



This discussion paper is/has been under review for the journal Natural Hazards and Earth System Sciences (NHES). Please refer to the corresponding final paper in NHES if available.

Post-earthquake ignition vulnerability assessment of Küçükçekmece District

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Received: 6 February 2013 – Accepted: 21 April 2013 – Published: 17 May 2013

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Published by Copernicus Publications on behalf of the European Geosciences Union.

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Abstract

In this study, a Geographic Information System (GIS) based model was developed to calculate the post-earthquake ignition probability of a building, considering damage to the building's interior gas and electrical distribution system and the overturning of appliances. In order to make our model more reliable and realistic, a weighting factor was used to define the possible existence of each appliance or other contents in the given occupancy. A questionnaire was prepared to weigh the relevance of the different components of post-earthquake ignitions using Analytical Hierarchy Process (AHP). The questionnaire was evaluated by researchers who were experienced in earthquake engineering and post earthquake fires. The developed model was implemented to HAZ-TURK (Hazards Turkey) earthquake loss assessment software, as developed by Mid-America Earthquake Center with the help of Istanbul Technical University. The developed post-earthquake ignition tool was applied to Küçükçekmece, Istanbul in Turkey. The results were evaluated according to structure types, occupancy types, the number of storeys, building codes and specified districts. The evaluated results support the theory that post-earthquake ignition probability is inversely proportional to the number of storeys and the construction year, depending upon the building code.

1 Introduction

Fires following earthquakes (FFE) can induce destructive damage. Damage caused by FFE can sometimes exceed the loss from direct damage caused by the earthquake. Many factors affect the intensity of FFE, such as the ignition sources, the types and density of fuel, weather conditions, the operation of water systems and the ability of fire fighters to suppress the fires (HAZUS, 1999).

Earthquakes not only cause damage by shaking, but secondary disasters like fires following earthquake, tsunami, liquefaction, land slide etc. also cause large-scale losses (Hosseini et al., 2009; Watabe et al., 1994). In some cases, fires following

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earthquakes result in more losses than shaking, as shown in the 1906 San Francisco earthquake and the 1923 Kanto earthquake. Fire following earthquake is the only issue investigated in this study.

Post-earthquake urban fires are generally caused by strong ground shaking. Strong shaking damages the structures and lifelines of cities, such as water, electrical and gas systems. Heavy damage to the electrical and gas systems can result in leakage which can cause many simultaneous fire ignitions. Moreover, many ignitions also occur due to the overturning of electrical appliances, heating equipment or flammable materials within structures. In addition to inner structure ignitions, damaged infrastructure elements, such as gas mains and pipelines, as well as damaged electrical transmission lines, can also cause ignitions. Some of these ignitions are put out by occupants and they do not induce much more damage. Some of them spread due to the amount of fuel available (combustible materials), the actual construction material, water capacity, firefighting capabilities, an inadequate number of firebreaks, the direction and speed of wind, any of which can turn these ignitions into large urban conflagrations. All of these effects can cause many destroyed buildings, numerous deaths and injuries, along with enormous economic losses.

Furthermore, firefighting activities are also a significant factor which can directly influence the spread of fire. The more a fire department's response is delayed, the further a fire can spread. Fire departments often have difficulties in reaching a fire when acting in response to a call after an earthquake, due to narrowed streets, closed roads, collapsed buildings, damage to their fire stations and injuries to firefighters, etc.

During firefighting activities, firefighters need highly pressured water and chemical materials to extinguish a fire. Strong earthquakes damage water mains and pipelines. Water systems frequently sustain many breaks and this can result in a reduction in water pressure that can cause difficulties for the firefighters.

Strong earthquakes also damage the communication systems in the affected area. Communication systems play an important role in fire response. Dispatching

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firefighters to different fires from a central fire department prevents all of them from responding to the same fire and allows for time saving.

The most common FFEs are caused by the restoration of an electricity supply in red tagged buildings which are unsafe, where nobody is allowed to enter. If there is a gas leak in the building, it will be ignited by the restoring of electrical power.

As mentioned before, some FFEs can cause much more damage than the earthquakes themselves, as shown in the 1906 San Francisco and the 1923 Kanto earthquakes. Most of the fires following the 1906 San Francisco earthquake occurred because of several ruptures in gas mains and pipelines. Scawthorn et al. (2006) stated that post-earthquake ignitions led to large urban conflagrations because of highly flammable construction, inadequate fire protection and an inadequate water supply in the 1906 San Francisco earthquake. In the 1923 Kanto earthquake, 277 fires occurred because of small charcoal braziers which were widely used for cooking at lunchtime (Scawthorn et al., 2005).

Within the scope of this study, a probabilistic post-earthquake ignition model was developed. This post-earthquake ignition model has been developed to estimate the ignition probabilities of structures by considering real sources. This paper represents the application of this model in Küçükçekmece District of Istanbul, Turkey.

2 Background

Researches on urban fire spread started in the 1950s because of large urban conflagrations caused by fire bombing during World War II (Martin, 2004). Hamada expressed the importance of FFE after the 1948 Fukui earthquake and subsequent major conflagrations within the affected areas (US Army, 1949). The first model was developed by Hamada and consists of a set of equations that estimate urban fire spread using fuel load, wind speed and other factors as its input parameters (Hamada, 1951). After this model was developed, some Japanese scientists continued to study this topic in the

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1970s (Horiuchi et al., 1974; Mizuno and Horiuchi, 1976; Mizuno, 1978; Lee et al., 2008).

In contrast, there were no studies about FFE in the United States until Steinbrugge (1968) mentioned the FFE problem in the San Francisco Bay Area and collected data about it (Steinbrugge, 1971). There were also no FFE models, but just several researchers who collected data and started defining the FFE problem (Oppenheim, 1984). Scawthorn developed the first integrated FFE model that includes post-earthquake ignitions, their spread and fire department responses in the late 1970s and early 1980s. This model was first applied in Japan (Scawthorn et al., 1981) and later applied in California (Scawthorn, 1986). This model was used as a source for the insurance industry and other modeling approaches for a long time (Lee et al., 2008).

Many scientists used their research to estimate the number of post-earthquake ignitions and they developed different models. Most of these models depended on ground motion. There have been some studies about multi-parameter ignition models in the last couple of years. Kawasumi developed an equation by using logarithmic regression analysis (Kawasumi, 1961; Kobayashi, 1984; Aoki, 1990; Scawthorn et al., 2005; Zhao et al., 2006). He only used data from the 1923 Kanto earthquake and showed a positive correlation between the rate of ignitions and the rate of collapsed wooden buildings. Mizuno developed an equation to estimate post-earthquake ignitions (Mizuno, 1978; Kobayashi, 1984; Aoki, 1990; Zhao et al., 2006) by proving a logarithmic regression relationship between the rate of ignitions per household and the rate of totally collapsed households. An ignition model developed by Li et al. (2001) estimated possible ignitions in a specific zone with a certain level of probability. The model assumes that post-earthquake ignitions are in a Poisson distribution in time and place. The model calculates the incidence of ignitions according to the area of buildings with moderate damage and above. A second order equation was developed by modifying the ignition model developed by Scawthorn (1987) in order to use for HAZUS (Hazard US) software. The new data points, representing the ignitions from the 1989 Loma Prieta earthquake, were taken into account; the ignition per single family equivalent dwelling

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(SFED) unit was changed to ignitions per 1 000 000 square feet of structure inventory and the MMI (Modified Mercalli Intensity) scale was converted to PGA (Peak Ground Acceleration) scale (HAZUS, 1999). Scawthorn updated this equation by taking seven earthquakes (1971 San Fernando, 1983 Coalinga, 1984 Morgan Hill, 1986 N. Palm Springs, 1987 Whittier Narrows, 1989 Loma Prieta, 1994 Northridge) into consideration. 238 data points were used in the regression equation. The number of ignitions per 92903.04 m² total floor area due to PGA is calculated by using Eq. (1) (Scawthorn, 2009).

$$\text{Ignitions} = \left(0.581895 \text{PGA}^2\right) - (0.029444 \text{PGA}) . \quad (1)$$

The URAMP software (Utilities Regional Assessment of Mitigation Priorities) estimates the post-earthquake ignition rate according to PGA or MMI for different types of building occupancy (residential, commercial and industrial) separately (Scawthorn et al., 2005). Ignition locations are determined randomly (Seligson et al., 2003). Cousins and Smith (2004) assumed that there is a linear relationship between the mean number of ignitions per millions of m² of floor area and the shaking intensity (MMI). Ren and Xie (2004) modified the ignition equation of HAZUS by taking into account the post-earthquake fires that occurred in USA, Japan and China, between 1900 and 1996. They produced a new second-order relationship between the number of ignitions and PGA. Davidson (2009) developed two different models for two different data sets to estimate the number of ignitions per census tract, by using negative binomial regression models. Two data sets were developed to explore the possible effect of missing ignition data. Zolfaghari et al. (2009) estimated the ignition probability of a building with an analytical approach. Three ignition sources are considered, depending on ground motion and structural damage. Building utility damage, damaged braced non-structural equipment and the overturning of braced equipment or contents are three main components of the model.

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3 Post-earthquake ignition and a probabilistic approach for post-earthquake ignition modeling

Post-earthquake ignitions occur as a result of building damage caused by strong earthquakes. Internal gas pipes and electrical distribution systems suffer damage because of the strong shaking and this can result in a leakage of gas and sparking from the electrical distribution system. Appliances containing a fuel source, an electrical mechanism or bare flames within dwellings can also cause ignitions. Leakage from an internal gas system or the spilling of flammable materials from the overturning of appliances can be ignited by overturned electrical appliances, wiring failures in electrical distribution systems or bare flames. Shelves containing flammable materials, parked automobiles under buildings and structures containing chemical materials, like universities, are also ignition sources. Each of these sources has an influence on ignition occurrence. These sources should be modeled to estimate potential post-earthquake ignitions.

In this study, the probability of a post-earthquake ignition is estimated by considering the damage caused to a building's internal gas and electrical distribution systems, and the overturning of appliances. The developed model was implemented by HAZTURK (MAEViz) earthquake loss assessment software, developed by Mid-America Earthquake Center with the help of Istanbul Technical University.

The model consists of three main components; utility systems, hazardous appliances and contents, and less hazardous appliances and contents, covering the different sources of post-earthquake ignitions as shown in Fig. 1.

3.1 Utility related post-earthquake ignition probability

Ignitions that are caused by damage to utility systems include damage to interior gas and electrical distribution systems. Ignition probability caused by a damaged utility system is calculated in relation to building damage from a specific ground motion. The approach of Peyghaleh (2006) was adopted to calculate utility related ignition probability in the model. Building damage was created by using HAZTURK (MAEViz) software for

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a specific earthquake scenario. Utility related ignition probability is calculated with four different damage states; insignificant, moderate, heavy and complete, obtained from a building damage analysis executed with HAZTURK (MAEViz). A building damage file produced by different software can also be used when importing this file into HAZTURK (MAEViz). A mapping operation is necessary to link the attributes of an input file with the required attributes for the model. The occurrence of ignition was defined by using an event tree in Fig. 2.

Structural damage triggers pipeline and wiring damage. This pipeline and wiring damage can result in gas leakage and electrical sparks. Finally, an ignition is caused by combination of these gas leakage and electrical sparks. Ignition probability is calculated by using Eq. (2) (Zolfaghari et al., 2009), where OS is other sources, ECG is electrical short circuit given, SD is structural damage, WDG is wiring damage given structural damage, GLG is gas leakage given pipeline damage, PDG is pipeline damage given structural damage and FC is existence of other flammable contents.

$$P(\text{Ig}) = (P(\text{OS}) + P(\text{ECG}) \times P(\text{SD}) \times P(\text{WDG})) \times (P(\text{GLG}) \times P(\text{SD}) \times P(\text{PDG}) + P(\text{FC})). \quad (2)$$

3.2 Appliances and contents related post-earthquake ignition probability

For hazardous and less hazardous appliances and contents, ignitions are caused by the overturning of appliances and the falling of flammable materials from shelves because of visible acceleration. Overturned appliances and fallen contents, including flammable material and appliances exposed to a live electrical current or bare flame, can produce ignitions. The probability of the overturning of appliances can be estimated by modeling the motion of the appliance due to acceleration.

The probability of ignition from appliances and other contents is obtained by using the methodology of Luis Esteva and his team from the Institute of Engineering at the National University of Mexico. According to Reinoso et al. (2010), the overturning of contents occurs when the horizontal acceleration exceeds the critical acceleration level

defined for each object, based on its size and shape. Recorded ground motions from 21 different earthquakes were used to obtain the minimum PGA value needed to produce overturning for each object. After a value of the failure intensity is obtained for each ground motion time history, which is then adequately scaled, a sample will be available and a function $F_{YF}(y)$ may be fitted to it, representing the probability distribution function of the minimum value of the intensity required to produce overturning.

The overturning probability of each object is calculated by using log-normal functions depending on exposed PGA value for a particular building (Eq. 3). Overturning probabilities were calculated according to the mean and standard deviation of experimental results with respect to the exposed PGA value.

$$F_{YF}(y) = \Phi \left[\frac{1}{\sigma_{\ln Y_F}} \ln \left(\frac{y}{\check{m}_{Y_F}} \right) \right], \quad (3)$$

y is PGA value, Φ is the cumulative standard normal distribution of the logarithm of the sample of random values of Y_F , the minimum intensity required to produce overturning failure, σ is the standard deviation of the natural logarithm, and \check{m} is the median value. Figure 3 shows the overturning probability curves for hazardous appliances and less hazardous appliances (Reinoso et al., 2010).

The existence of an appliance depends on the type of occupancy of dwellings in a building. To assume all the same appliances and contents exist in all types of buildings is not a realistic approach. In order to make our model more reliable and realistic, a weighting factor is used to define the possibility of the existence of each appliance or object in a given type of occupancy.

Residential Energy Consumption Survey (RECS) and Commercial Buildings Energy Consumption Survey (CBECS) data from United States Energy Information Administration (USEIA) was used to produce probabilities for the existence of appliances. Then the existence probabilities of appliances and other contents, according to occupancy type, were calculated. HAZTURK (MAEViz) software is able to use this file in CSV (Comma Separated Value) format.

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Each component and sub component has a different level of significance in its contribution to post-earthquake ignition. The Analytical Hierarchy Process was used to weight the main and sub components. Figure 4 shows the structure of AHP for post-earthquake ignition. In Fig. 4, ignition probability of building is the aim, utility systems, hazardous and less hazardous appliances and contents and their sub-components are the criterias and building A, B and C are the alternatives.

AHP is a method of prioritizing different components in decision making. The method is based on a pairwise comparison of components. The importance of components is determined by creating a pairwise comparison matrix. Pairwise comparisons should be performed by experts in the subject. The comparisons are made using a scale of absolute judgements that represents how much more one element dominates another, with respect to a given attribute (Table 1).

A questionnaire was prepared to rank in order of significance the different components of post-earthquake ignitions. The questionnaire was evaluated by scientists who were experienced in earthquake engineering and post earthquake fires. 57 % of them were researchers in earthquake engineering departments and 43 % of them worked in geomatics engineering departments, having experience in disaster management. The results were evaluated to calculate the significance of all the main components and subcomponents. According to the questionnaires, the overall weights of the main components and their consistency ratios are given in Table 2. The weights of the main components and their consistency ratios with respect to two different disciplines are also given in Table 2 and this also denotes the dissidences between the different perceptions of post-earthquake ignition concept.

According to Table 2, while geomatics engineers consider the utility system as the most important component in post-earthquake ignition, earthquake engineers consider the most important to be hazardous appliances. However, both disciplines agreed on less hazardous appliances being the least important component.

4 Application

Turkey appears at top of the list of the most seismically active countries in the world. Parsons et al. (2000) and Parsons (2004) declared that the probability of a magnitude 7 earthquake from the Main Marmara fault is approximately 35–70 % within the next 30 yr, with an estimation of a rupture beneath the Sea of Marmara to the south of Istanbul. The seismic activity around the city of Istanbul also encouraged the researchers to develop advanced scientific models to estimate the possible losses during and following such an earthquake (Karaman et al., 2008).

There are 36 151 buildings in the Küçükçekmece database. Most of these are concrete frame buildings with unreinforced masonry infill walls. The number of buildings with respect to their structure types is given in Table 3. The building inventory is also given in a visual form in Fig. 5.

Most of the buildings were constructed between 1975 and 1997. The number of storeys was between 1 and 7 (Table 4).

0.2 s S_a (Spectral Acceleration) and PGA earthquake hazard maps (EHM) of the Küçükçekmece district in Figs. 6 and 7, respectively were obtained from Erden and Karaman's (2012) study on the Küçükçekmece region for a 7.5 moment magnitude earthquake scenario on the Main Marmara Fault. The attenuation function for the EHM of this study was from Boore and Atkinson (2007) which is a study from the Next Generation Attenuation Models of Pacific Earthquake Engineering Research (PEER) Center.

A building damage analysis was carried out to estimate damage probabilities for insignificant, moderate, heavy and complete damage states. Fragilities and building fragility mapping were taken from the Karaman et al. (2008), which were developed for the Istanbul building inventory, and were used to complete the earthquake damage analysis. The attributes of the aforementioned inventory were formatted to match the HAZTURK software's data requirements as shown in Table 5.

The earthquake damage analysis for the buildings was run with respect to four damage states; insignificant, moderate, heavy and complete. The damage states are

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defined inside the parametric fragility curves of Istanbul. The parameterized fragility method (PFM) used in this study were developed by Jeong and Elnashai (2007) and offered as an “efficient tool for rapidly deriving probabilistic fragility relationships with quantifiable levels of uncertainty and especially useful for practical application of analytical fragility curves to the planning of seismic rehabilitation, and regional earthquake mitigation where fast estimation of probabilities of reaching damage states for a large number of structural configurations and different mitigation measures are required” (Jeong and Elnashai, 2007).

With respect to fragility curves and EHM of the study region, the earthquake damage analysis for the buildings of Küçükçekmece District was run. The results of the analysis are given in Table 6 with reference to the structure types. Figure 8 envisages the building damage distribution of the region.

According to the results of the earthquake damage analysis for the buildings of Küçükçekmece District, the most vulnerable buildings are URM and PC1 buildings. Respectively, they have 44 % and 36 % overall collapse probability. When the results are evaluated according to the number of storeys of the buildings, 1-storey, 2-storey and 3-storey buildings are more vulnerable than the others. 1-storey buildings have a 40 % overall collapse probability. Another inference obtained from the results is that buildings constructed before 1975 are more vulnerable than buildings constructed after 1975, with their overall collapse probability being between 40 % and 50 %.

Post-earthquake ignition analysis was carried out, incorporating the building damage file, PGA distribution map and an appliance existence probability table. The required attributes for the building damage file are shown in Table 7. After the analysis, maximum ignition risk was determined as 46 % for buildings in Küçükçekmece.

The results of the analysis are given in Table 8 with reference to the structure types in the form of mean ignition probabilities caused by utility systems (P_{US}), hazardous and less hazardous appliances (P_{HA} and P_{LHA}) and overall ignition probabilities (P_{ig}) respectively. Figure 9 visualizes the distribution of post-earthquake ignition probability for the region.

5 Results and conclusions

According to the results of post-earthquake ignition analysis for Küçükçekmece District, the most vulnerable buildings are URM and PC1 buildings. They have a 39 % overall collapse probability. When the results are evaluated according to the number of storeys of buildings, 1-storey, 2-storey and 3-storey buildings are more vulnerable than the others. 1-storey buildings have a 37 % overall collapse probability. Industrial buildings in the study region are more vulnerable to post-earthquake ignition than the other buildings. They also have a 37 % overall ignition probability.

Another inference obtained from the results is that buildings constructed before 1975 are more vulnerable than buildings constructed after 1975. The overall ignition probabilities of these buildings are between 37 % and 44 %. This demonstrates that collapsed buildings have a significant post-earthquake ignition risk.

When the results are evaluated based on the sub-districts, the most vulnerable regions are Yenimahalle and Yeşilova. Both districts have a 38 % overall ignition probability. Cennet and Cumhuriyet districts also have a post-earthquake ignition risk, with a 37 % and 36 % ignition probability, respectively.

The number of wooden buildings is also important from the aspect of fire-spread. Wooden buildings that are exposed to intense shaking are seriously dangerous when the fire spread potential of these types of buildings is considered. The spread of fire in wooden buildings is faster than other types of structure. This puts people in wooden buildings under a noteworthy risk. Wooden buildings have a 27 % overall ignition probability and some of them have critical ignition probabilities. When the results of the analysis are examined, it is clear that post-earthquake ignition probability is inversely proportional to the number of storeys and construction year, depending on the building code. The results of the analyses given in Table 9 indicate that building damage and an exposed PGA value are of great significance in post-earthquake ignitions.

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The distribution of mean building damage, PGA, and ignition probability are compared on a chart, based on their assessment results. According to the comparison, PGA and mean building damage values showed a close correlation with the ignition probability in the aspect of the trendline as seen on Fig. 10.

As future improvements, seasonal atmospheric conditions, use of appliances with respect to the seasons, spread of the ignited fire to the neighbouring buildings are also planned to be added to the system in the future studies.

Acknowledgements. Authors acknowledge Amr S. Elnashai from University of Illinois at Urbana-Champaign for his vision and contribution.

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Table 1. The fundamental scale of absolute numbers in AHP (Saaty, 2008).

Intensity of Importance	Definition
1	Equal importance
2	Slight importance
3	Moderate importance
4	Moderate plus importance
5	Strong importance
6	Strong plus importance
7	Very strong or demonstrated importance
8	Very, very strong importance
9	Extreme importance

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Table 2. Weights for the main components of post-earthquake ignition.

Name	Overall Weights	Weights (Earthquake Engineers)	Weights (Geomatics Engineers)
Utility System	0.51588	0.39492	0.66098
Hazardous Appliances	0.38378	0.51128	0.23833
Less Hazardous Appliances	0.10034	0.09380	0.10069
Consistency Ratios	0.00094	0.00661	0.03263

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Table 3. Number and structure types of buildings.

Structure Type	Definition	Number of Buildings
C3	Concrete Frame With Unreinforced Masonry Infill Walls	30 151
PC1	Precast Concrete Tilt-up Walls	75
RM	Reinforced Masonry	369
URM	Unreinforced Masonry Bearing Walls	5534
W1	Wood, Light Frame	22

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Table 4. Number of buildings according to number of storeys.

Number of Storeys	Number of Buildings	Percentage
1	5108	0.141
2	5099	0.141
3	6651	0.184
4	7547	0.209
5	5775	0.160
6	3786	0.105
7	2185	0.060

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Table 5. Required attributes in building inventory data.

Attribute	Definition	Data Type
Struct_Type	General structure type of the building	String (Text)
Occ_Type	Broad HAZUS Occupancy Category	String (Text)
No_Stories	Total number of storeys for the building	Integer
Year_Built	The year the structure was built	Integer

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**Post-earthquake
ignition assessment**S. S. Yildiz and
H. Karaman**Table 6.** Results of earthquake damage analysis for the buildings for different damage states with respect to structure types.

Structure Type	Insignificant (%)	Moderate (%)	Heavy (%)	Complete (%)	Mean Damage (%)
C3	0.11	0.30	0.33	0.26	0.46
PC1	0.08	0.22	0.35	0.36	0.55
RM1	0.12	0.23	0.37	0.28	0.49
URM	0.09	0.20	0.27	0.44	0.58
W1	0.18	0.43	0.23	0.11	0.29

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Table 7. Required attributes in building damage data.

Attribute	Data Type
Occ_Type	String (Text)
Insignificant	Double
Moderate	Double
Heavy	Double
Complete	Double

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Table 8. Results of post-earthquake ignition analysis for the buildings.

Structure Type	P_{US} (%)	P_{HA} (%)	P_{LHA} (%)	P_{ig} (%)
C3	0.27	0.36	0.50	0.33
PC1	0.35	0.40	0.53	0.39
RM1	0.30	0.39	0.52	0.36
URM	0.36	0.39	0.51	0.39
W1	0.18	0.33	0.50	0.27

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Table 9. Distribution of ignition probability with respect to building damage and PGA values.

Structure Type	Mean Building Damage (%)	PGA (g)	P_{ig} (%)
C3 (min)	0.37	0.41	0.22
C3 (mean)	0.46	0.56	0.33
C3 (max)	0.59	0.61	0.44
PC1(min)	0.54	0.44	0.30
PC1(mean)	0.55	0.59	0.39
PC1(max)	0.62	0.68	0.45
RM (min)	0.30	0.50	0.25
RM (mean)	0.49	0.59	0.36
RM (max)	0.55	0.68	0.42
URM (min)	0.47	0.43	0.26
URM (mean)	0.58	0.57	0.39
URM (max)	0.63	0.68	0.46
W1 (min)	0.26	0.51	0.24
W1 (mean)	0.29	0.55	0.27
W1 (max)	0.41	0.62	0.34

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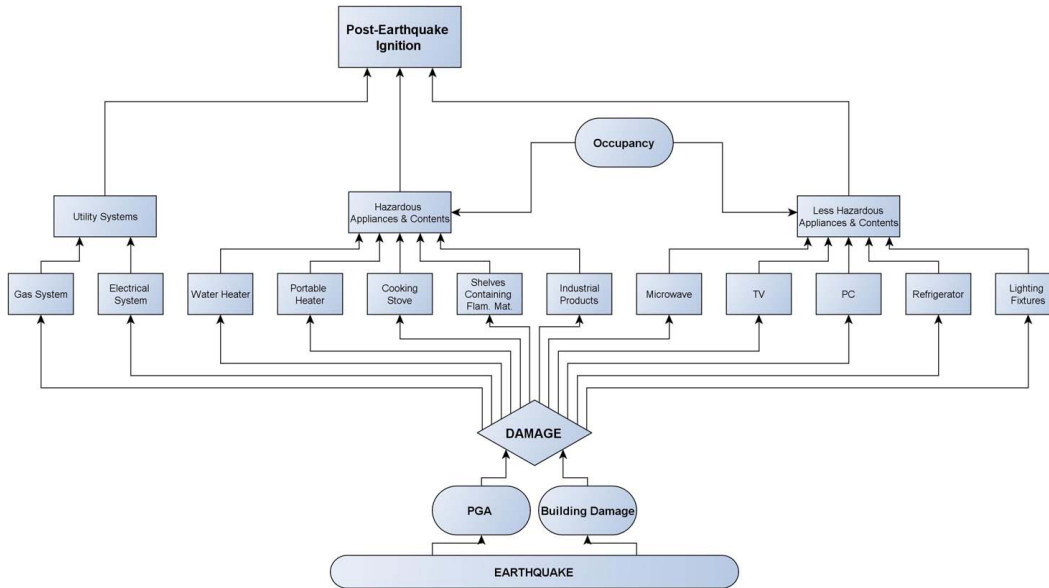


Fig. 1. Structure of post-earthquake ignition model.

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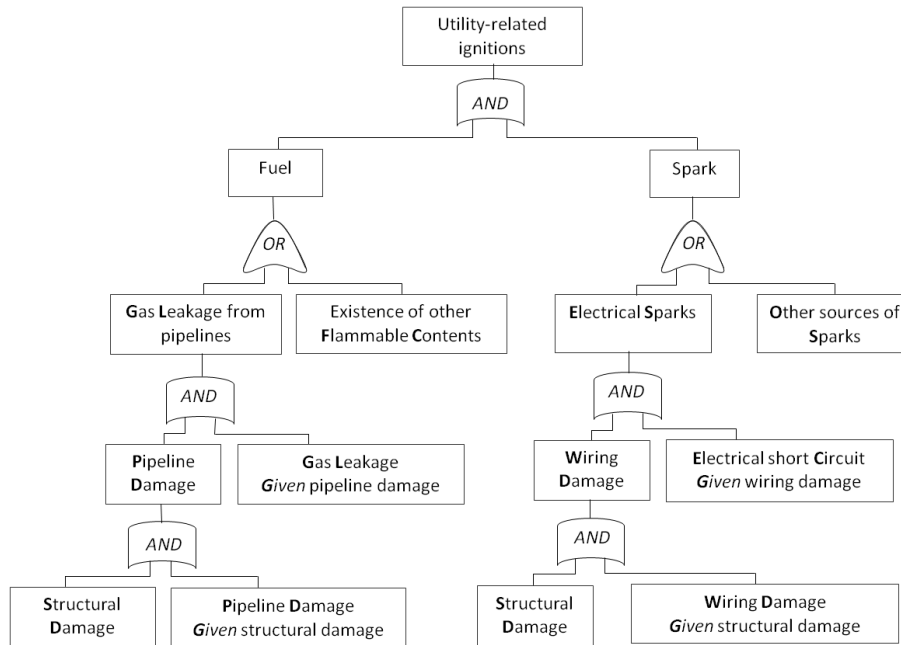


Fig. 2. Event tree of ignition probability caused by damaged utility systems (Peyghaleh, 2006).

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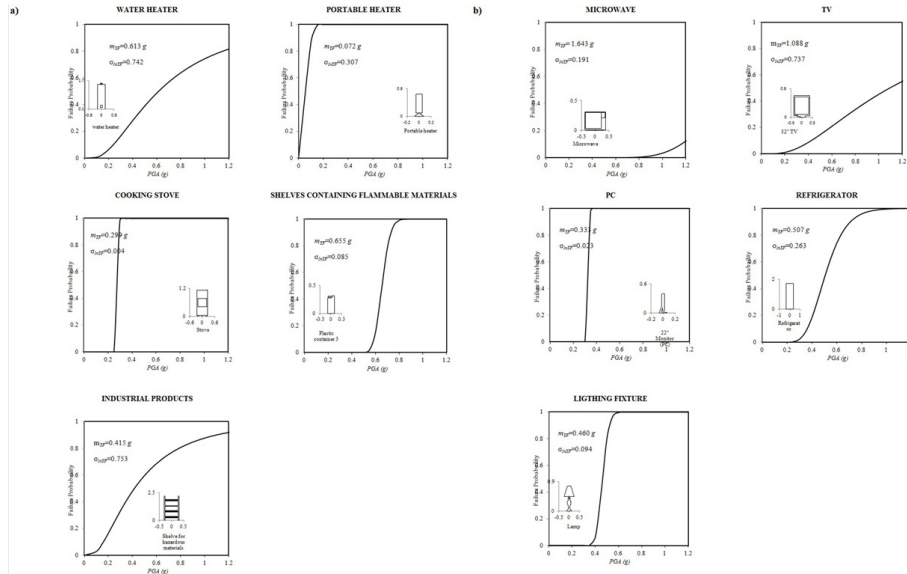


Fig. 3. Overturning probability for **(a)** hazardous appliances and **(b)** less hazardous appliances (Reinoso et al., 2010).

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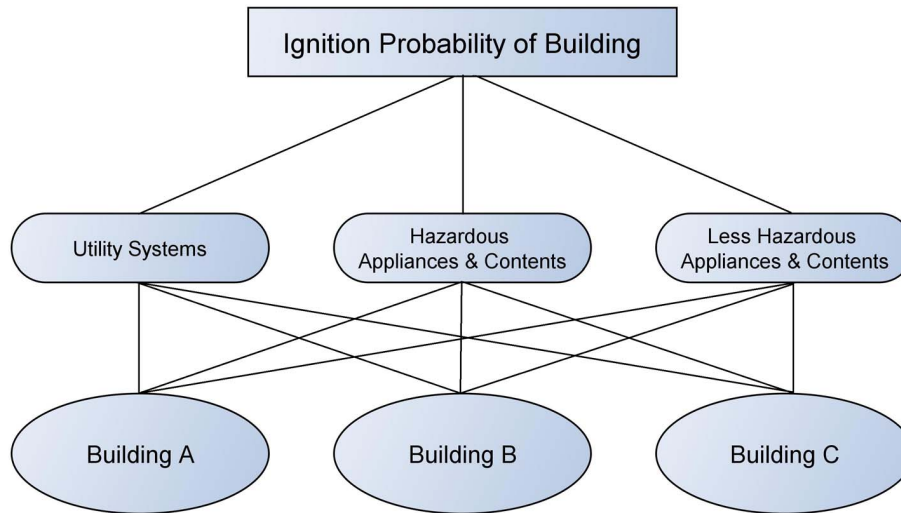


Fig. 4. Structure of AHP for post-earthquake ignition.

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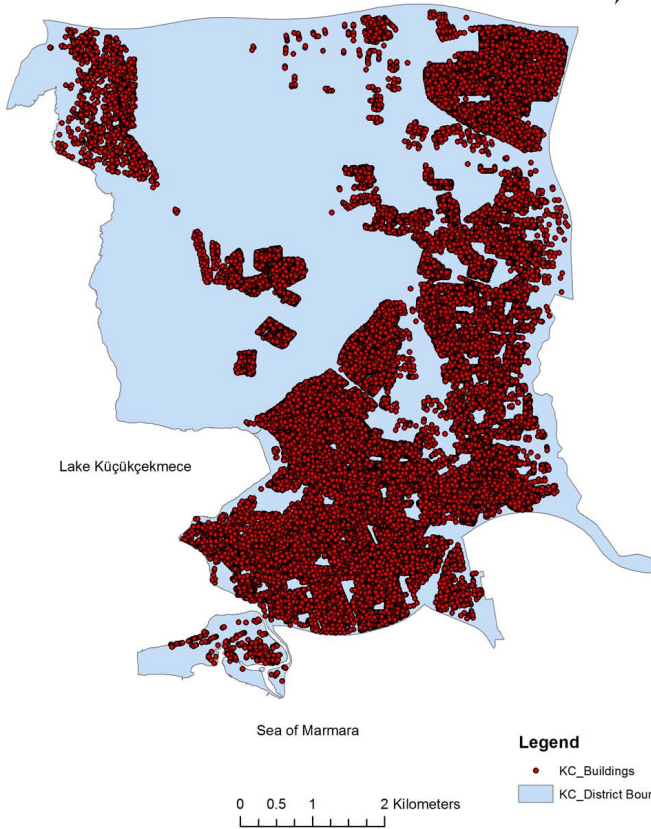
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Küçükçekmece Building Inventory



Legend

- KC_Buildings
- KC_District Boundary

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Fig. 5. Küçükçekmece building inventory.

Earthquake Hazard Map of Küçükçekmece District
by Boore & Atkinson (2007) for 7.5 Mw Earthquake

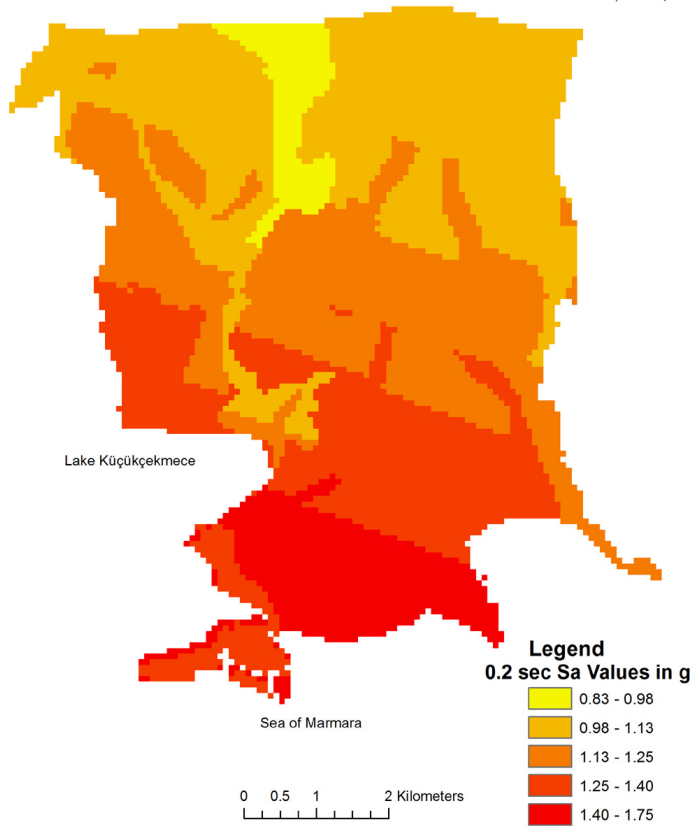


Fig. 6. 0.2 s S_a earthquake hazard map of Küçükçekmece district.

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Earthquake Hazard Map of Küçükçekmece District
by Boore & Atkinson (2007) for 7.5 Mw Earthquake

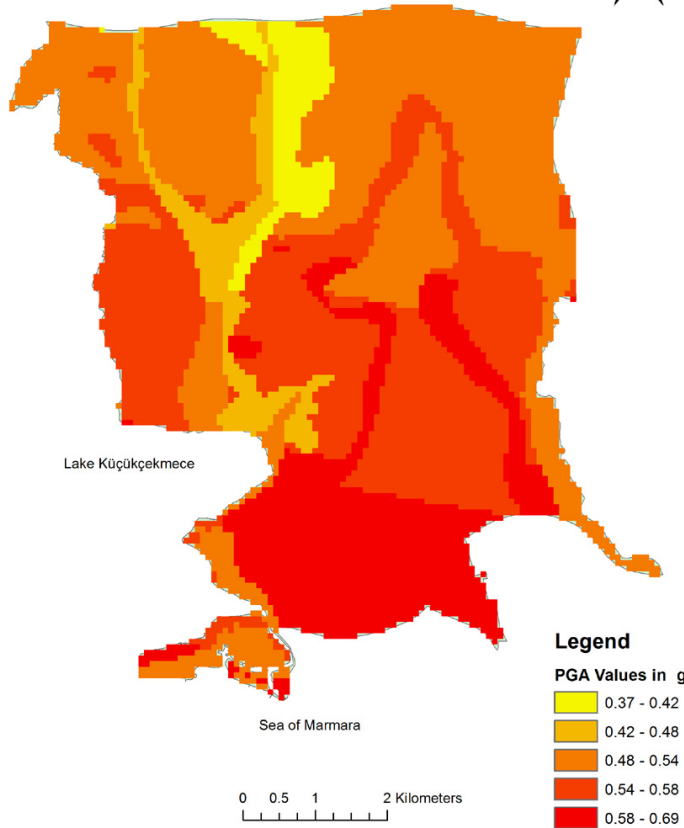


Fig. 7. PGA earthquake hazard map of Küçükçekmece district.

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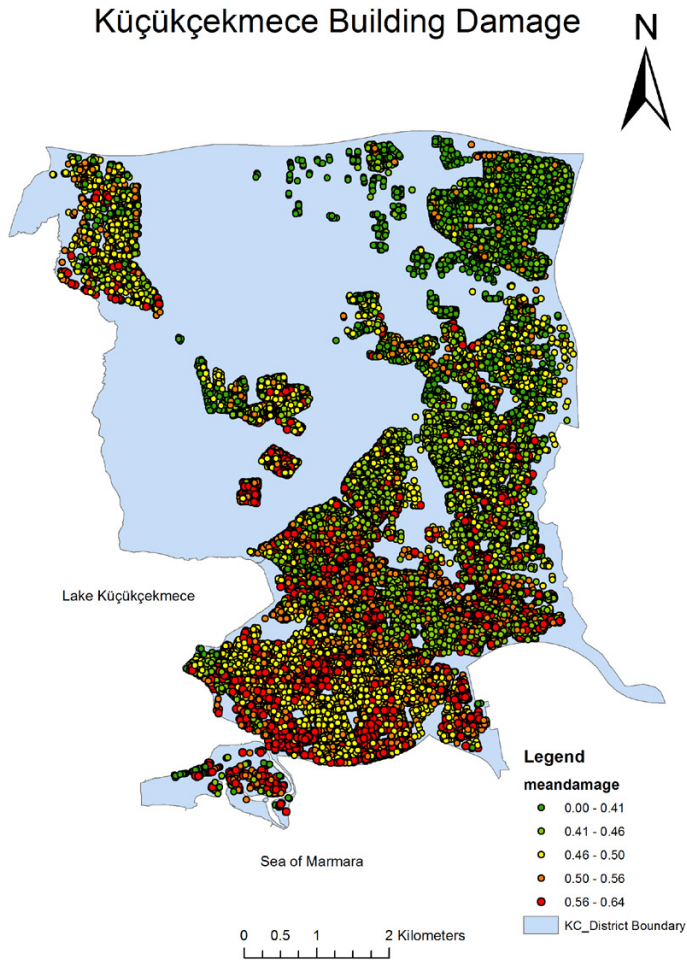


Fig. 8. Visualized results of earthquake damage analysis for the buildings.

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Küçükçekmece Buildings Post-Earthquake Ignitions

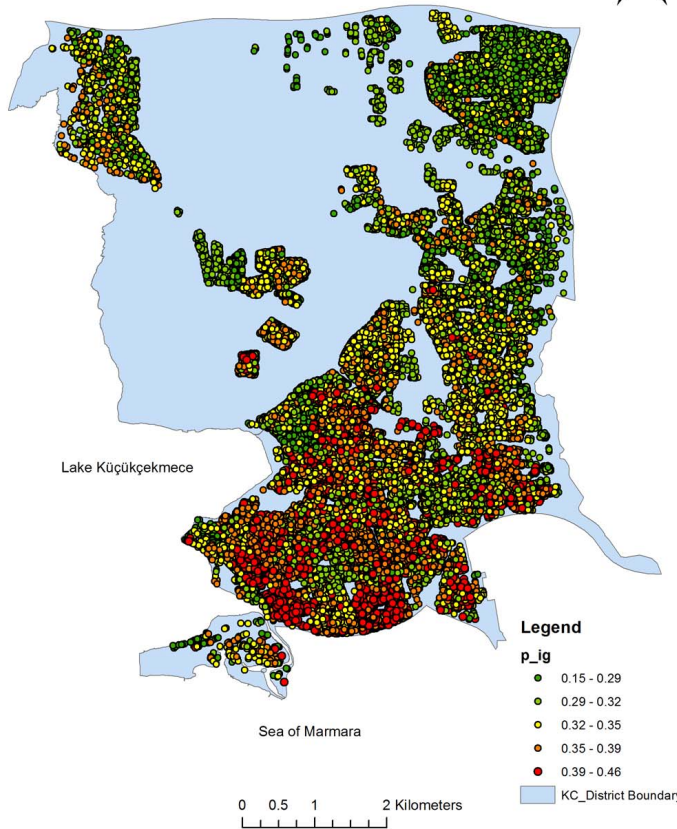


Fig. 9. Visualized results of post-earthquake ignition analysis.

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Fig. 10. Distribution of mean building damage, PGA, and ignition probability.

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