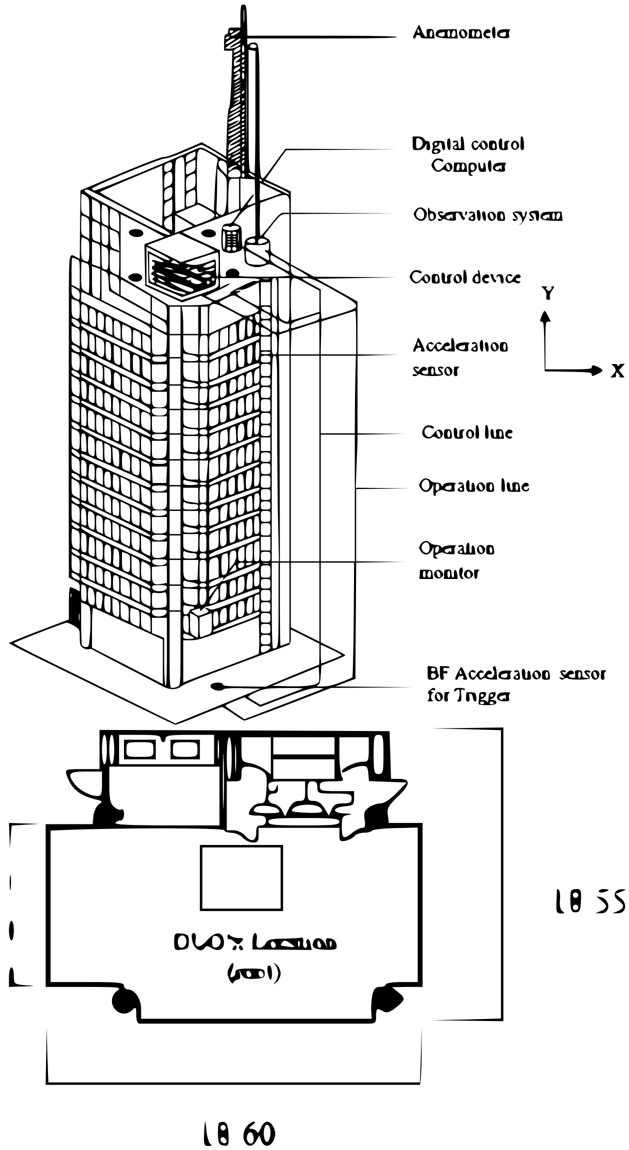

Fig. 6: Active control system, (a) with dynamic intelligent 12 storey building design, and (b) control device design specifications

5.1.3 Response spectra

The response of different structures to the same quakes is widely different. This precisely results in the requirement of expressing the structural response range to ground movement of dissimilar frequency contents. It is termed to be a response spectrum, which resembles a graph, in which the maximum response results of acceleration, speed and dislocation are plotted in terms of time and frequency, and plays a significant role in earthquake engineering. Figure 8 shows the response spectral graph of the proposed research study. The accelerated level that a structure experiences during earthquakes is a critical

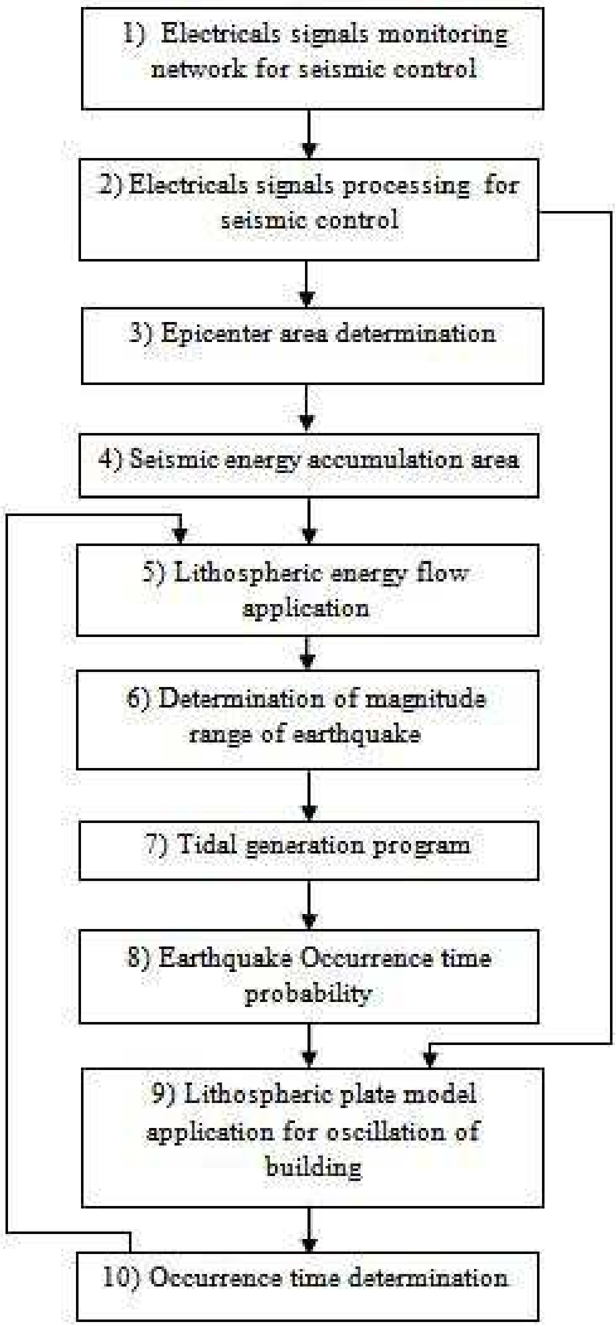

Fig. 7: Closed loop active control system

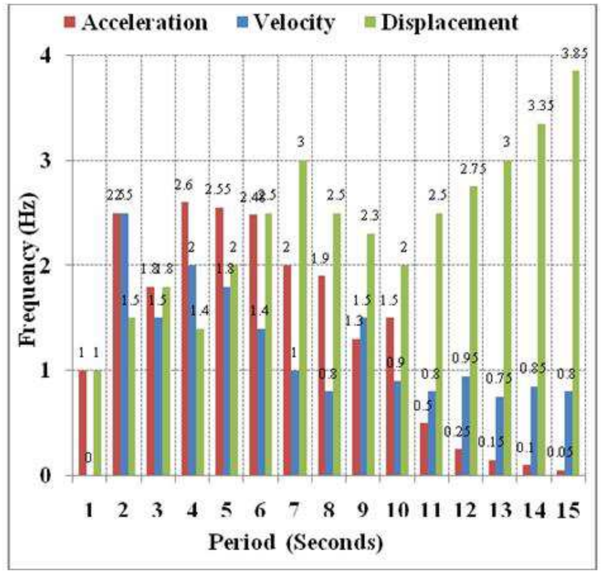

Fig. 8: Response spectrum for 12 storey building

characteristic to determine its degree of damage. Figure 8 indicates the relation between accelerations and frequency, and proves its application. Identification of resonant frequencies to a structure undergoing peak accelerations is vital to make the building much more resistant to earthquakes.

6 Conclusion

This paper presents the measure of earthquake damage using GIS and BDEM to support Chennai-based earthquake disaster management. In this regard, it discusses remote-sensing and GIS-based approaches besides the mechanism to overcome the limitations of data sharing. Prevention measures to mitigate disaster scenario are elaborated along with the relevant details and strategies to support planning and decision making. Geological and meteorological conditions contribute more to natural disasters other than social factors, where orbital platforms are effective to manage natural disaster emergency control. Tremendous conditions can be monitored, reduced or prevented using satellite images. Remote sensing data with GIS analyzes vulnerable areas, and methods are applied based on the analyzed regions. Geo technology is easily accessed by the use of internet facility, that enables to obtain GIS software and satellite images rapidly using tools and process implementation. Further the system can be worked as full-fledged means by citizen participation. Additionally GPS can be combined with Volunteered Geographic Information (VGI) to gain added advantages. The conclusions for our research study are listed below:

1. Developing and maintaining additional spatial database infrastructure can yield spatial data applicable to manage natural disaster-related risks. Typical systems to provide seismic resistance rely on strength, stiffness and inflexible deformation ability of the building.

2.GIS and BDEM systems enable cost optimization by supporting the management to decide productively and provide rapid response right after the seismic disasters.
3.Meanwhile implementation of energy dissipation passive-control system and modern concepts of Dynamic Intelligent Building (DIB) active control system in the buildings results in better preventive methods to control seismic disasters.
4.Active-control dynamic-intelligent building with closed loop system can provide safety to human beings and flexibility to buildings, which also controls material and human loss drastically. So these new system techniques are suitable for green building construction projects in Chennai and applicable for other regions also with slight modification in design to attain better environmental and economic benefits.

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