COMPREHENSIVE GIS-BASED SOLUTION FOR ROAD BLOCKAGE DUE TO SEISMIC BUILDING COLLAPSE IN TEHRAN

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ABSTRACT :

Tehran is highly vulnerable to large earthquakes. Known active faults are surrounding the city and the Ray fault, in south of Tehran, in west-east direction, has high potentials to devastate the city. The municipality district 17 of Tehran is the area of interest for this research as it is considered a seismic hard hit zone comprising of extremely vulnerable dwellings. It is of crucial importance to estimate the road network performance after the occurrence of a disastrous earthquake in urban areas. A proper disaster management scheme requires that such studies be completed ahead of time before a devastating event to have a thorough understanding of the situation and to plan especially for emergency activities (search/rescue, safe evacuation, medical aid, etc…).

This paper describes our comprehensive GIS-based methodology for modeling and estimating the severity and the spatial distribution of road blockage as probability measures, for each road segment (between consecutive intersections) and for the given scenario earthquake. The methodology has four major steps namely seismic hazard identification, building inventory and road network geodatabase development, building vulnerability functions assignment followed by identification of building collapse, and finally producing a risk map for road blockage by a simplified computed index.

The seismic hazard is the estimated worst case scenario from the Ray fault model (JICA 2000). The building inventory has been produced using aerial remote sensing cartographic data that reflect parcel information and attributes from different field surveys. The road network has been extracted from our semi-automated algorithm using 1:2000 scale city maps. Some structural vulnerability functions for various structural typologies have been chosen and reported by JICA (2000) for Tehran. We have found and implemented essential corrections to these functions and used for our building loss estimation model. Ultimately, we introduce a method to report the severity and the spatial location of the blocked roads within the network.

1. INTRODUCTION

It is of crucial importance to estimate the physical vulnerability of the building stock in urban areas, as the basic step to estimate the human loss, the monetary building loss, and also to evaluate the road network performance after the occurrence of a disastrous earthquake in dense urban areas. A proper disaster management scheme requires, completed studies before the event, in order to gain a thorough understanding of the situation and to plan especially for emergency activities (search/rescue, safe evacuation, medical aid, etc.). This paper describes the dedicated comprehensive GIS-based methodology in modeling multi-facet three-dimensional seismic risk

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maps of Tehran. The process involves generation of the city geodatabase, development of the proper building vulnerability functions, and development of a probabilistic method in order to estimate the spatial distribution and the severity of the road network blockage following an earthquake in a timely manner. This is the most crucial information needed for emergency response and in the associated disaster decision support systems.

Considering Figure 1 and other seismic studies, Tehran is situated in highly seismic zone. The District-17 is chosen due to its old vulnerable buildings. The basic elements for conventional pre-event seismic loss estimation in urban areas are to estimate the ground motion at the surface, to compile the city inventory, to obtain vulnerability functions in accordance to the actual building typologies, and to devise a method to evaluate and estimate the loss. Another reason for this site selection is that enough inventory data with parcel resolution is gathered, pre-processed and made GIS ready (Mansouri et al. 2008).

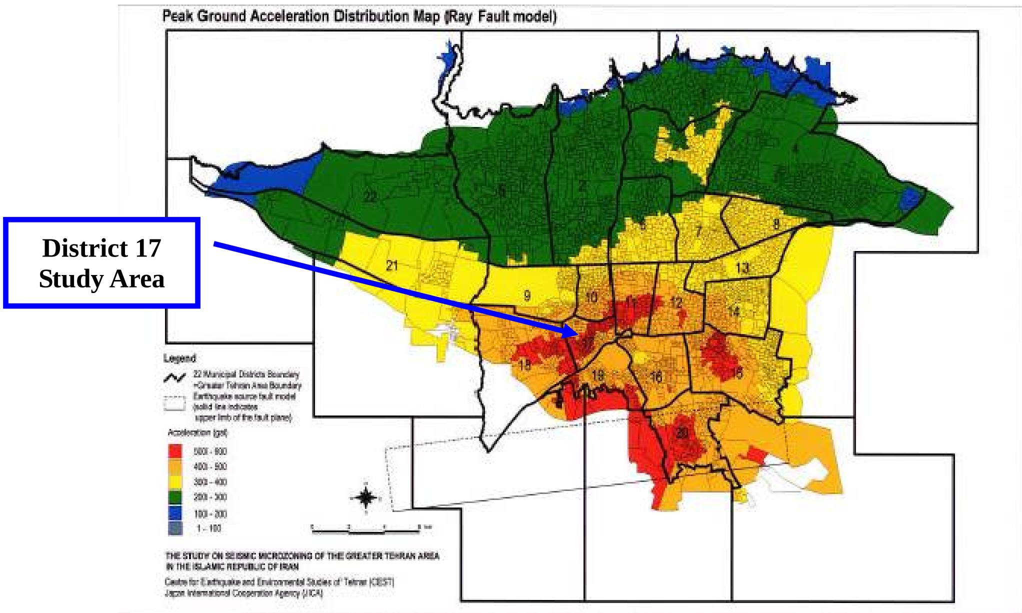

Figure 1 Ray fault scenario microzonation map of Tehran – (JICA 2000)

2. METHODOLOGY

Figure 2 depicts the steps involved in analyzing the Road Blockage Index (RBI) in GIS. Considering the microzonation map, the inventory data and also the structural vulnerability functions, the physical loss estimation is made possible. The building loss and consequently the road network blockage is evaluated and can be described briefly in three phases. In phase one, the development of the city geodatabase and modeling the city in GIS is focused. This involves the compilation of the city topography, the building inventory, the road network and the seismic hazard data. Phase two concerns the modeling of the structural vulnerability functions and defining the road network blockage index. This includes generating probabilistic/analytic procedure to compute the building stock vulnerability for local conditions and road network blockage modeling. In phase three, the site specific RBI estimation and implementation in GIS is in mind. The 3D mapping of the building stock with the relative expected levels of building damages, and the related spatial distribution of the RBI within the extent of the road network is made possible in this stage.

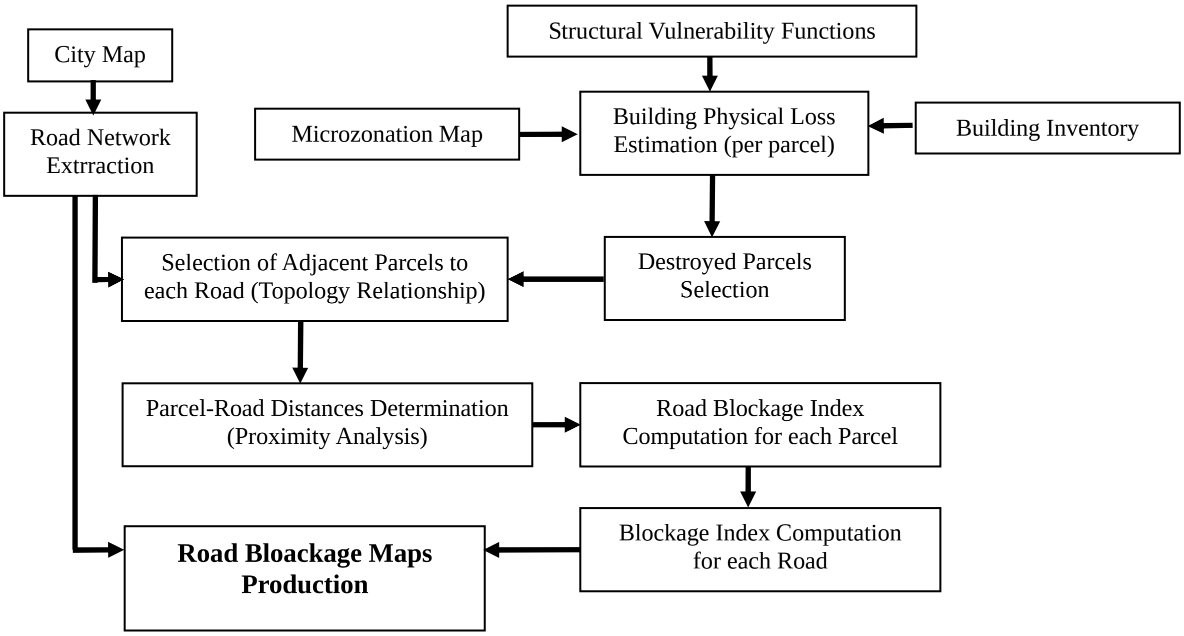

Figure 2 Flow diagram corresponding to the steps involved and implemented in GIS

2.1 Geodatabase

Very high resolution (VHR) optical satellite data, aerial stereo-photos and also survey data have been gathered and processed for the area of study. The height information was extracted from stereo-photography technique and complemented with survey data. The process involves building stock database creation with 3D modeling in digital format with parcel resolution pronouncing building height. Also the road network has been extracted from the 1:2000 scale digital maps using a semi-automated procedure in GIS. The results of the road network classification are shown in Table 1 and Figure 3. The microzonation map for Ray fault scenario has been considered as input for the building loss estimation and stored in the geodatabase.

Table 1 Classification of the study area roads based on the road width

Road classes	Road width (m)	Road length (m)
Class 1	1~3	21495
Class 2	3~6	110553
Class 3	6~12	75383
Class 4	12~24	13684
Class 5	24~35	1144
		Total: 222259

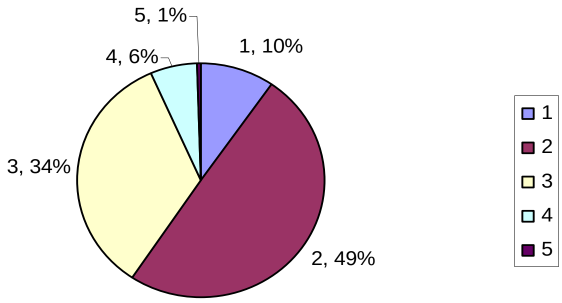

Figure 3 Pie chart of the road class distribution within district 17

2.2 Vulnerability Modeling

2.2.1 Building stock vulnerability modeling

The most common building typology in Tehran, especially in District-17, encompasses the traditional un-reinforced masonry with bearing brick walls and steel and slightly-vaulted brick roofs. Usually these buildings are relatively old (more than 30 years), and do not comply with the Iranian building codes nor have been retrofitted according to published expert recommendations. Different damage functions have been presented using data and observation from worldwide and/or domestic past earthquakes and also by using suitable analytical methods. A series of such curves were introduced for Tehran (Mansouri et al. 2008). By relating these curves with the scenario microzonation data and the inventory database (parcel resolution), a spectrum of structural damage levels (with their proper probabilities) is evaluated within the extent of the city. Figure 3 shows a 3D seismic risk map for the building for a part of the study area. In here, damage factor is defined as the ratio of the repairing cost to the replacement value of the structures according to the ATC13 report.

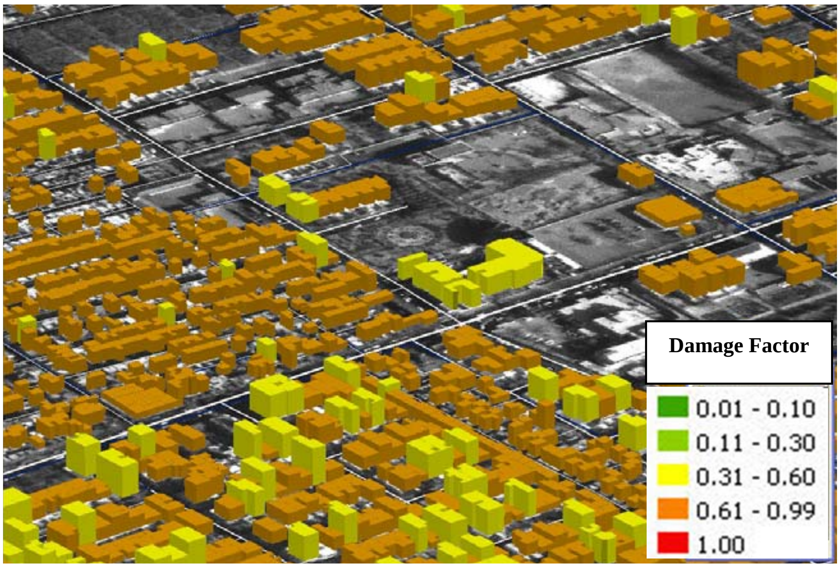

Figure 3 Scenario-based 3D seismic risk map associated to district 17 building stock

2.2.2 Road network vulnerability modeling – Debris model

Completely collapsed buildings that are adjacent to the roads are assumed to be the main cause of the road network blockage. This modeling involves locating the completely collapsed buildings (or more sophistically to find the probability of a building being completely collapsed), finding the topology relationship to locate the parcels that are adjacent to each road, performing the proximity analysis in order to determine the parcel distance relative to the road and finally to calculate the blockage index. The blockage indices for completely collapsed buildings are summarized in Table 2 which shows the severity levels according to the building height “H” and road width “W”. These criteria were first introduced by using Manjil (Iran earthquake of 1990) field data (Bahreini 1993) in Iran.

Table 2 Building specific road preliminary blockage index

RBI	Criteria
4	$W/H < 0.5$
3	$0.5 < W/H < 1$
2	$1 < W/H < 2$
1	$2 < W/H$

To complement the simplistic debris model described above, another condition was set to compute the final RBI. From the urban setting point of view, buildings are situated on the North or the South (or can be East or West) side of the adjacent road. Therefore, buildings usually posses open spaces (in front or in the back) relative to the building footprint. The distance between the buildings footprints and the property boundaries are computed and regarded as the "Proximity Analysis". For one-story, two-story and three-story buildings (representing the whole building inventory) the distances of 3 m, 4.5m and 6 m are judged as the proximity threshold for considering the debris that will affect the road blockage. Figure 4 depicts highlighted buildings (among all collapsed structures form the computed risk map) that satisfy both conditions described in Table 2 and the proximity threshold conditions. Considering this refinement, 36% of the buildings were filtered out from the process.

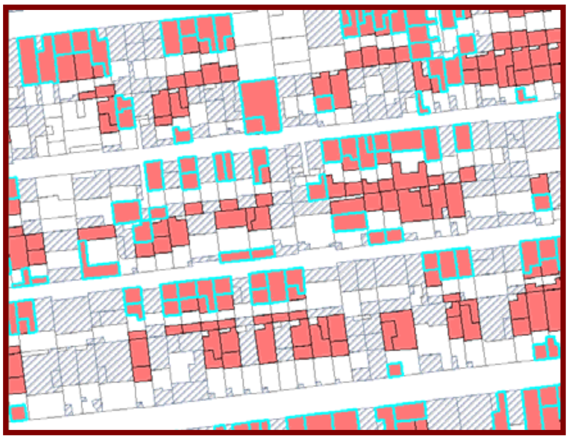

Figure 4 Buildings contributing in road blockage satisfying the debris model conditions (two-story buildings shown)

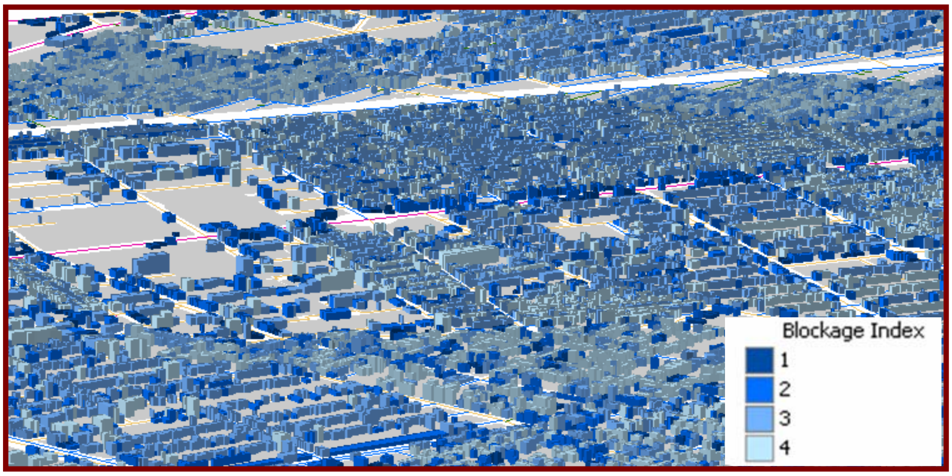

Figure 4 3D view of the RBI distribution shown for each parcel – a part of district 17

3. RESULT

The building physical loss is computed using the vulnerability function sets as described above. This result serves as input to the road blockage estimation procedure. Determining the spatial distribution of the estimated completely damaged buildings, a Road Blockage Index (RBI) is assigned per each parcel. The probability of a building being completely damaged is combined with its RBI value. For each segment of the road, all contributing parcels are considered and their combined indices are aggregated. Figure 5 shows the contributing buildings situated in a row and adjacent to the road. Given similar urban settings, the road that is longer will have a higher probability of blockage unless the probability of at least one totally collapsed building that blocks the path (in the shorter road) is unity. In other hand, when among all totally blocked pathways, the least amount of work and time in clearing the obstacles is of interest, then all contributing parcels must be considered. Figure 6 shows the road blockage chart for the area of study as an aggregation of the RBI value of all the contributing buildings.

Figure 5 Contributing parcels for the road blockage are highlighted are

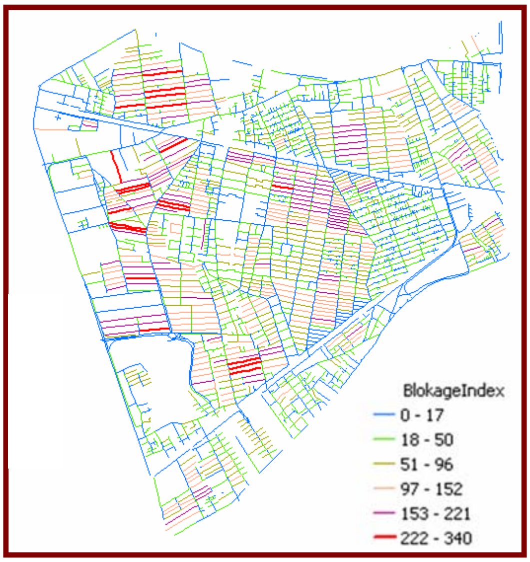

Figure 6 Aggregated RBI for individual roads

4. CONCLUSION

In order to have an optimal risk management plan considering all pre and post earthquake phases in the disaster management cycles, such estimations are crucial. These results potentially help in reducing the monetary loss and more importantly in reducing human loss. Given the volume of the data compiled and processed in this research, it is of great benefit to promote such a project, especially in vulnerable urban areas timely and supportively.

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