# ASSESSING URBAN STREETS NETWORK VULNERABILITY AGAINST EARTHQUAKE USING GIS – CASE STUDY: 6TH ZONE OF TEHRAN

Abdolmotalleb rastegar
instructor department of engineering and technology of Golestan university, Golestan, Iran
amrastegar1986@gmail.com

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**Abstract:**

Great earthquakes cause huge damages to human life. Street networks vulnerability makes the rescue operation to encounter serious difficulties especially at the first 72 hours after the incident. Today, physical expansion and high density of great cities, due to narrow access roads, large distance from medical care centers and location at areas with high seismic risk, will lead to a perilous and unpredictable situation in case of the earthquake.

Zone # 6 of Tehran, with 229,980 population (3.6% of city population) and 20 km2 area (3.2% of city area), is one of the main municipal zones of Tehran (Iran center of statistics, 2006). Major land-uses, like ministries, embassies, universities, general hospitals and medical centers, big financial firms and so on, manifest the high importance of this region on local and national scale.

In this paper, by employing indexes such as access to medical centers, street inclusion, building and population density, land-use, PGA and building quality, vulnerability degree of street networks in zone #6 against the earthquake is calculated through overlaying maps and data in combination with IHWP method and GIS.

This article concludes that buildings alongside the streets with high population and building density, low building quality, far to rescue centers and high level of inclusion represent high rate of vulnerability, compared with other buildings. Also, by moving on from north to south of the zone, the vulnerability increases. Likewise, highways and streets with substantial width and low building and population density hold little values of vulnerability.

## Introduction

After earthquake, due to fall down of buildings and possible street blocks, efficiency of street networks substantially falls off (Rashed and Weeks, 2003). While, in case of any incident or great urgency, street networks play a critical role in saving lives, speeding up the reconstruction operations and the recovery of the city to stable condition (Liu et al, 2003). In other words, street networks are of crucial importance in the aftermath of earthquake especially in restoration and recovery of the city. (Nojima & Sugito, 2000).

In other words, roads and paths trapped between demolished buildings play a key role in the aftermath of the earthquake.

Each earthquake kills a lot of people and regarding the lack of preparation for it, this problem raises more complications in Iran. However, 1% of world population is accommodated in Iran; victims of earthquake in Iran consist 6% of world casualties (Ablaghi, 2005). The necessity to mitigate the social damages of earthquake (victims and injured people), economic damages (reconstruction costs and shutdown of financial activities in city) and physical damages (demolishing of buildings) is perfectly intelligible to every person. In addition, there will be many other concerns such as demolition of fabrics, delay in evacuation of residents, blockage in street networks, absence of on time rescue and digging out trapped people under the wreckage (Minami and Akatani, 2003).

Earthquake will bring about several difficult situations like destruction of residential regions, buildings, structures, infrastructures, bridges, roads, railways, power lines and water supply. These damages will have considerable effects on the neighboring access networks.

Identifying major environmental challenges has made the urban transportation planning face many difficulties. Design of corridors, streets and roads is to provide safe locomotion and access for people and to resolve economic, social and environmental problems (Kennedy et al, 2005). One of the biggest natural disasters that man is facing earthquake.

Structure of urban environment has multi-layer characteristic including distribution of human activities, amenities and infrastructures. This will lead to inconsistency within the city and the answer to this contradiction is street networks (Huang, 2003).

Urban street network has a huge impact on the vulnerability of city against the earthquake. If the street network of city remain intact and maintain its functionality after the earthquake, number of casualties, due to access to safe spots and free circulation of rescue vehicles, will substantially drop (Abdollahi, 2001).

Zone No. 6 of Tehran, with 229,980 population (3.6% of city population) and 20 km$^2$ area (3.5% of city area), is one of the main municipal zones of Tehran (Iran center of statistics, 2011).

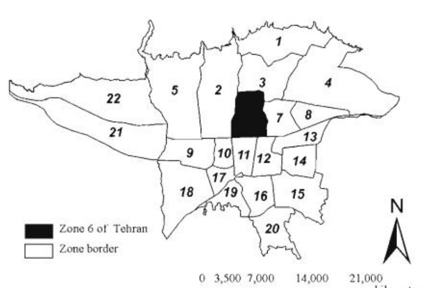


Fig 1. The location of zone# 6 in Tehran city

Major land-uses, like ministries, embassies, universities, general hospitals and medical centers, big financial firms and so on, manifest the high importance of this region on local and national scale. Thus, it is necessary to pay close attention to issues concerning crisis management because any possible damage, caused by natural disasters, to this zone will result in adverse consequences for urban management and will bring about various economic and social damages to officials and citizens. A set of these facts and factors made this zone an adequate case study to investigate.

## Experimental

Urban vulnerability against earthquake depends on human attitude which indicates the degree of exposure or resistance of economic, social and physical units of the city against earthquake (Rashed & Weeks, 2003). Earthquake of Kobe in Japan in January 17th of 1995 was a milestone in studying the role of street networks in mitigating hazards of earthquakes (Minami et al, 2003). This incident considerably affected the planning process for preparation against the earthquake in Japan. Delayed reaction and absence of adequate preparation against such a devastating earthquake held the local and central governments responsible (Habibi et al, 2010). After this earthquake, the role of street networks came to attention and various researches, such as the work of Nojima & Chang (1998), Tsukaguchi & Li (1999), Odani & Uranaka (1999), Chen et al (2002), Lee & Yeh (2003), Liu et al (2003), Minami et al (2003), Samadzadegan & Zarrinpanjeh (2008), were conducted all around the world.

In 2006, Baghvand et al in their article identified main factors which threatened the access networks after earthquake. They proposed number of recommendations in order to increase the efficiency of street networks in urban areas and particularly in dilapidated urban fabrics after the disaster (Baghvand et al, 2006).

In 1998, Chang and Nojima studied the functional conditions of high ways after the earthquake in US and Japan (earthquakes of 1989 in Loma Prieta, 1994 in Northridge and 1995 in kobe) (Nojima & Chang, 1998).

In 1999, Tsukaguchi and Li, after the earthquake of Hanshin Avaji, developed a model to identify the factors resulting the blockage of roads and presented an improved version of their model to enhance the design and the structure of street networks (Tsukaguchi & Li, 1999).

Liu et al, in their research in 2003, proposed an algorithm to evaluate the traffic capacity of street network using demand control criteria like traffic regulation for damaged street networks (Liu et al, 2003).

Minami et al, in 2003, started to collect Data, from Yube in Japan, such as building name, number, type of structure, and number of floors, backyard type and height, distance from street as well as road properties like name, width, length, and sidewalk width and analyzed them in GIS environment (Minami et al, 2003). Lee and Yeh (2003), after examining 921 great earthquakes of world, concluded that the main reason of streetblock, during the earthquake, is the road width less than 4 meters (Lee & Yeh, 2003).

Samadzadegan & Zarrinpanjeh (2008) focused on design and development of a method to evaluate the vulnerability of street networks using digital photogrammetric maps prior to the earthquake and high quality aerial photographs after the earthquake (Samadzadegan & Zarrinpanjeh, 2008).

Recently conducted surveys lacks focused and detailed analysis of governing parameters such as street inclusion, building quality, building and population density, land-use, sidewalks structures, and easy access to medical centers in spite of their significant importance. Above mentioned indices play an important role in reduction of earthquake destructions while investigation of vulnerability of street networks regarding their effects can be very helpful in decrease of earthquake destructive effects.

**Results and Discussion**

## 1. Vulnerability of street network

Assessing street network vulnerability studies the spatial structure of the street network and identifies areas of city which have high exposure and generally is used in evacuation of city. This vulnerability is significantly connected with network structure, environment and traffic (Husdal, 2006). Vulnerability of network structure depends on street network and it's concerning factors like topology, and geometrical form. Natural and environmental conditions affect the street networks by altering circulation on the network especially at rush hours.

Despite this, various points of view have been presented on vulnerability of street networks. Most of these standpoints have concentrated on destroying vulnerable areas or networks (Taylor et al, 2006). Also, street networks have been studied by applying optimum comparison methods of failure scenarios in order to find the best possible circumstances (Shen et al, 2007). Identifying critical situations is an approach to evaluate different alternatives of network downgrade during an incident (Taylor et al, 2006). Critical point of an area in street network is a place that if downgraded or shut down, will dramatically affect the access circulation within the network (Miriam & Shulman, 2008).

In studying street network vulnerability, two concepts which are frequently referred to are redundancy and flexibility. Redundancy refers to areas in which various paths between origin and destination exist (sohn, 2006). And the purpose of flexibility, the possibility of rapid evacuation is street. Most of roads bring about high expenses; but as long as safety is concerned, roads with redundancy provide more escape possibility. As a result, when a road is unusable; there exist various ways to run off (Cova & Johnson, 2003).

## 2. Evaluation of street network vulnerability

**Step #1: presenting chosen indexes to identify vulnerable areas against the earthquake**

In order to access the vulnerability of case study against earthquake seven indexes were picked out:

1. Road width to alongside building height ratio (closure degree): this is a critical factor because increase in closure degree (higher buildings and limited road width) escalates the possibility of blockage in streets. This will result in accumulated debris on roads and considerably impede the rescue operations and sheltering.
2. Population density: an index which indicates the distribution of population over the roads and streets during the earthquake. High density of population will slow down the rescue operation and finding a safe place.
3. Building density: another important factor that if increased, will cause more damage and vulnerability.
4. Land-use: type of alongside land-uses may increase or decrease the vulnerability of street. Hence, land-uses of the case study area are categorized in three classes of high risk, medium risk and low risk.
5. Building quality: this factor profoundly affects the vulnerability of the building. Newly built buildings seem to have more resistance against the earthquake rather than repaired or dilapidated ones.
6. PGA (peak ground acceleration): one of the major factors in building design and consequently building vulnerability is the magnitude of PGA during the earthquake. PGA is calculated by a coefficient derived from the earth gravity acceleration which is represented by g (Ghodrati, 2007). This article measures PGA by $cm/s^2$.
7. Access to health & service centers: access to medical centers is provided through street networks. This speeds up the process of rescue and service providing. Thus, by getting away from health & service centers, vulnerability increases.

**Step #2: IHWP -Inversion Hierarchical Weight Process-method:**

Estimating potential vulnerability is usually surrounded by obscurities and uncertainties for the Boolean sets do not let the vulnerability factors to be a member of a continuous spectrum. Thus, IHWP model is applied (Habibi, 2006). The process of applying this model is described As follows:

- **Determining the importance and weight of data**

After selecting desired layers based on the importance value of each factor, chosen indexes will be ranked using entropy index (collecting expertise opinions). Then, the reversed score of each layer is considered as its weight in the IHWP model (Habibi et al, 2010).

- **Literature review and weighting assumptions**

At this stage, assumptions are assigned to each index According to Table ().

Table1. shows the rank and the inverse of rank of the selected indices according to Delphi's model.

| Index | Score | Reversed score | Weighting assumptions |
|---|---|---|---|
| Inclusion degree | 4 | 4 | Less closure = less vulnerability |
| Population density | 3 | 5 | Less population density = less vulnerability |
| Building density | 2 | 6 | Less building density = less vulnerability |
| Land-use | 5 | 3 | Less risky land-use = less vulnerability |
| Building quality | 1 | 7 | More building quality = less vulnerability |

| | | | |
|---|---|---|---|
| PGA | 6 | 2 | More PGA = less vulnerability |
| Access to medical centers | 7 | 1 | More access to medical centers = less vulnerability |

Reference: writer

- **Calculating selected layer scores using Inversed Hierarchy Weighting Process (IHWP) model**

$$X = \frac{D}{N} \tag{1}$$

Where X=primary score of each index, D=score derived from Delphi model, N=number of classes of each index.

$$j = D - (N - i)X \tag{2}$$

Where j=score calculated for different classes of each index, i= assigned number to different classes of each index.

number assigned to different classification of each index (i). In the end, score of each class of indexes is calculated.

In figure #1, tables of selected indexes and their classification and score are presented. Embraced numbers with parentheses under index column indicate scores derived from Delphi model (D) and numbers in parentheses under classification table show the

Table 2. Seven indexes, their classifications and calculating the score of each class using IHWP method

| score | classification | index |
|---|---|---|
| 0.55 | 0-50(1) | building density (layer score=6) |
| 1.09 | 50-100(2) | |
| 1.64 | 100-150(3) | |
| 2.18 | 150-200(4) | |
| 2.73 | 200-250(5) | |
| 3.27 | 250-300(6) | |
| 3.82 | 300-350(7) | |
| 4.36 | 350-400(8) | |
| 4.91 | 400-450(9) | |
| 5.45 | 450-500(10) | |
| 6 | more than 500(11) | |

| score | classification | index |
|---|---|---|
| 1.4 | 0(1) | building quality (layer score =7) |
| 2.8 | new(2) | |
| 4.2 | maintainable(3) | |
| 5.6 | fixed(4) | |
| 7 | dilapidated(5) | |

| score | classification | index |
|---|---|---|
| 0.1 | 0-50(1) | access to medical centers (layer score=1) |
| 0.2 | 50-100(2) | |
| 0.3 | 100-200(3) | |
| 0.4 | 200-300(4) | |
| 0.5 | 300-400(5) | |
| 0.6 | 400-500(6) | |
| 0.7 | 500-750(7) | |
| 0.8 | 750-1000(8) | |
| 0.9 | 1000-1250(9) | |
| 1 | more than 1250(10) | |

| score | classification | index |
|---|---|---|
| 0.83 | less than 100(1) | population density (layer score=5) |
| 1.67 | 100-200(2) | |
| 2.50 | 200-300(3) | |
| 3.33 | 300-400(4) | |
| 4.17 | 400-500(5) | |
| 5 | more than 500(6) | |

| score | classification | index |
|---|---|---|
| 0.57 | less than.3(1) | inclusion degree (layer score=4 ) |
| 1.14 | (2).3 - .6 | |
| 1.71 | (3).6 - .9 | |
| 2.29 | (4).9 - 1.2 | |
| 2.86 | (5)1.2 - 1.5 | |
| 3.43 | (6)1.5 - 2 | |
| 4 | more than2(7) | |

| score | classification | index |
|---|---|---|
| 0.5 | (1)244.05-255.37 | PGA (layer score=2) |
| 1 | (2)255.37-260.69 | |
| 1.5 | (3)260.69-277-07 | |
| 2 | more than 277.07(4) | |

| score | classification | index |
|---|---|---|
| 1 | low risk(1) | land-use (layer score=3) |
| 2 | medium risk(2) | |
| 3 | high risk(3) | |

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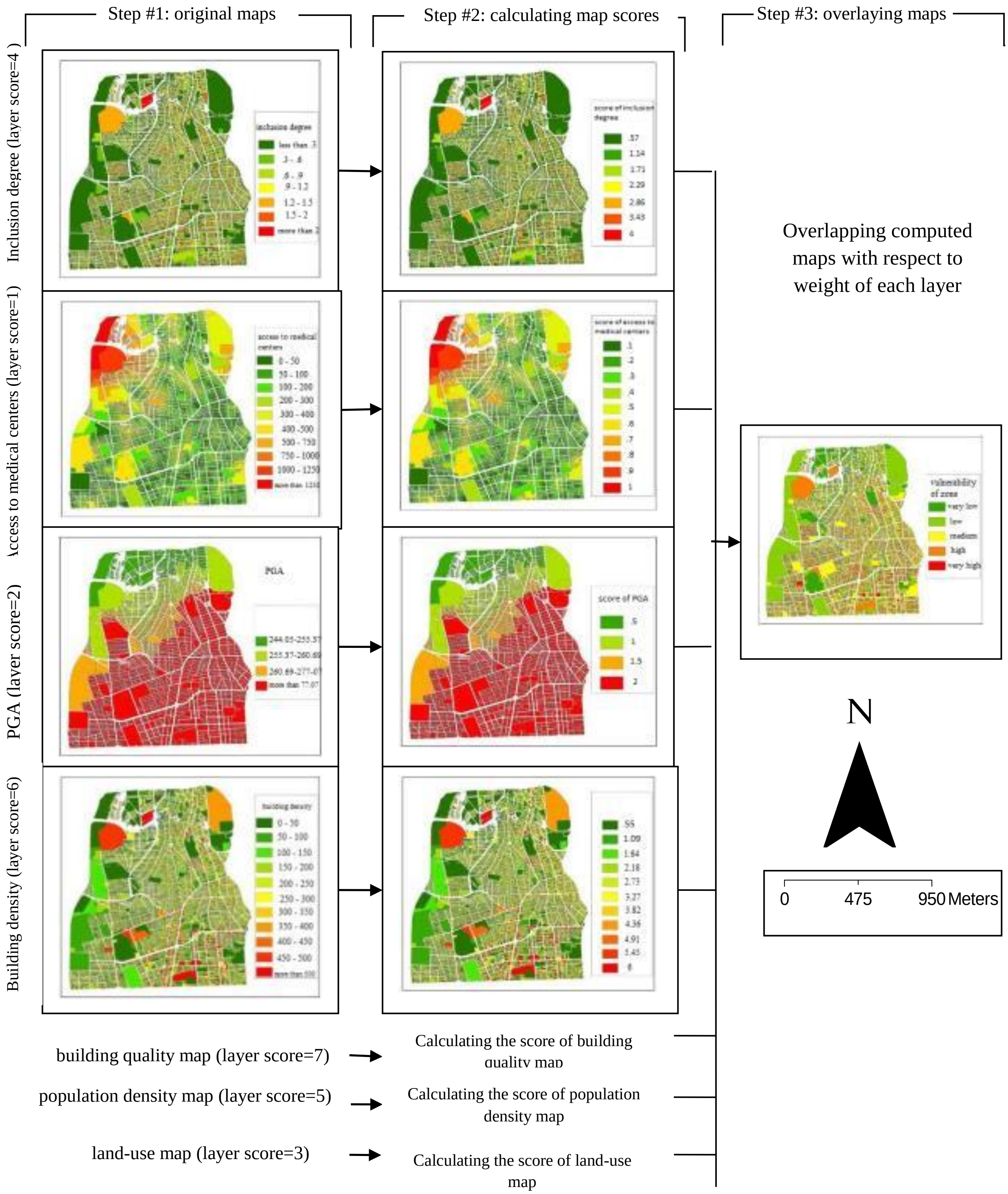


Step #3: overlaying maps

At this stage, according to reversed score gained, the classes of each layer are weighted and by applying Raster Calculation tool, score columns of data layers add up. Creation of final vulnerability map of region

Figure 2: modeling steps for evaluating street network vulnerability against the earthquake in zone #6 of Tehran

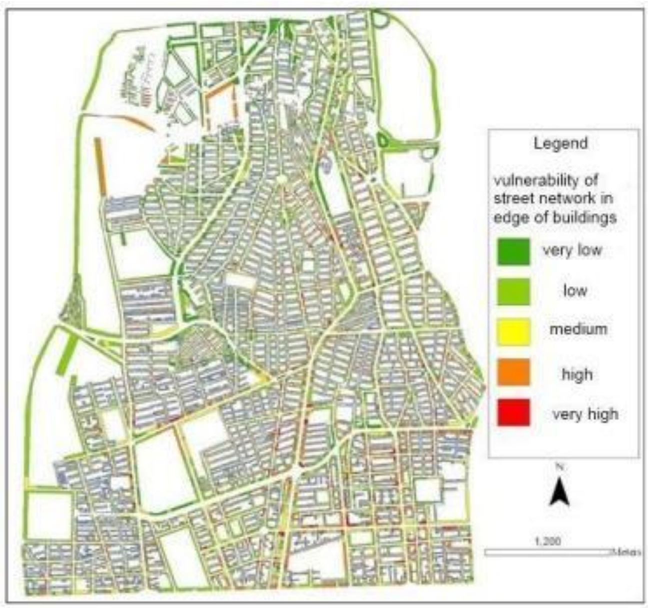


Figure 3: determining the vulnerability degree of street networks against the earthquake in zone #6 of Tehran

In general, streets located at the north of the zone have a low level of vulnerability. By moving on from north to south over the zone, vulnerability raises. The reason is that northern areas of the zone, compared to southern areas, have streets with adequate width and reinforced and new buildings. The congestion of ultra-regional land-uses, such as Tehran and Amirkabir universities and also ministries, in the southern part of the zone and existence of commercial land-uses absorbing traffic, particularly in Enghelab and vali-asr streets, both have made the southern part of the zone more vulnerable to earthquake. Likewise, Kargar Street, due to narrow width, being dead-end, abundance of intersections with red-light and the lack of elevated separations, is not in a good condition. The vulnerability of Kargar Street, especially after Jalal-e-al-e Ahmad Avn. At the east side, is largely evident. The reason is the high density land-uses located at the east side of the street.

Mentioned streets and places positions in manuscript are shown in Fig. 4.


Figure 4. Position streets and important elements such as urban freeways, parks and universities in zone #6 of Tehran

**Conclusion**

Communication networks are a place for providing aid and safeguard. If communication networks excel at their duties, death-toll and economic loss will be minimized in the city. A path can be efficient in aiding and safeguarding process which itself experiences the least destructions during disaster. Dominant specifications of a path efficient in reduction of earthquake destructions can be addressed as: less street inclusion, easy access to medical centers, hierarchical feature and being not isolated, possessing no traffic issues, safety, robust structures, less population and building density, being not located on earthquake-line, healthiness of structures' sensitive applications.

In order to evaluate the vulnerability degree of street networks, at the first stage, seven indexes of closure, land-use, building density, population density, building quality, access to medical centers and PGA were selected and vulnerable lots to earthquake were identified. The result was the seismic vulnerability map of zone #6. By applying these indexes, the vulnerability map of street networks in zone #6 was created. This map indicates that the streets in the south of the zone have the greatest vulnerability to earthquake.

In general, the 6th zone north communication network structures due to low population and building density and newly-built structures have better situation regarding vulnerability. Also, these streets possess less inclusion and due to network safety and hierarchical feature have better access to medical centers.Path structure vulnerability increases from the St. shahid Ghomnam toward south and reaches its maximum at south of zone. So it is obvious that networks which are located in southern zone are inefficient as earthquake hitting.Highways located inside or boundary of zone have less or moderate vulnerability regarding factors such as safety, speed, possessing less conjunctions, better structure quality, less inclusion degree and population density. Long streets such as the Kargar and Valiasr up to central zones, are not safe enough and are considered as the most danger-exposed streets.

Inclusion is an important in increase or decrease of path's vulnerability. As inclusion degree is greater than one, the probability of street closure due to fall of destructions increases. This item increases the rescue-time and earthquake death-toll.

Inclusion degree in southern zone due to its high commercial and official role increases just the St. Of Enghelab and Karghar are in a good situation. In northern part zones possess less inclusion degree.Streets which have a better access to medical centers may reduce the rescue-time in accordance with other factors. Hospitals and medical centers are target points in rescue operation. In other words, the final destination of ambulances is medical centers and hospitals. So hospital buildings should be located along the streets which play a critical role in rescue operation.

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