DEVELOPING A GIS-BASED MODEL FOR ROAD BLOCKAGE ASSESSMENT

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ABSTRACT

Road plays a significant role in evacuation in post-earthquake emergency. This study looks at the function of road in post-earthquake scenarios. A methodology is developed to estimate the possibility of road blockage level. Factors of building damage, characteristics of the building, and relative distance between the building and the road are taken into the estimation. The study proposes a model to measure and to incorporate those factors. This research brings upon two novel approaches in modeling the road blockage. Firstly, the debris caused by damage to buildings are treated separately according to different building typology (including structural type, height, age…) and the associated proximity to the roads considering each building footprint widths. And secondly, the potential blockage share of each building is estimated by the relative debris heap and the road width.

The methodology is tested with real data of road network in District 17 of Municipality of Tehran. At first, the geospatial information for buildings and road inventories of their existing condition were compiled and processed as to generate a geodatabase. In the next phase, ground shaking maps are produced for scenario or actual earthquakes considered for the case studies. The third phase emphasizes on the vulnerability modelling of the building stock. In the final phase, the estimate of the building damage is calculated for these two earthquake scenarios. Residential building loss and road blockage are calculated for two important earthquake scenarios produced by North Tehran Fault (NTF) and Rey Fault (RF) for Tehran as case study. Based on the result of implementation of the model, up to 10 percent of the roads with width more than 15 meter will be blocked.

INTRODUCTION

Immediately after disastrous earthquake events, the knowledge regarding the status and the potential performance of the road network is essential in managing related emergency activities such as search and rescue and evacuation of injured and dead people. In most urban settings of Iran, especially in old fabrics, buildings are densely packed within their neighborhood while surrounded by relatively narrow or congested roads. A large number of constructions are severely vulnerable and potentially subject to collapse resulting in the spread of large amount of debris around them after severe ground shaking. Although the collapse of some network elements such as bridges, overpasses, tunnels, etc…, are very important; but, the debris spread can be regarded as the major cause of transportation failure in such urban settings.

Transportation infrastructure system has important spatial characteristics, because it connects different locations with various attributes. Geographic Information Systems (GIS) is a useful tool in creating efficient databases and for analyzing complex transportation systems as utilized in this study for implementation.

The blockage indices for completely collapsed buildings which shows the severity levels according to the building height and road width were first introduced by using Manjil (Iran earthquake of 1990) field data (Bahreini 1993) in Iran.

Mansouri et al. (2008) implemented a 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. Determining the spatial distribution of the estimated completely damaged buildings using the vulnerability function sets, 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. The result was the production of a risk map for road blockage by a simplified computed index.

In the following sections, the methodology for developing the road blockage model, geospatial databases and also the procedure for deriving the vulnerability functions are described. The implementation results of the study provide our findings regarding the vulnerability assessment and road blockage model for Iran that can be expanded for everywhere. The last part discusses the application and the results for the case studies. As case studies, risk assessment results for Tehran concerning important earthquake scenarios are reported in this paper. Briefly, this requires the development of ground motion maps, building inventory databases and vulnerability functions to be used in an earthquake loss estimation routine such as ELER.

METHODOLOGY

Developing Model of Road Blockage Estimation

It can be concluded that there are many factors affecting possible road blockage. However, taking all these factors into account was not feasible, because of the lack of data. For that reason, this study only focuses on the aspect of road blockage caused by collapsed buildings and then developing road blockage assesment model. The possibility of debris from buildings blocking the road depends on the following factors:

+ The number of collapsed buildings. The higher this number, the higher the possibility of road blockage.

+ Characteristics of buildings along the road. For example, the presence of weak buildings (adobe, brick-mud buildings), stronger buildings (reinforce concrete, steel buildings) and the presence of buildings with soft story or without cantilevers toward the road.

+ The ratio between building height and distance from front-walls of the buildings to the road center line. The higher this ratio, the higher possibility of debris blocking the roads.

For developing the model of severity level assessment of road blockage, in this research the following indicators have been considered for estimation of debris volume caused by building damage and then development of road blockage model.

Fig. 1 is a flowchart of the methodology to incorporate density of collapsed buildings, type of building, and relative distance between the road and the building into road blockage level.

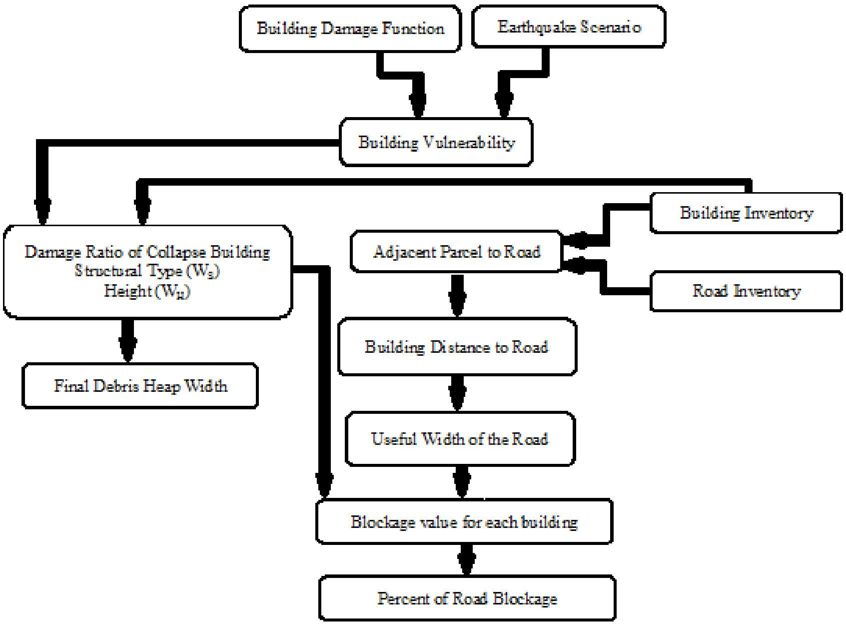


Figure 1. Flow diagram corresponding to the implementation steps of road blockage by buildings in GIS

Calculating Debris volume caused by building damage

Since only debris from collapsed buildings that are in close proximity to the route and face directly to the same route may have chance to block the route, thus only homogenous unit consisting of those buildings are selected.

- *Distribution of building damage* - *Vulnerability modelling*

Increase the percentage of collapsed buildings and the amount of debris on the road, increase road blockage. Thus, due to direct impact of this factor on increasing the amount of debris and the possibility of road blockage, percentage of very heavy damage and destruction consider as a major indicator in development of building debris volume and severity level of road blockage, and is considered as damage factor (DF).

The procedure includes the derivation of vulnerability curves for some most common structural types in Tehran. Empirical fragility curves are generally preferred for regions that have experienced devastating earthquakes in the past. But, because such data is not available for Tehran, some analytical results are proposed. These curves are compared and adjusted with the empirical data from the devastating Manjil-Iran Earthquake (Tavakoli and Tavakoli 1993) and also with the vulnerability results for the concrete buildings destroyed in Kocaeli-Turkey earthquake of 1999 (JICA 2000).

A set of vulnerability or fragility curves are presented for the existing building typologies. These functions are derived using the RISK-UE (2003) procedure but with some modifications according to empirical or analytical (Capacity Spectrum Method) results or expert judgment.

In the following sections, the methodology for developing the building damage estimation are described.

- *Fragility Curve Derivation* - *Capacity Spectrum Method (CSM)*

For calculating Damage Factor (DF), at the first phase, structural fragility curves were developed according to the Capacity Spectrum Method (CSM) considering building taxonomy and site conditions for Tehran (Mansouri and Kiani 2011). The capacity curve is a simplistic representation for the dynamic behavior of the entire structure by considering a SDOF system. The capacity curves are determined by two sets of points, the yield and the ultimate capacity points, where the first indicate the limit for linear response and the second is related to the nonlinear part of the capacity curve. The seismic demand spectrum was derived according to NEHRP-97 procedure were the spectral acceleration was calculated for 0.3 s and 1.0 s periods (*Sa@0.3s*, *Sa@1.0s*) for different zones within the study area. Utilizing the selected GMPEs (described in the previous section), three different spectral acceleration maps were created and the average values of the spectral accelerations were calculated for each earthquake scenario.

- Fragility Curve Derivation - Macroseismic Method (intensity-base)

Intensity-based vulnerability curves were developed in this research for calculating buildings' Damage Factor. The process for developing such curves usually requires detailed empirical damage data that is generally missing for Iran earthquakes. However, the intensity-based curve parameters are derived by comparing the results of the capacity spectrum modelling and some available damage curves. Macroseismic method is a semi-empirical method where the mean damage of a specific building type is determined by the vulnerability and quality indices and the earthquake intensity. Using these parameters and considering the Beta distribution function, damage probability matrices and fragility curves are derived. Table 1 lists the vulnerability indices for the designated building stock (Mansouri et al. 2015).

Table 1. Calibrated vulnerability indices according to RISK-UE (2003) with regional modification

Typology	Description	Earthquake Resistant Design Level	Building Height	Quality Index	Regional Modifier	Total Vulnerability Index
Ad	Adobe	-	Low	1.80	0.160	1.00
M1	Reinforced Masonry Walls	(High Code)	Low	2.3	0.179	0.63
M2 & M3	Unreinforced Masonry	(Pre or Low Code)	Low	2.00	0.114	0.89
RC1	RC Frame + Infill Walls	(High Code)	Medium	2.3	0.338	0.62
RC2	RC Frame + Infill Walls	(Medium Code)	Medium	2.0	0.248	0.69
RC3	RC Frame + Infill Walls	(Pre or Low Code)	Medium	2.0	0.218	0.82
S1	Steel Braced Frame + Infill Walls	(High Code)	Medium	2.3	0.106	0.59
S2	Steel Frame + Infill Walls	(Medium Code)	Medium	2.1	0.266	0.75
S3	Steel Frame + Infill Walls	(Pre or Low Code)	Medium	2.0	0.336	0.82

Type of collapse related to construction material

Note that the type of building is also taken into account. Even in the estimation of the number of the collapsed building, the type of building was considered. However, the debris shape or collapse form are various from different types of building. In the evaluation of road blockage possibility another factor related to the construction material type of the main structure of the building. The masonry buildings (brick-cement, brick-mud, adobe) are likely to disintegrate and collapse vertically, so the debris is likely not to go far away from the building plan. Meanwhile, "rigid" buildings (reinforced concrete and steel structures) are likely to lean and collapse towards one side. The rigid buildings, even though they seem to be "stronger" than the soft masonry buildings, are likely to lean forward to the collapsing side, once they collapse, causing debris to go far away from the original building position. Consequently, it leads to a larger width of the debris heap, and a the higher possibility of blocking the road. Based on reviewing the satellite images and visiting the regions of previous earthquake, expert opinion and also previous studies (Thanh (2004) and RISK-UE (2003)), the values for the material based factor W_S for reinforced concrete and steel buildings was assigned 30% more than other material types and assumed as 1.3.

Height of the buildings

Another important is related to the height of the buildings along the road. By investigation on the building in Tehran, the average height of one story is estimated as 3.20 meters. The width of the debris away from the building is estimated, based on debris shape and size from collapsed buildings in historical earthquakes, as compared to the height of the building and the type of buildings. It is estimated that the average debris width depends on the height of the buildings. Based on the other studies (Thanh (2004) and RISK-UE (2003)) and some experiences of building debris, the angle between the building front wall and the line, that connects the top of the front wall of the building and the furthest point of debris, is estimated as 20□. Based on this assumption the volume of the heap is about 30% of the height of the building. Thus, width of the debris heap is calculated as a function of height of the building and consequently the number of story so the coefficient W_H is as follows:

$$W_H = No.\ of\ Story \times 3.20 \times \tan 20^0 \qquad (1)$$

A final debris heap width W_D is a function of DF, W_S and W_H and due to aggregative effects of the factors is calculated as follow:

$$W_D = DF \times W_S \times W_H \qquad (2)$$

DF, W_S and W_H stands for coefficients of damage factor, structural type and height of the building respectively.

The distance between the buildings and the road influences the possibility of the road blockage: The longer distance, the lower possibility of road blockage. The W_R presents for passable width of the road in a post-earthquake scenario, when vehicles might be allowed to travel even on sidewalks.

The blockage assessment tries to quantify the probability of debris occupying the road and is based on the debris heap and the relative distance between the road and the buildings. This is shown, perpendicular to the road center line, and this type of blockage is called lateral blockage.

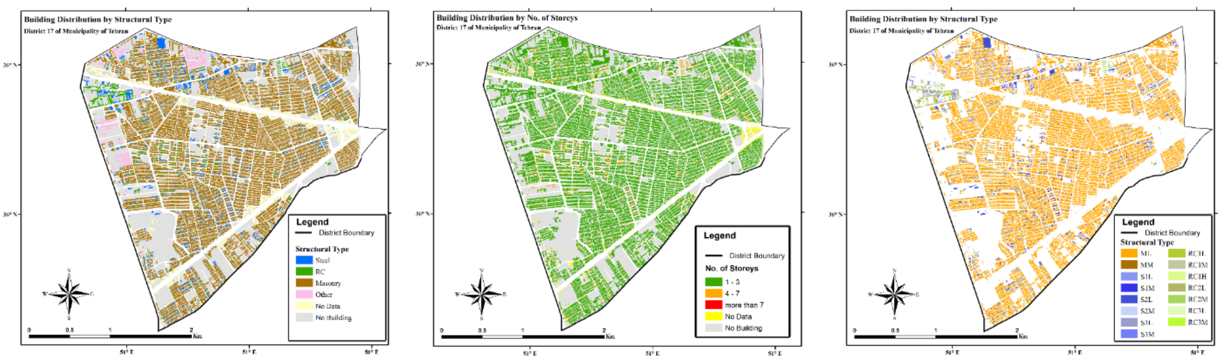
A ratio between the debris heap width, on one side of the road, and the useable width of the road W_R is used to evaluate the lateral blockage by debris on the road surface at the corresponding road segment. The road blockage ratio (RB) is calculated as follows:

$$RB = \frac{W_D}{W_R} \qquad (3)$$

IMPLEMENTATION AND RESULTS

For the implementation phase of the algorithm, the District 17 of Municipality of Tehran is chosen due to its old vulnerable buildings. In previous seismic studies, this district is estimated as a very vulnerable area and implementation results of assessment of buildings vulnerability and consequently the amount of casualties bring up alarming values for officials and crisis management planner.

Using collected database, the existing building typologies in the study area were divided into 15 structural building types. The four major building categories are adobe, masonry, reinforced concrete and steel. The definitions of building types are describe in Table 1. Distribution of buildings in the study area based on the type of structures, number of stories and buildings types are shown in Fig. 2.



(a) by structure (b) by story (c) by building types

Figure 2. Building distribution by structure, story and building types in District 17 of Municipality of Tehran

Existing road network in the district 17 of Tehran Municipality has been identified and is shown in Fig. 3 based on their width. Highways and main urban roads in large scale with streets and service transitions of residential areas have been modeled in the GIS environment.

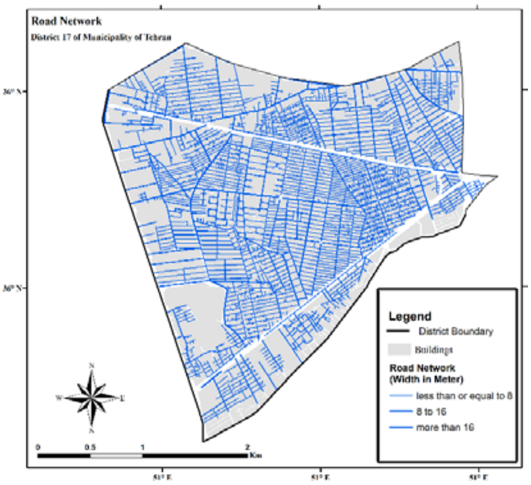


Figure 3. Road network based on its width for District 17 of Municipality of Tehran

Based on some previous studies (JICA, 2000), the most probable hazardous faults are known as Mosha (MF), North Tehran (NTF) and South Rey (RF) faults. More recently, Gholipour et al. (2011) have reported these faults' parameters as shown in Table 2.

Table 2. Seismic parameters for three major faults in greater Tehran region (Gholipour et al. 2010)

Fault Name (Abbreviation)	Fault length (km)	Moment Magnitude	Mechanism	Elastic Thickness (km)	Horizontal slip rate (mm/y)
Mosha (MF)	79	7.0	S	15	-
N. Tehran (NTF)	59	7.1	T/S	15	0.70-1.00
N. Rey (RF)	25	6.7	T	15	0.30

In conclusion, the following two models for scenario earthquakes were considered:
- Ray Fault Model
- North Tehran Fault (NTF) Model

In this research and for the studied cases, Boore et al. (1997) relation is selected for predicting the ground motion and Wald et al. (1999) equation is used for producing the instrumental intensity at the ground surface. A major benefit in using such a methodology is the speed and the ease of implementation. The peak ground acceleration (PGA) distribution maps for North Tehran and Ray Faults model are respectively shown in Fig. 4.

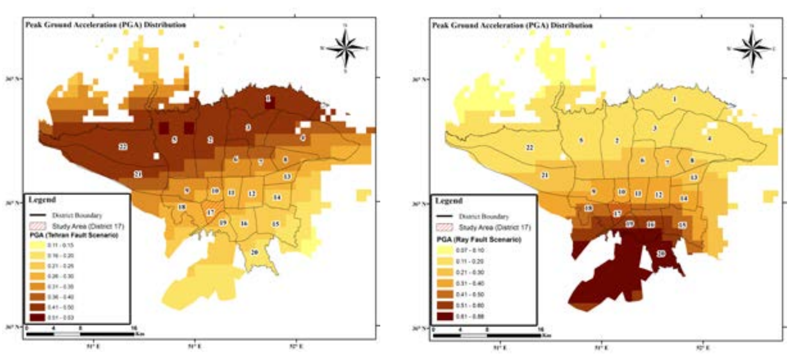


Figure 4. Peak ground acceleration (PGA) distribution maps for Ray Fault and North Tehran Fault model

The distribution of housing unit damages (damage grades of D4+D5) is shown for North Tehran Fault and Ray Fault scenarios in Fig. 5.

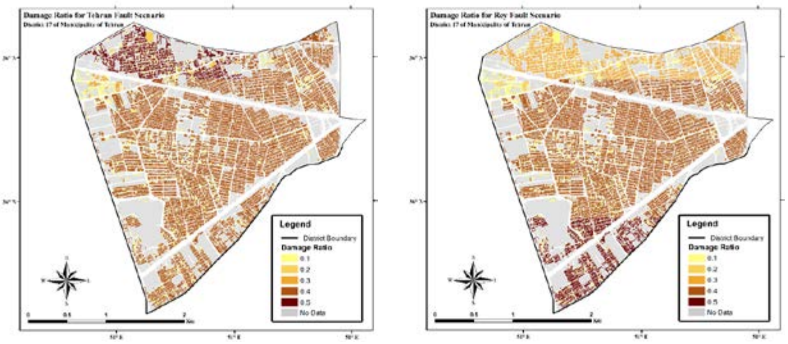


Figure 5. Distribution of damaged housing units for NTF and RF scenario for District 17 of Municipality of Tehran (Grades of D4+D5)

Debris of the buildings that are adjacent to the roads is assumed to be the main cause of the road network blockage. Proximity analysis performed in order to find the topology relationship to locate the parcels that are adjacent to each road and determine the parcel distance relative to the road and finally to calculate the blockage index. Fig. 6 shows the result of finding adjacent building related to each road for study area.

Figure 6. The result of finding adjacent building related to each road for District 17 of Municipality of Tehran

Based on above description, the implementation of the developed model to estimate the volume of debris is provided here. Then, taking into account the mass of debris of a building to relevant passable width, the contribution of each building in blocking related road is determined. Figure 14. Percentage of contribution of each building in relevant road blockage for NTF and RF scenario for District 17 of Municipality of Tehran.

Since the road is blocked by one of the adjacent buildings, the whole passage is blocked, thus the highest percentage obstruction by surrounding buildings as a percentage of road blockage is selected. The result of road blockage percentage for road network of district 17 for RF and NTF scenarios are shown in Fig. 7. Also Table 3. is shown total length (m) of the blocked roads.

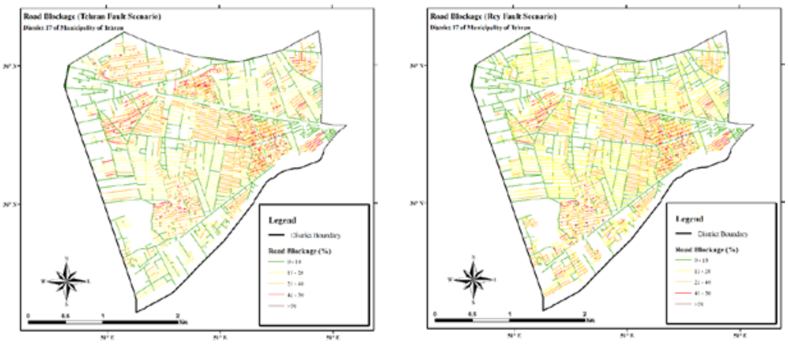


Figure 7. Road blockage for road network of district 17 for North Tehran Fault scenario

Table 3. Total length (m) of the blocked road for TF and RF Scenario

Width (m)	TF							RF						
	0-10	10-20	20-30	30-40	40-50	50-60	60-70	0-10	10-20	20-30	30-40	40-50	50-60	60-70
3	626.6	1514	13723	9191	12631	246.1	12.29	938.3	3400	17501	6815	8694	596.4	0.00
6	4441	32280	36177	281.6	0.00	0.00	0.00	5639	35304	32018	217.9	0.00	0.00	0.00
8	5303	34411	1308	0.00	0.00	0.00	0.00	8973	29914	2135	0.00	0.00	0.00	0.00
10	9142	10543	25.64	0.00	0.00	0.00	0.00	9448	10230	33.31	0.00	0.00	0.00	0.00
12	10304	6877	0.00	0.00	0.00	0.00	0.00	12725	5456	0.00	0.00	0.00	0.00	0.00
15	5994	75.94	0.00	0.00	0.00	0.00	0.00	6182	161.3	0.00	0.00	0.00	0.00	0.00
20	5423	0.00	0.00	0.00	0.00	0.00	0.00	5643	0.00	0.00	0.00	0.00	0.00	0.00
24	4006	0.00	0.00	0.00	0.00	0.00	0.00	4226	0.00	0.00	0.00	0.00	0.00	0.00
30	1246	0.00	0.00	0.00	0.00	0.00	0.00	1325	0.00	0.00	0.00	0.00	0.00	0.00
35	1941	0.00	0.00	0.00	0.00	0.00	0.00	2098	0.00	0.00	0.00	0.00	0.00	0.00
45	585.1	0.00	0.00	0.00	0.00	0.00	0.00	701.1	0.00	0.00	0.00	0.00	0.00	0.00

CONCLUSION

In this study, a new simplified methodology is proposed for assessment of development of fragility curve and then building vulnerability in urban fabrics. In addition, a model for assessment of road blockage is also considered.

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.

Based on the result of implementation of the model, up to 10 percent of the roads with width more than 15 meter will be blocked. Due to the large distance between road and buildings, this result is logical. The percentage of roads with 3m width which will be blocked between 30-50 percent is 50 and 40 percent in TF and RF model consequently. About 41 percent of total road blockage will be between 10-20% and about 30% will be below 50%.

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