ISSN: 2148-9173 Vol: 3 Issue:3 December 2016

International Journal of Environment and Geoinformatics (IJEGEO) is an international, multidisciplinary, peer reviewed and open access journal.

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**Alper Şen and Vedat Ekinci**

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Received 29 August 2016
Accepted 15 December 2016

**Abstract**

The inadequate evaluation of geologic factors and unqualified and unplanned structuring play effective role in giant damage and loss of lives created by the earthquakes and faulty areas choice and structure construction cause building damages during the earthquake, thus it also causes giant loss of lives. Istanbul province and its immediate environment are located in north of North Anatolian Fault Zone having 1500 km length. Hence, it causes that the settlement's Sea of Marmara coastal region is located in 1st seismic belt. The earthquake risk in Istanbul and related risk factors should be determined besides vulnerability and earthquake risk. A mathematical model has been created in geographic information systems for Kadıkoy, Maltepe and Prince Islands sub-provinces by using Fuzzy Logic method which is one of the artificial intelligence methods by considering 4 vulnerability parameters and earthquake vulnerability analysis have been made in this study. The used parameters are the location by fault line, geologic structure, building structure and the number of floors. The vulnerability grades emerged as a result of analysis have been studied and the distribution of buildings according to those levels have been presented via a thematic map. The pre-earthquake precautions should be determined for the study field by considering the vulnerability grades in case of any earthquake and the loss of life and property should be minimized.

**Keywords:** Earthquake, geographic information systems, fuzzy logic, risk, vulnerability

## Introduction

While the destructive effects of the earthquake have been known for many centuries, the seism risk determination studies have hardly been developed in the recent past. Turkey is located on one of the most active seismic belts of the world. Turkey is under the effect of three giant plates. These plates are Eurasia, Africa and Arabic plates. As there are many small plates amongst the big plates in the region of Turkey, it causes that the great part of Turkey is located in the seismic belt. Anatolia plate, in which the great part of Anatolia located, is the small part of Eurasia plate (Keskin, 2005). Northern border of Anatolia plate is the North Anatolian Fault where August 17 Marmara Earthquake was happened. A possible seism to affect Istanbul is expected to occur in Sea of Marmara.

As known, the studies about the field gained acceleration post Marmara and Düzce earthquakes happened respectively on August 17 and November 12, 1999 in our country and caused great deal of damage and loss of lives. After the losses in Marmara and Düzce earthquakes, the need of the preparation of an extensive seism intervention plans basing on detailed earthquake risk analysis has emerged (Gökaşan et al., 2002). In case of a giant earthquake, the damages whose qualities change will occur on the buildings. Serious loss of lives is considered to happen in heavily damaged buildings. Thus, the risk factors about the earthquake risk in Istanbul, the possibility

of damage and earthquake risk should be determined.

Istanbul, throughout the history, has exposed to many destructive earthquakes. The city had been affected by 32 earthquakes between 4th and 19th centuries and it equals to a moderate size of earthquake in every 50 years (Gazioğlu et al., 2002). Besides, Istanbul is exposed to severe earthquakes in about every 300 years (Gazioğlu et al., 2005; Hebert et al., 2005). When setting the anomaly observed in Avcilar during August 17, 1999 Kocaeli earthquake aside, Istanbul has not been exposed to a significant earthquake since 1894 earthquake (Erdik and Durukal, 2007).

The Marmara region is one of the most tectonically active fault zone. The North Anatolian Transform Fault Zone (NAFZ) cuts across the region in an E–W direction, following the major axis of the Sea of Marmara. In the region the rate of right-lateral offset along the NAFZ has been measured to be about 18 mm/yr (Flerit et al., 2003 and Pondard et al., 2007). The NAFZ is widely known to have generated large earthquakes (M > 7) at 125–150 yr intervals. In the Düzce and Marmara (Golcuk or Izmit) earthquakes of 1999, the lateral offset along the fault locally exceeded 5 m (Toksöz et al., 1999). The Istanbul area is a fault block bounded on the south by the NAFZ and on the north by the South Boundary Fault of the Black Sea Basin (Yılmaz et al., 2010). This fault-bounded block is forced to rotate anticlockwise due to the sinisterly shear. Rotation is uttered plainly in the geomorphology; major hills and the valleys trend indirectly to the two faults, following a long way before reaching the surrounding seas. Instantaneously with the anticlockwise rotation, the fault block has been raised at a rather slow rate of about 0.2 mm/yr (Algan et al., 2011).

Among the secondary hazards, the possibility of a tsunami is the most notable and widely examined one in the literature. According to Alpar et al. (2004; 2003), Istanbul has been beset by different-sized tsunamis throughout its history. It is rather problematic to estimate a near-field tsunami impact on the southern coastal districts of Istanbul, due to the long interval between the past earthquakes, insufficient historical data, and the short distance between the NAF and Istanbul (Başkaya, 2015).

Many different models have been revealed in order to pre-determine the place and time of earthquakes in both our country and different earthquake belts over the world and also reveal the earthquake risk analysis. Risk, in general sense, is the resultant of the possibility of any danger and the results that the danger may cause. In other words, it is proportionate to the gravity of the risk level danger and the vulnerability of affected elements (Kundak and Türkoğlu 2007).

Among the suite of problems associated with the ill-structured nature of vulnerability analysis, perhaps the most important one is that vulnerability is often confused with the notion of risk. In fact, each of these two notions represents a distinct concept (i.e. risk=hazard×vulnerability) (Rashed and Weeks, 2003)

The way that buildings respond to earthquake is expressed by their vulnerability. For instance, if two building groups are subjected to exactly the same earthquake then one group may perform better than the other, which means than the buildings that are less damaged have lower earthquake vulnerability than the ones that are more damaged (Şen, 2010).

It is essential to reduce the disaster vulnerability grade and positioning the risk factors (population, structure stock etc.) from the danger point as far as possible in order to decrease the risk of earthquake. Disaster vulnerability is defined as the degree of the loss to happen in a risk factor (or risk factor group) in case the predicted danger occurs in predicted damage level.

The vulnerability risk should primarily be determined and studies should be made concerning the change of vulnerability of the buildings where the risk is not acceptable in order to enhance the structures which are considered not to have adequate earthquake safety (Akbulut and Aytuğ, 2005). An important step for the reduction in the seismic risk requires the evaluation of physical

vulnerability of buildings (Lestuzzi et al., 2016). As the available buildings vary according to their residential area features, architecture, structures, materials, regulations and quality of construction, their attitudes and damage levels shall not be similar in case of a severe earthquake. Thus, the attitude of buildings depends on various parameters during the earthquake. Their evaluation of vulnerability generally bases on the controlling of these parameters (Akbulut and Aytuğ, 2005).

Many techniques are available in the literature and have been developed for building vulnerability assessment and loss estimation: empirical, heuristic and analytical methods (FEMA-249 1994; Tesfamariam and Sanchez-Silva, 2011).

Calvi et al. (2006) reviewed the most significant contributions in the field of vulnerability assessment. The various methods for vulnerability assessment that have been proposed in the past for use in loss estimation can be divided into two main categories: empirical or analytical, both of which can be used in hybrid methods.

Fischer et al. (2002) advised the use of fuzzy logic algebra in structural damage estimation. Rashed and Weeks (2003) attempted to address the ill-structured nature of vulnerability by proposing a methodology base on the techniques of spatial multi-criteria analysis and fuzzy logic.
Demartinos and Dritsos (2006), discussed the performance of a fuzzy logic based rapid visual screening procedure that results in the categorization of buildings into five different types of possible damage with respect to the potential occurrence of a major seismic event.
Tesfamariam and Saatcioglu (2008, 2010) have proposed a heuristic-based hierarchical structure and performed aggregation through fuzzy logic.
Sen (2010) classified buildings into 5 distinctive classes based on the fuzzy logic model which are without, slight, moderate, heavy, and complete vulnerability categories. He presented the preliminary modeling stages in reinforced concrete building evaluation against possible earthquakes of magnitude seven or over in Zeytinburnu quarter of Istanbul.

Tesfamariam and Sanchez-Silva (2011) presented a model that incorporates, in the life-cycle cost of a structure, concepts of fuzzy logic to evaluate information coming from different sources and building irregularities. A four-level hierarchical structure was proposed to model the building damageability.

In this study, a mathematical model has been created in geographic information systems for Kadikoy, Maltepe and Prince Islands by using Fuzzy Logic method which is one of the artificial intelligence methods regarding 4 vulnerability parameters and earthquake vulnerability analysis has been made. The used parameters were the location by fault line, geologic structure, building structure and the number of floors. The vulnerability grades obtained as a result of the analysis have been calculated as low, medium and high. The distribution of buildings has been presented through a thematic map according to mentioned levels. As a result of vulnerability analysis, 17 313 buildings -included in the study- out of 62 315 are high risk, 35 555 are medium risk and 9 447 are low risk.

## Materials and Methods

### *Study Area*

1:250 000 scale active fault map series of Turkey, Bursa (NK 35-12) quadrangle (serial no: 9) has been utilized for North Anatolian Fault Line in Marmara Sea (Emre et al., 2011). The fault line used in this study was produced by total of 38 points. The study areas are Kadikoy, Maltepe and Prince Islands (Figure 1).

The structures in polygon geometry and their attributes have been provided by Istanbul Metropolitan Municipality (IMM). As post 2008 database has been used in the study, Kadikoy sub-province border is not in updated state. The attributes of related building layer to be used in the study were the number of building floor (normal and basement), structure construction type (reinforced concrete,

masonry, wooden and steel construction) in the geographic database obtained from IMM. The attributes belonging to related geologic data is available in IMM geographic database. Totally 62315 buildings have all the attribute values have been evaluated.

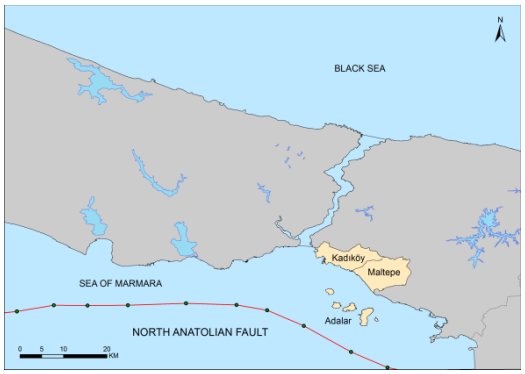


Figure 1 Study area and North Anatolian Fault

*Fuzzy Logic*

Traditional methods are based on a set of classical logic inference method, which requires ‘‘white” or ‘‘black” information ignoring any type of uncertainty. In areas of uncertainty for the earthquake behavior characterization can be considered fuzzy logic approach, which evaluates ‘‘grey” information. In this study, for example, distance to fault is a fuzzy (grey) input in order to categorize into a risk set for vulnerability analysis.

A fuzzy set is a class of objects with a continuum of grades of membership (characteristic) function which assigns to each object a grade of membership ranging between zero and one.
Let $X$ be a space of points (objects), with a generic element of $X$ denoted by $x$. Thus,

$$X = \{x\} \quad (1)$$

A fuzzy set (class) $A$ in $X$ is characterized by a membership (characteristic) function $f_A(x)$ which associates with each point in $X$ a real number in the interval [0, 1], with the value of $f_A(x)$ at $x$ representing the grade of membership of $x$ in $A$. Thus, the nearer the value of $f_A(x)$ to unity, the higher the grade of membership of $x$ in $A$. When $A$ is a set in the ordinary sense of the term (ordinary sets or simply sets), its membership function can take on only two values 0 and 1, with $f_A(x)$=1 or 0 according as $x$ does or does not belong to $A$.

As in the case of ordinary sets, the notion of containment plays a central role in the case of fuzzy sets. This notion and the related notions of union and intersection are defines as follows. The union of two fuzzy sets $A$ and $B$ with respective membership functions $f_A(x)$and $f_B(x)$ is a fuzzy set $C$, written as $C = A \cup B$, whose membership function is related to those of $A$ and $B$ by

$$f_C(x) = Max[f_A(x), f_B(x)], x \in X \quad (2)$$

or, in abbreviated form

$$f_C = f_A \vee f_B \quad (3)$$

The intersection of two fuzzy sets $A$ and $B$ with respective membership functions $f_A(x)$and $f_B(x)$ is a fuzzy set $C$, written as $C = A \cap B$, whose membership function is related to those of $A$ and $B$ by

$$f_C(x) = Min[f_A(x), f_B(x)], x \in X \quad (4)$$

or, in abbreviated form (Zadeh, 1965).

$$f_C = f_A \wedge f_B \quad (5)$$

The knowledge base defines the relationships between the input and output parameters of a system. The most commonly used representation of the input-output relationships is Mamdani type fuzzy models (Mamdani, 1977). In this type of fuzzy models, linguistic propositions are used both in antecedent and consequent parts of IF-THEN rules. The fuzzy rule base consists of a collection of rules of which can express the decision maker’s opinion valuation for a particular uncertain environment.
The IF-THEN rules can be established as:

$$R_i: IF\ x_1\ is\ A_{i1}\ AND\ x_2\ is\ A_{i2}\ THEN\ y\ is\ B_i \quad i = 1, \dots, n \quad (6)$$

where $R_i$ represents the $i^{th}$ rule $x_1$ and $x_2$ are inputs (antecedent) linguistic variable, $n$ is the total number of rules, $A_{i1}$ and $A_{i2}$ are input

fuzzy sets, y is output (consequent) linguistic variable and $B_i$ is the consequent fuzzy set (Tesfamariam and Saatcioglu (2008).

Defuzzification is the process of converting fuzzy output into a crisp number. Various defuzzification techniques are reported, such as centroid of area, bisector of area, mean value of maximum, smallest (absolute) value of maximum and largest (absolute) value of maximum. In this paper, the centroid of area is used for defuzzification.

The membership functions used in the study are (Matlab Help, 2016):

The function *gauss2mf* is a combination of two of these two parameters. The first function, specified by *sig1* and *c1*, determines the shape of the left-most curve. The second function specified by *sig2* and *c2* determines the shape of the right-most curve. Whenever *c1* < *c2*, the *gauss2mf* function reaches a maximum value of one. Otherwise, the maximum value is less than one. The parameters are listed in the order:

$$f(x;\ \sigma, c) = e^{\frac{-(x-c)^2}{2\sigma^2}} \quad [sig1, c1, sig2, c2] \quad (7)$$

The triangular curve is a function of a vector, *x*, and depends on three scalar parameters *a*, *b*, and *c*, as given by;

$$f(x;\ a, b, c) = \max(\min\left(\frac{x-a}{b-a}, \frac{c-x}{c-b}\right), 0) \quad (8)$$

The parameters *a* and *c* locate the "feet" of the triangle and the parameter *b* locates the peak.

**Earthquake Vulnerability Analysis**

*Parameters*

1. Distance to North Anatolian Fault Line

Istanbul and its immediate environment including the residential areas where the shanty houses and low quality non-zoning houses occupy great density are located in a region which is predicted to be affected by 7 and higher magnitude earthquakes 20-30 km near North Anatolian Fault, one of the limited active faults of the world (Özgül, 2011).

Kadikoy, Maltepe and Prince Islands, according to General Directorate of Mineral Research and Exploration, comprise 1st degree earthquake risk. The density of the energy that the seismic waves diffuse in the areas near fault lines will increase the amount of the damage. Thus, the distances of buildings to fault lines have been calculated according to Euclidean Distance (Figure 2). Euclidean Distance gives the distance from each cell in the raster to the closest source.

Euclidean Distance between $P=(p_1,p_2,...,p_n)$ and $Q=(q_1,q_2,...,q_n)$ vectors in *n* size euclidean space:

$$\sqrt{\sum_{i=1}^{n}(p_i - q_i)^2} \quad (9)$$

2. Structure of Soil (Geologic Structure)

The magnitude and distribution of earthquake damages have close relationship with geologic and geotechnical features of the soil to a large extent (Özgül, 2011). Thus, it presents a great importance to have knowledge about the structure of soil in order that the study field determines the earthquake vulnerability. The soil-formation classification produced by IMM has been used while establishing vulnerability analysis and structure of soil relation in study field (Figure 3). The soil-formation classification made by IMM is given in Table 1. Accordingly, the number of buildings in the regions classified as precaution area, settled area and the area requiring a detailed geotechnical study of Kadıkoy, Maltepe and Prince Islands have been given in Table 2.

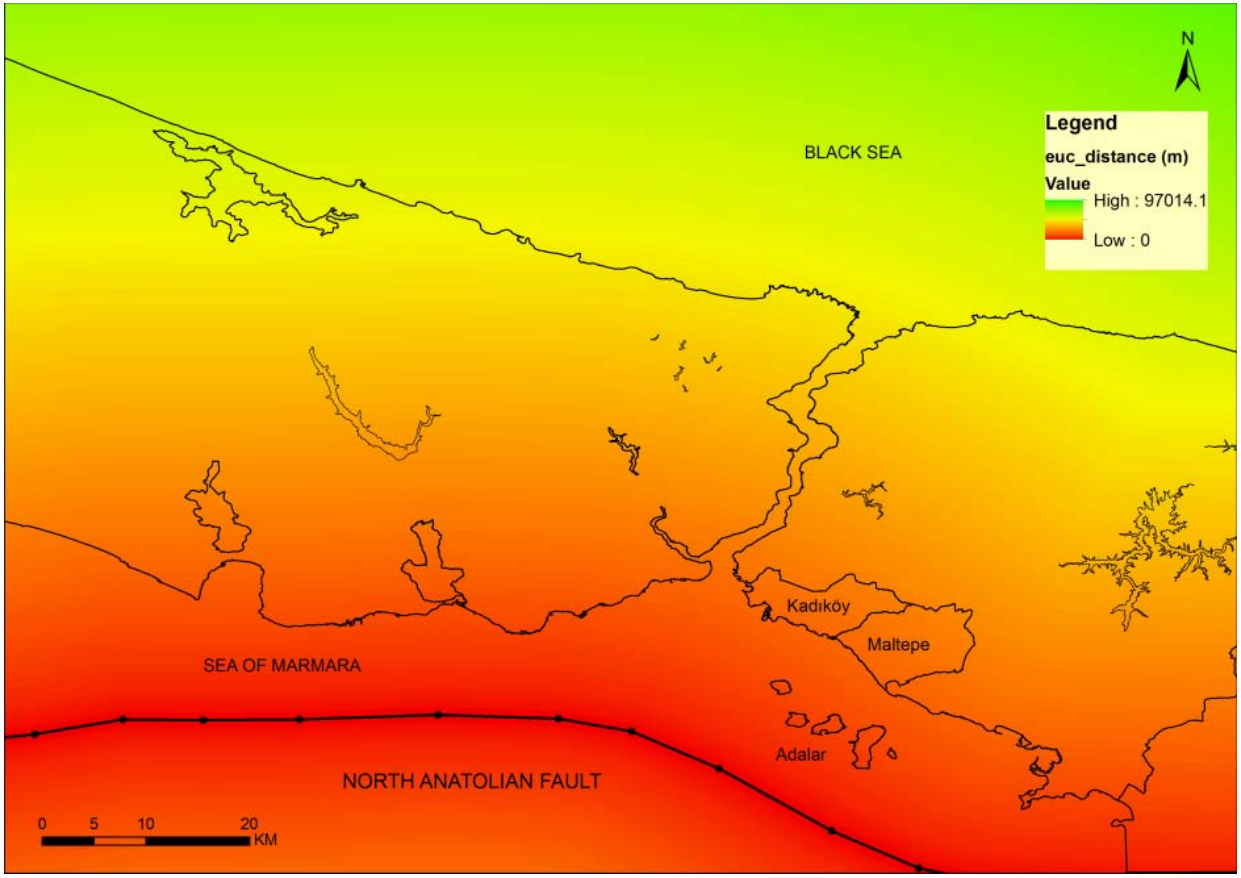


Figure 2. Euclidean Distance Map of Kadıköy, Maltepe and Prince Islands According to North Anatolian Fault Line

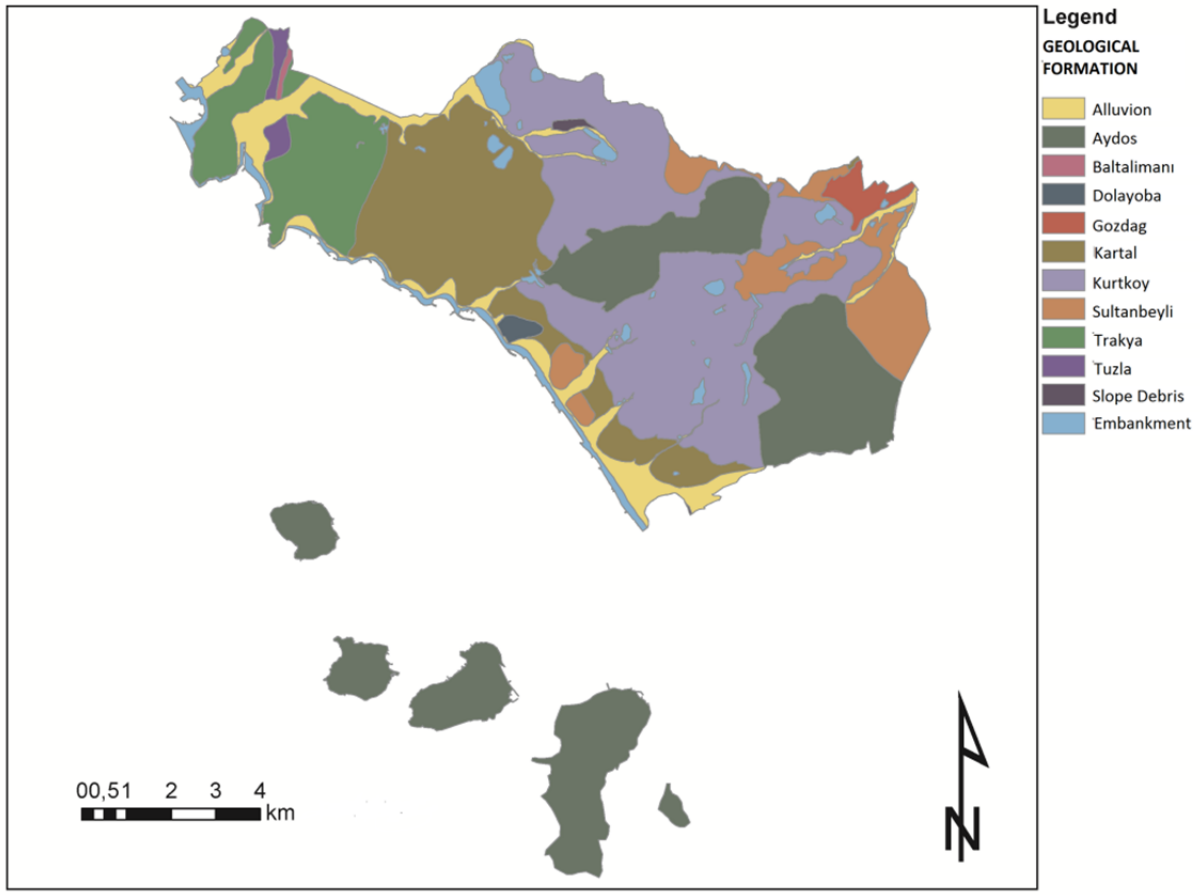


Figure 3.Geology (Formation) Map of Kadıköy, Maltepe and Prince Islands.

Table 1. Classification of Study Area Soil-Formation (IMM Database)

| Definition of Settlement | Feature | Formation |
|---|---|---|
| Area Requiring Detailed Geotechnical Study | Thick Filling Areas with a Slope between 5% and 10% | Artificial Filling |
| | Rock Fall Areas | Kurtköy and Kartal Formations |
| | Thick Alluvium Environments with Liquidity Risk | Alluvium |
| Precaution Areas | Deterioration Zone | Thrace Formation |
| | Areas with a Slope More Than 30% | Kurtköy, Aydos, Gözdağ, Tuzla and Dolayoba Formations |
| | Areas with a Slope between 0% and 30% | Sultanbeyli Formation |
| | Areas with a Slope Less Than 30% | Slope Wash |
| Area Convenient to Settlement | Rock Areas with a Slope Less Than 30% | Dolayoba, Kartal, Gözdağ, Tuzla, Kurtköy, Thrace and Baltalimanı Formations |
| Area Not Convenient to Settlement | Coast Artificial Filling | Artificial Filling |

Table 2. Number of Buildings in Classified Areas (IMM Database)

| Number of Buildings in Precaution Areas | Number of Buildings in Area Convenient to Settlement | Number of Buildings in Area Requiring Detailed Geotechnical Study |
|---|---|---|
| 41167 | 16386 | 4762 |

## 3. Structure of Building

The determination of structural and delicate features of housing zones covering 60-70% of residents is essential especially in the realization of loss predictions. 75% of loss of lives and injuries in earthquake arise from the demolition of the buildings. The losses arise especially from masonry buildings are about 60%. Furthermore, the reinforced concrete constructions may be more fatal than masonry buildings when established uncontrolled even if they are safer than masonry buildings (Kundak and Türkoğlu, 2007).

There are four types of building classes in steel construction, wooden, reinforced concrete and masonry class which consists of 62320 in total in IMM data inventory. However, there are totally 5 steel construction class buildings in total in IMM database and this building class has not been included in the analysis as it is lack of number.

The building vulnerability indexes determined by IMM-Directorate of Earthquake and Geotechnical Investigation through macroseismic method (2009) of the building classes included in study field and to be used in risk analysis have been considered (Table 3).
The building damage is calculated using the European Macroseismic Method (Giovinazzi, 2005). The vulnerability models are pertinent to EMS-98 vulnerability classes and correlate the

mean damage grade $\mu_D (0 \leq \mu_D \leq 5)$ with the seismic intesity ($I$) and the vulnerability index ($V_I$),

$$\mu_D = 2.5\left[1 + \tanh\left(\frac{I + 6.25V_I - 13.1}{2.3}\right)\right]$$

The parameter $V_I$ defines the membership of the particular building type in a specific vulnerability class. The probabilities of occurrence of damage grade $D_i$ for seismic intensity $I_i$ (percentage of buildings of damage grade $D_i$) are then beta-distributed considering the ranges of the mean damage grade.

The values of the vulnerability indices for the EMS-98 vulnerability classes: (1) $V_0$ is the most probable value of the vulnerability index $V_I$ for a specific building type (considered as a centroid of the membership function). (2) [$V^-$ ; $V^+$] are the bounds of the plausible range of the vulnerability index $V_I$ for a specific building type. (3) [$V_{min}$;$V_{max}$] are the upper and the lower bounds of the possible values of the vulnerability index $V_I$ for a specific building type (Trendafiloski et al., 2011).

According to Table 3, the resistance of building structures against 7 magnitude earthquake calculated with macroseismic method is ranked from bigger to smaller; wooden (0.27), reinforced concrete (0.71) and masonry (1.08). The vulnerability degrees of building types for different earthquake magnitudes are given in Figure 4.

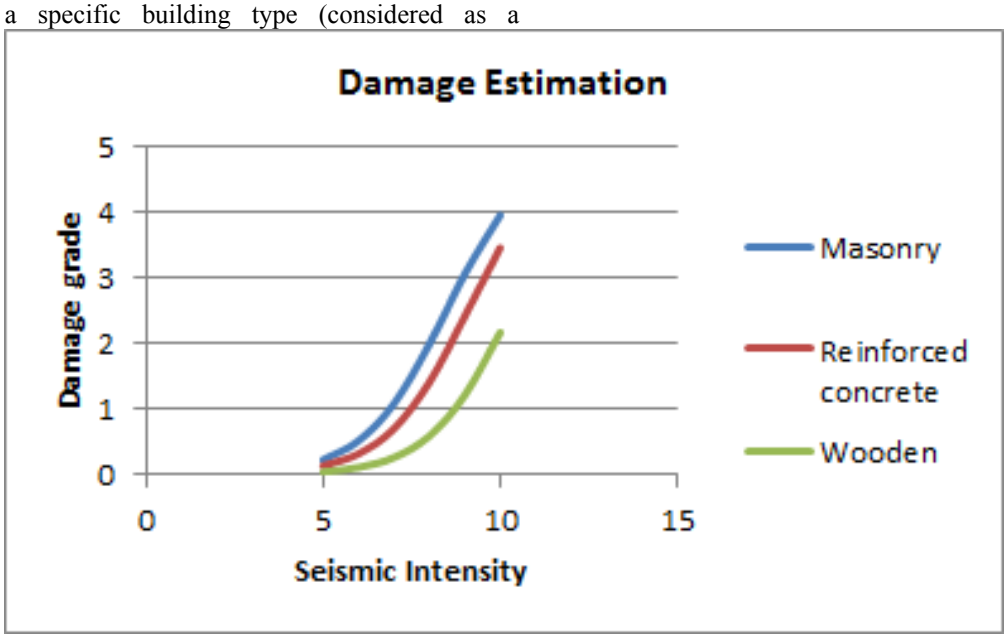


Figure 4. Vulnerability calculation of different earthquake magnitudes.

Table 3. Vulnerability indices of building classes (IMM, 2009)

| Building Type | Vulnerability Indices | | | | | Damage (seismic intensity:7) |
|---|---|---|---|---|---|---|
| | $V_{min}$ | $V^-$ | $V_0$ | $V^+$ | $V_{max}$ | $\mu_D$ |
| Masonry | 0.46 | 0.65 | 0.74 | 0.83 | 1.02 | 1.08 |
| Reinforced concrete (seismic resistant design not applicable | 0.3 | 0.49 | 0.64 | 0.8 | 1.02 | 0.71 |
| Wooden | 0.14 | 0.21 | 0.45 | 0.64 | 0.86 | 0.27 |

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4. Number of Building Floors

Previous giant earthquakes have shown that the earthquake damages in urban settlement are directly proportionate to the number of building floors. The situation is available especially for the buildings deprived from earthquake design. The land observations made after 1999 Kocaeli and Düzce earthquakes have shown that there is a close relation between building damages and total number of floors. The number of floors is the most significant factor determining the degree of the damage in Turkey. 'Number of floors' means the free number of floors whose oscillation is not limited by the soil of the building.

The database comprised of 3-6 floor 454 buildings selected from the city center post-earthquake occurred on November 12, 1999 in Düzce is given in Table 4 according to the damage distribution of buildings. This region is quite smooth and the type of soil is not variable in the region (Sucuoğlu, 2007).

Revising IMM database, it has been seen that the proportion of buildings having 4 or lower number of floors is 68%. This value can be considered positive in terms of earthquake risk (Table 5 and Figure 5).

Table 4. Damage distribution of buildings investigated in Düzce (Sucuoğlu, 2007).

| Number of Floors | Observed Level of Damage | | | | |
|---|---|---|---|---|---|
| | Damage Free | Mild | Medium | Heavy/Landslide | Total |
| 3 | 18 | 62 | 29 | 15 | 124 |
| 4 | 17 | 43 | 60 | 27 | 147 |
| 5 and 6 | 18 | 30 | 60 | 75 | 183 |
| Total | 53 | 135 | 149 | 117 | 454 |

Table 5. Number of floors in Kadıkoy, Maltepe and Prince Islands

| | Number of floors | | | | | |
|---|---|---|---|---|---|---|
| Sub-provinces | 1 | 2 | 3 | 4 | 5 | >=6 |
| Kadıkoy | 6422 | 4458 | 4338 | 5629 | 4515 | 9077 |
| Maltepe | 5924 | 4057 | 3523 | 3711 | 3364 | 2631 |
| Adalar | 946 | 1361 | 1650 | 614 | 92 | 3 |
| Total | 13292 | 9876 | 9511 | 9954 | 7971 | 11711 |

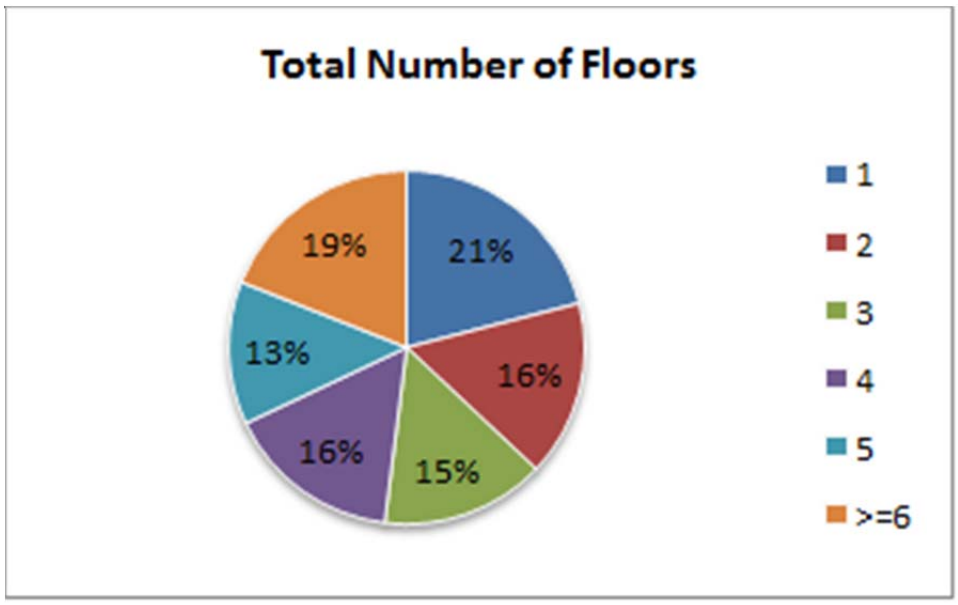


Figure 5. Distribution of number of floors in buildings in Kadıköy, Maltepe and Prince Islands

*Fuzzy Logic Model Application*

Matlab Fuzz Logic Toolbox was used for earthquake vulnerability analysis. A model has been formed according to the Mamdani type inference used commonly in fuzzy logic. The determined parameters/attributes define the input variables to be used in fuzzy logic analysis. Four attributes, in other words, input variable has been used in the application.

The input variables/parameters were formed by the distance to fault line, structure of soil structure of building and number of floors. The numerical values have been assigned to linguistic attributes such as the structure of building and soil in this database. Other parameters have been transferred to the model as defined distance to fault line in km unit and the number of floor has been transferred as it has already been determined. The input and model parameters have been given in Table 6.

It has been determined how many membership functions to be used by considering input ranges in order to determine the membership functions of each four input parameters by opening FIS editor window typing "fuzzy" command on Matlab command line and the functions have been assigned. Triangle or gauss membership functions have been used according to the feature of data in this study. The rules have been formed after assigning membership functions for output variable. Defuzzification method to be used for fuzzy logic system has been chosen as the centroid of area. The membership functions formed for input and output units are given in Figure 6.

Total of 39 rules have been determined. The rules are used in equal proportion. Some of the rules are given below:

- If (FLOOR is LOW) and (SOIL is STRONG) and (CONSTRUCTION is WOODEN) and (FAULT is FAR) then (VULNERABILITY is LOW)
- If (FLOOR is LOW) and (SOIL is MODERATE) and (CONSTRUCTION is WOODEN) and (FAULT is FAR) then (VULNERABILITY is MEDIUM)
- If (FLOOR is HIGH) and (SOIL is WEAK) and (CONSTRUCTION is CONCRETE) and (FAULT is CLOSE) then (VULNERABILITY is HIGH)

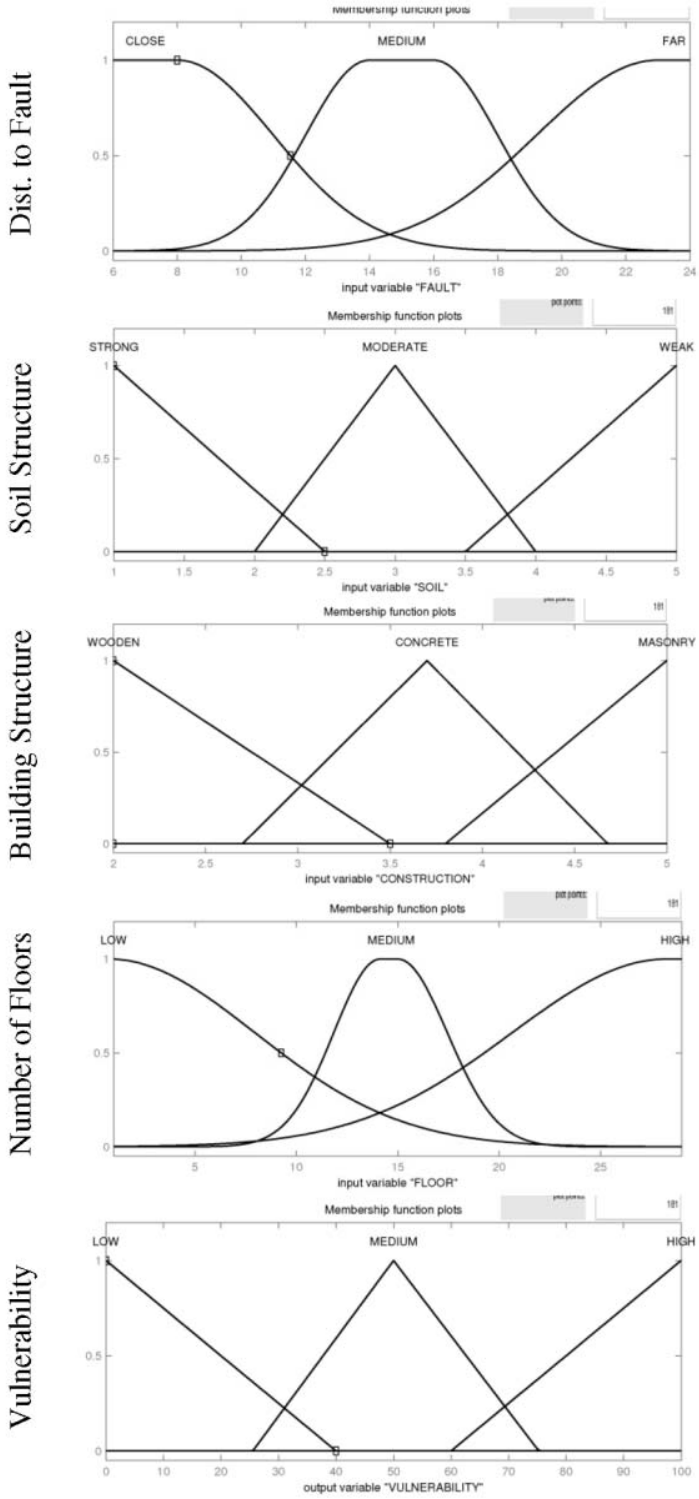


Figure 6. The membership functions formed for input and output units

**Results**

The membership functions and rule relations belonging to input and output variables have been examined on graphic. It is seen that the vulnerability risk ratio is increased in the areas where the fault line distance is reduced and the number of floors increase (Figure 7).

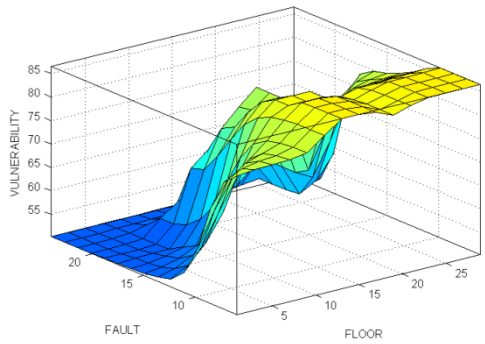


Figure 7. Vulnerability depends on distance to fault and number of floors

In created fuzzy logic model, the defuzzification values have been evaluated in the range of 0-50 in low risk values, 50-65 in moderate risk and 65-100 in high risk values. 17313 buildings out of 62315 have been determined as high risk, 35555 of them moderate risk and 9447 of them low risk in the study field as a result of vulnerability analysis. And this is the precursor of a desperate situation, loss of lives and damage to occur in case of any possible high magnitude earthquake.

As a result of the analysis, it has been determined that 28% of buildings are high risk, 57% of buildings are moderate risk and 15% of them are low risk in mentioned three sub-provinces (Figure 8).

Table 7 and Figure 9 show the earthquake vulnerability grades of the buildings in Kadıköy, Maltepe and Prince Islands

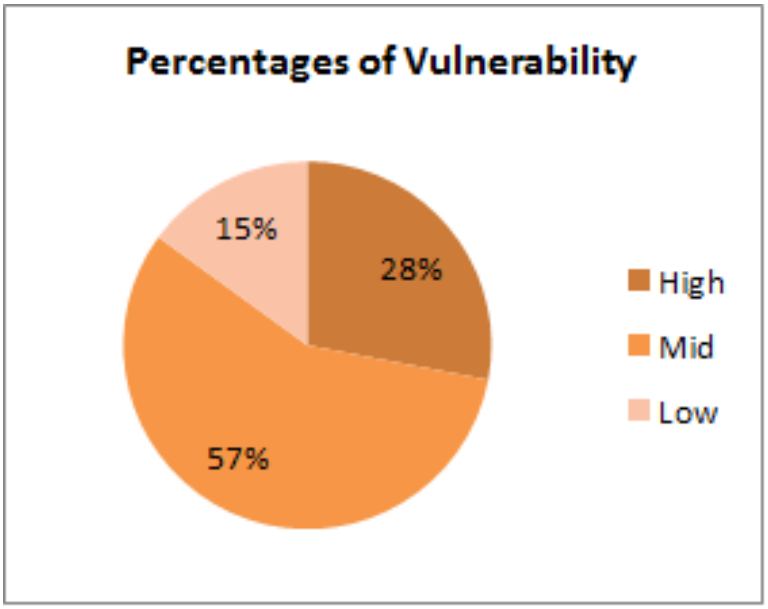


Figure 8. Distribution of vulnerability of the structures in Kadıköy, Maltepe and Prince Islands

Table 6. Input variants and fuzzy logic parameters.

| | | | Fuzzy Logic Parameters | | | | |
|---|---|---|---|---|---|---|---|
| | | **GIS Value** | **Range** | **Membership function (MF)** | **MF1** | **MF2** | **MF3** |
| **INPUT** | **Distance to Fault Line** | Unit: km | [6, 24] | gauss2mf | Close [3.79 23 2.45 24.5] | Medium [2 14 2 16] | Far [2 5.5 3 8] |
| | **Structure of Soil** | Area convenient to settlement: 1<br>Precaution Area: 3<br>Area Requiring a Detailed Geologic Study :5 | [1, 5] | trimf | Strong [0 1 2.5] | Moderate [2 3 4] | Weak [3.5 5 6] |
| | **Structure of Building** | Wooden:3<br>Reinforced concrete :4<br>Masonry: 5 | [2, 5] | trimf | Wooden [2 2 3.5] | Concrete [2.7 3.7 4.679] | Masonry [3.8 5 6] |
| | **Number of Floor** | [1, 29] | [1, 29] | gauss2mf | Low [4.01 - 2.11 7.227 0.7407] | Medium [2.306 14.15 2.45 15] | High [7.662 28.3 3.98 31.2] |
| **OUTPUT** | **Vulnerability** | [0, 100] | [0, 100] | trimf | Low [-40 0 40] | Medium [25.5 50 75.26] | High [60 100 140] |

Table 7. Vulnerability grades of buildings in Kadıköy, Maltepe and Prince Islands.

| | **Vulnerability** | | | |
|---|---|---|---|---|
| **District** | **Low** "vuln" < 50 | **Medium** " vuln " >= 50 AND " vuln " <65 | **High** "vuln" >= 65 | **Total** |
| Kadıkoy | 8988 | 18753 | 6698 | 34439 |
| Maltepe | 459 | 16445 | 6306 | 23210 |
| Adalar | 0 | 357 | 4309 | 4666 |
| Total | 9447 | 35555 | 17313 | 62315 |

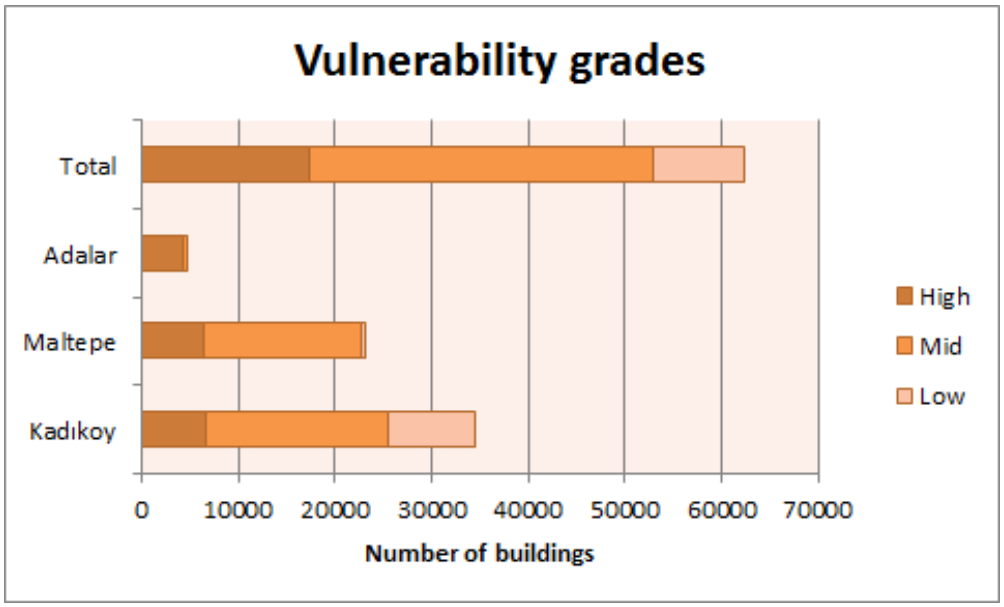


Figure 9. Vulnerability grades of buildings in Kadıköy, Maltepe and Prince Islands.

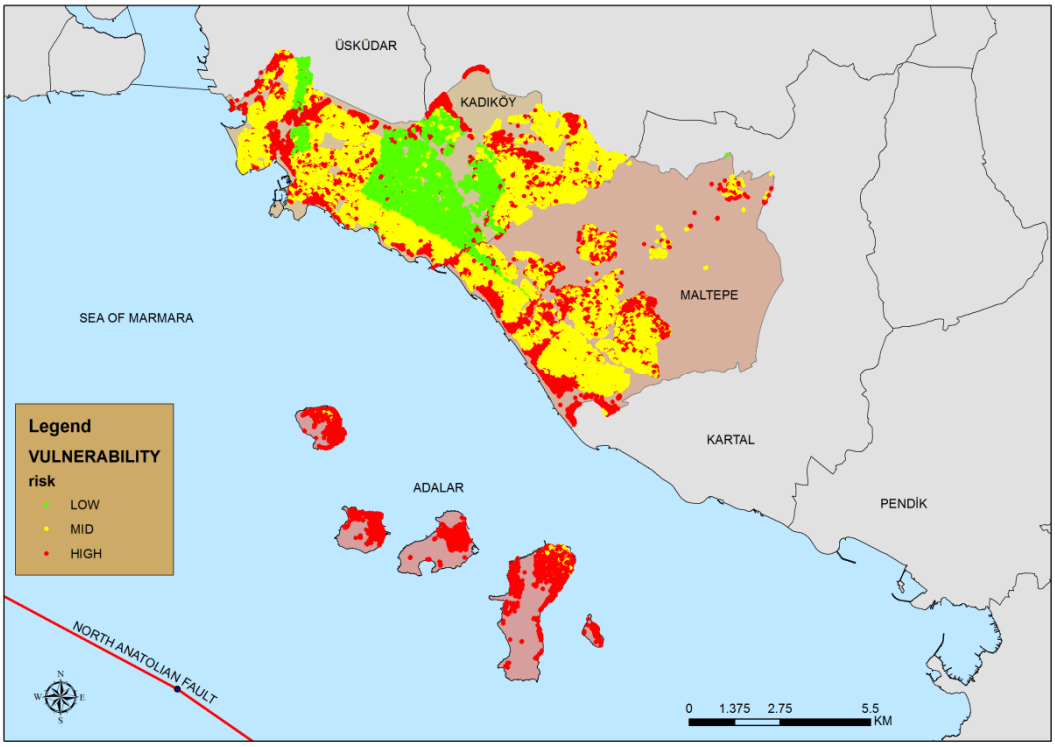


Figure 10. The earthquake vulnerability risk map in Kadıköy, Maltepe and Prince Islands.

The earthquake vulnerability grades emerged as a result of analysis have been studied and the distribution of buildings according to those levels have been presented via a thematic map (Figure 10).

**Discussion and Conclusion**

An earthquake vulnerability analysis of Kadikoy, Maltepe and Prince Islands sub-provinces for a possible earthquake has been made with the data obtained through fuzzy logic method. The distribution of defined effective factors in the place was revealed in GIS environment and the effective factors have been analyzed in terms of their interrelations by being handled by fuzzy logic method in the study. Experimental studies have been done in the parts related to the set of rules in order that mathematical model in fuzzy logic method gives better and near true results. As the distance to fault lines, the structure of soil, structure of building and the number of floors in the border of provinces show difference values, it caused the difference in the distribution of vulnerability.

It creates a significant issue that the areas are opened to settlement without realizing required soil studies and deprived from planning as Kadikoy, Maltepe and Prince Islands are very close to active fault lines and take place in 1$^{st}$ earthquake region and the earthquake always causes a great menace in the region. It should be remembered that the seismic waves are transmitted increasingly in the areas formed especially by loose alluvial soils. Correspondingly, these kinds of areas should not be opened to settlement unless it is really necessary, the opened areas should be discharged and micro zoning studies should be done according to the carrying capacity of soil and other features in the areas required to be opened and the number of floors should be determined accordingly.

Recommended fuzzy logic model will show more effective results with the supply of the data of other different factors such as the age of the building, amount of corrosion, the quality of construction, the post damages of the structure,

repairs of the structure and additional loadings of the structure in earthquake risk analysis.

**Acknowledgements**

The author wish to thank to Prof. Dr. Uğur Doğan (Yıldız Technical University, Geomatic Engineering Department) for the valuable comments and Istanbul Metropolitan Municipality for the database.

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