Determination of Road Functionality for Küçükçekmece District Following a Scenario Earthquake for Istanbul

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Abstract

Istanbul has been affected by earthquakes throughout its history. The most recent earthquake to shake Istanbul was on August 17 1999, along the North Anatolian Fault, 12 km southeast of the Izmit Province, with a magnitude of 7.4. Following the 1999 Izmit earthquake, the earthquake risk in Istanbul started to draw attention and many scientific studies were conducted on the potential earthquake risk in this city. Based on these studies, predictions are that Istanbul is going to face a major earthquake in the near future and this will cause severe damage to the built environment. It is estimated that the damage caused by the anticipated earthquake will be extensive as a consequence of Istanbul’s low quality building stock of Istanbul. The buildings that have the possibility of being damaged cause debris around them. If roadside buildings collapsed during the earthquake, the scattered parts of the buildings could cause roads to lose their functionality. Not only building damage but also transportation damage analysis is necessary to use risk mitigation studies and decisions, being that experiences showed that the functionality of transportation structure effects post-earthquake emergency response and recovery operation seriously. This study aims to reveal a method for road functionality in Küçükçekmece following a potential Istanbul Earthquake by using building collapse direction and bridge damage.

Keywords: Road functionality, bridge damage, building collapse, debris spreading distance, building damage, earthquake damage analysis, building age, building code, risk analysis, remote sensing

Introduction

Istanbul is very important city not only for Turkey but also for the world because of its geopolitics position and historical frame. It is located between Asian and European continental as a bridge. Besides that Istanbul has been affected by earthquakes throughout its history. Based on worldwide historical catalogues, Istanbul has suffered repeated damage due to earthquakes (Utsu 1990). When the historical earthquake data of Istanbul is analysed, we see that the city has been affected by a moderate intensity earthquake every fifty years and a high intensity earthquake every 300 year (Ambraseys and Finkel 1991). Several scientific studies have proven that the possibility of Istanbul facing a major earthquake in the near future is high (Ambraseys and Finkel 1991; Le Pichon et al. 2003; Parsons et al. 2000). It is estimated that the damage caused by the anticipated earthquake will be extensive as a consequence of Istanbul’s low quality building stock of Istanbul (Kaya and Gazioğlu, 2015; Karaman 2009).

In order to mitigate earthquake damage, many scientific studies has been made. “The Study on A Disaster Prevention / Mitigation Basic Plan in Istanbul including Seismic Microzonation in the Republic of Turkey” is one of the most important studies for Istanbul in a large scale in order to assess earthquake risk. Regarding this study, Küçükçekmece has the highest risk against to earthquake (Table 1) (JICA and IMM 2002). For this reason Küçükçekmece is chosen as a study area for this study.

Within the scope of this study, it was revealed the road functionality in Küçükçekmece following a potential Istanbul Earthquake by
using building collapse direction and bridge damage. Hence two steps are needed to determine the road blockage in Küçükçekmece. One is to determine road blockage due to building collapse direction. Firstly a recent, accurate building dataset in Küçükçekmece has been created, Then, building damage analysis were made for every single building in Küçükçekmece. In order to determine building collapse direction in Küçükçekmece, collapsed buildings in Gölcük during the 1999 Kocaeli earthquake was studied. Collapse distance have been obtained from Gölcük study and this result has been applied to the buildings in Küçükçekmece that have damage possibility.

The second step will then be determine the bridge damage and functionality after an earthquake. Because, non-functional bridges have cause roads to lose their accessibility. By combining these two data sets, the potential road blockage because of the earthquake in Küçükçekmece has been revealed (Figure 1).

Table 1. Building damage in Küçükçekmece

| District Name | Model | Total Building Number | Heavily number | % | Heavily + Moderately number | % | Heavily + Moderately + Partly number | % |
|---------------|-------|-----------------------|----------------|---|-----------------------------|---|-----------------------------------|---|
| Küçükçekmece  | A     | 45817                 | 4915           | 10.7 | 10325                      | 22.5 | 20642                           | 45.1 |
|               | C     | 45817                 | 4299           | 9.4 | 9219                        | 20.1 | 19.293                          | 42.1 |

Fig. 1. Steps of determination road blockage in this study

The estimation of possible building damage is very useful data to conduct risk reduction studies. There are several loss assessment tools existing worldwide in order to estimate building damage. However, most of them are proprietary, closed code, region-specific, or all above (Karaman et al. 2008b). The pioneer and the leader of these tools are HAZUS, which was developed by National Institute for Building Science (NIBS) and Federal Emergency Management Agency (FEMA) (Elnashai et al. 2008). Besides HAZUS, SELENA (Seismic Loss Estimation using a logic tree Approach) (Molina and Lindholm 2005), ESCENARIS (Strasser et al. 2008), SIGE (Di Pasquale et al. 2004), DBELA (Displacement-Based Loss Assessment) (Crowley et al. 2004) and ELER (Crowley et al. 2004) are the other loss estimation program that were used in a world. In this study HAZTURK was used to calculate building damage in Küçükçekmece. HAZTURK is the software that visualizes the earthquake risk and its possible damage to structures and people, considering all the aspects of a seismic risk assessment process and offering options for decision makers all in one tool (Elnashai et al. 2008). HAZTURK needs construction type, number of floor and building age for every single building in order to calculate building damage.

The building construction year (building age) in building risk analysis gives information about the construction standards regarding building codes. When the building age is produced in GIS, it is possible to classify the buildings with their building code. In this study, the building codes that came into force in Turkey are used in order to determine the building age for every single building in Küçükçekmece. Because the building data set for Küçükçekmece did not consist of building age. In Turkey, following the foundation of Turkish Republic, many different rules were tried for building construction and it has been revealed as disaster regulation. (Table 2). The most recent earthquake regulation of Turkey published in 2007.
In this study, the building codes dates that have come into force in Turkey from 1940 to 2007 were taken as a reference in order to determine building age classification for Küçükçekmece. Remote sensing data (aerial photographs, satellite images and ortho photo mosaics) were obtained compatible with the date of the building codes. The literature review of studies shows that aerial photographs and satellite images were used in lots of national and international publications in order to detect collapsed buildings. These achieved over an 80% success rate for detecting collapsed buildings at local sites (Turker and San (2003); (2004), and Kaya et al. (2005); Gupta et al. (1994) and Saraf et al. (2002)).

Table 2. Building Code and Building Age Classification

| Building Code Name                                      | Building Code Year | Building Age Classification | Data Source          |
|--------------------------------------------------------|--------------------|-----------------------------|----------------------|
| Italian Structure Regulations                          | 1940               |                             |                      |
| Temporal Structure Code for the Earthquake Zone        | 1944               |                             |                      |
| Constructions                                          |                    | Before 1982                 | 1982 Air Photo       |
| Structure Regulation for Turkey Earthquake Zones       | 1949               |                             |                      |
| Regulation for the Structures that are going to be     | 1953               |                             |                      |
| Constructed within the Earthquake Zones                |                    | Before 1982                 | 1982 Air Photo       |
| Specification for Buildings to be Built in Seismic     | 1962               |                             |                      |
| Zones                                                  |                    | After 1982 to 1996          | 1996 Ortho Photo Mosaic |
| Specification for Buildings to be Built in Seismic     | 1968               |                             |                      |
| Zones                                                  |                    | 1996 - 2004                 | 2004 Satellite Image |
| Specification for Buildings to be Built in Seismic     | 1975               |                             |                      |
| Zones                                                  |                    | 1997 - 2004                 | 2004 Satellite Image |
| Specification for Buildings to be Built in Seismic     | 1997               | 1997 - 2004                 | 2004 Satellite Image |
| Zones                                                  | 1997 - 2004        | 2004 - 2012                 | 2013 Ortho Photo Mosaic |
| Specification for Buildings to be Built in Seismic     | 2007               |                             |                      |
| Zones                                                  | 2004 - 2012        |                             |                      |

Building damage is the one of the highest causes of death and injuries during earthquakes. Besides this, the collapsed buildings can create debris around the buildings and this debris may cause road blockages in the vicinity of the damaged buildings, especially in narrow roads. Road blockages decrease road functionality during a disaster.

In this study, we have estimated the building collapse direction and debris spreading distance (debris area radius of buildings) of collapsed buildings for the buildings in Küçükçekmece, which have the possibility of damage during the potential Istanbul earthquake. One of the basic reason for determining “building collapse direction” is to reveal the road blockages and then road functionality after an earthquake in order to identify open roads and suitable response routes. This method of definition building collapse direction was developed for Gölcük based on the investigations of collapsed buildings after the 1999 Kocaeli earthquake. It used the 1994 and 1999 aerial images of Gölcük Gölcük has been choosen as a study area for this developing method because there were lots of damaged buildings during the 1999 Izmit (Kocaeli) Earthquake. According to Özmen (2000), 35.7 % of buildings in Gölcük had heavily damaged and 5025 people died in Gölcük because of the 1999 Izmit Earthquake. There are lots of literature for determining the existing and collapsed buildings during the earthquakes by using aerial photographs and
remote sensing images. Fraser et al. (Fraser et al. 2002) tried to define buildings by using IKONOS Satellite Image in their study in 2002 (Fraser et al. 2002). Gupta et al. studied collapsed buildings at Uttarkashi during the Uttarkashi Earthquake in their 1994 study. Remote Sensing data were used to determine changes caused by earthquakes in their studies (Gupta et al. 1994). Kaya et al. used three different data sources to estimate the proportion of Adapazarı that contained collapsed buildings in their study in 2005. One of them is SPOT HRVIR XI image, the other one is SPOT HRVIR Panchromatic image and the last one is government statistics (Kaya et al. 2005). Turker et al. used SPOT HRV images to detect earthquake-induced changes in the 1999 Kocaeli earthquake in 2003. (Turker and San 2003). In this study, the manual building digitization method was chosen in order to obtain highest accuracy. Because digitizing the buildings manually was, the highest accuracy methods including the airborne laser or lidar techniques with the addition of digital elevation models of the study area (Awrangjeb, 2015; Matikainen et al., 2010; Niemeyer et al., 2014).

It is not only collapsed buildings but also bridge damage that affect the functionality of the road network. A system, such as a highway system, is configured into a network which will consist of a large number of links and nodes (Chang and Nojima, 1998; Kameda, 2000). The disruption of any of these links (e.g. roadway) or nodes (e.g. bridge or tunnel) can disrupt a section of the network, the impact of which is dependent on the redundancy in the system (Rojahn et al., 1992). Thus, a systems or network analysis of a highway system is required to be able to link structural damage of a bridge or roadway to social and economic impacts (Chang and Nojima, 1998; Werner and Taylor, 2002). In this study, HAZTURK was used to calculate bridge damage in Küçükçekmece.

Materials and Methods

A major disadvantage of Istanbul case is the lack of knowledge for the absolute number of buildings and the ages of those buildings in GIS system. Any building database for Istanbul does not consist of a building age for every single building at GIS based. The building data of this study is acquired from the Istanbul Metropolitan Municipality. This data includes the attributes of location, construction type, number of floors and occupancy types of buildings; however, does not contain building ages.

Not to obtain the building age for buildings in Küçükçekmece, the building age data were produced for every single Küçükçekmece building using aerial photo (1982), ortho photo mosaic (1996, 2013) and satellite image (2004) (Figure 2).

Fig. 2. Remote sensing data for using building age in Küçükçekmece

1982 aerial photo was used to determine the buildings that were constructed before 1982. The buildings were created by digitisation on ArcINFO program. Then this digitisation data were added to 1996 ortho photo mosaic in order to determine new built and demolished buildings from 1982 to 1996. Again this data were added to 2004 satellite image for defining
new built and demolished buildings from 1997 to 2004. Then this data were added to 2013 ortho photo mosaic for defining new built and demolished buildings from 2005 to 2013. Thus the building age data were produced to the Geographic Information System (GIS) for every single buildings in Küçükçekmece. When the building age is provided in GIS, it is possible to make reliable building damage analysis for Küçükçekmece buildings. The dataset including building age in Küçükçekmece and the dataset including number of floors and construction type were joined for getting Küçükçekmece buildings. There are 35589 number of building in Küçükçekmece (Figure 3).

Hazard is described as an input ground motion parameter or a spectral response value (Karaman et al. 2008a). In this study, HAZTURK software was used for the estimation of building damages in Küçükçekmece based on a scenario earthquake. Model A produced by JICA and IMM (2002) study was used as a scenario earthquake. Model A is defined as a fracture in the eastern part of the fault line and is the most anticipated model. The magnitude of this scenario earthquake was assumed as Mw 7.5 (JICA and IMM 2002). The probability of the damage to buildings is estimated by matching every building in the dataset to a fragility curve in the database by using the number of stories, construction year, structure type, and hazard values at the building location. Fragility curves used in this study were developed by using the Parameterized Fragility Method (PFM) of Jeong and Elnashai (2006).
Fig 4. Earthquake hazard map for Istanbul Sa (T=0.2 s) demands.

In order to use building data in the HAZTURK software, the necessary reclassification and standardization process were done (Table 3). These data were classified according to the HAZUS Handbook (FEMA 2003).

### Table 3. HAZUS Building Structural Type (FEMA 2003)

| Description                                      | Label | Height   | Stories |
|--------------------------------------------------|-------|----------|---------|
| Wood, Light Frame                                | W1    | 1 – 2    |         |
| Wood, Commercial and Industrial                 | W2    | All      |         |
| Steel Moment Frame                               | S1L   | Low-Rise | 1 – 3   |
|                                                  | S1M   | Mid-Rise | 4 – 7   |
|                                                  | S1H   | High-Rise| 8 +     |
| Steel Braced Frame                               | S2L   | Low-Rise | 1 – 3   |
|                                                  | S2M   | Mid-Rise | 4 – 7   |
|                                                  | S2H   | High-Rise| 8 +     |
| Steel Light Frame                                | S3    | All      |         |
| Steel Frame with Cast-in-Place Concrete Shear Walls| S4L   | Low-Rise | 1 – 3   |
|                                                  | S4M   | Mid-Rise | 4 – 7   |
|                                                  | S4H   | High-Rise| 8 +     |
| Steel Frame with Unreinforced Masonry Infill Walls| S5L   | Low-Rise | 1 – 3   |
|                                                  | S5M   | Mid-Rise | 4 – 7   |
|                                                  | S5H   | High-Rise| 8 +     |
| Concrete Moment Frame                            | C1L   | Low-Rise | 1 – 3   |
|                                                  | C1M   | Mid-Rise | 4 – 7   |
|                                                  | C1H   | High-Rise| 8 +     |
| Concrete Shear Walls                             | C2L   | Low-Rise | 1 – 3   |
|                                                  | C2M   | Mid-Rise | 4 – 7   |
|                                                  | C2H   | High-Rise| 8 +     |
| Concrete Frame with Unreinforced Masonry Infill Walls| C3L   | Low-Rise | 1 – 3   |
|                                                  | C3M   | Mid-Rise | 4 – 7   |
|                                                  | C3H   | High-Rise| 8 +     |
| Precast Concrete Tilt-Up Walls                   | PC1   | All      |         |
| Precast Concrete Frames with Concrete Shear Walls| PC2L  | Low-Rise | 1 – 3   |
|                                                  | PC2M  | Mid-Rise | 4 – 7   |
|                                                  | PC2H  | High-Rise| 8 +     |
| Reinforced Masonry Bearing Walls with Wood or Metal Deck| RM1L | Low-Rise | 1 – 3   |
|                                                  | RM2L  | Low-Rise | 1 – 3   |
|                                                  | RM2M  | Mid-Rise | 4 – 7   |
|                                                  | RM2H  | High-Rise| 8 +     |
| Reinforced Masonry Bearing Walls with Precast Concrete| RM1L | Low-Rise | 1 – 3   |
|                                                  | RM2L  | Low-Rise | 1 – 3   |
|                                                  | RM2M  | Mid-Rise | 4 – 7   |
|                                                  | RM2H  | High-Rise| 8 +     |
| Unreinforced Masonry Bearing Walls               | URML  | Low-Rise | 1 – 3   |
|                                                  | URMM  | Mid-Rise | 4 – 7   |
| Mobile Homes                                     | MH    | All      |         |
HAZTURK calculates the probability of earthquake damage on a building in four limit states based on 0.2 sec Sa and Sd demands (Karaman et al. 2008b). In this study, Boore and Atkinson (2008) ground motion estimation equation has been used to simulate the earthquake hazard map for Istanbul Sa (T=0.2 s) demands (Figure 4).

In order to determine building collapse direction in Küçükçekmece, the collapsed building in Gölcük because of the 1999 Kocaeli earthquake, were studied. For this reason, 80 collapsed buildings were chosen in Gölcük. Debris spreading lines were drawn in all directions around the collapsed buildings in Gölcük. As a result 317 debris spreading vectors in every direction were obtained (Figure 5).

According to the statistical process between 317 debris spreading vectors in every direction, the average distance of the debris of the collapsed buildings in Gölcük was 17.45m.

The bridge data (including location, construction year, girder type, bearing type, height of abutment, structure) were obtained from the General Directorate of Highways – 17 the Division by Excel format and all were transferred to GIS. There are 16 bridges (9 Overpass Bridge, 6 Underpass Bridge, 1 viaduct) related to road in Küçükçekmece (Figure 6).
Every bridge has been classified according to Bridge classification given in Table 4 by using their attributes. This classifications describes the bridges according to their span configuration – simply supported (SS), multi-span simply supported (MSSS), multi-span continuous (MSC) – and their girder material type – concrete or steel.

The fragilities, using by calculating bridge damage in HAZTURK, had been developed according to construction types listed in NBI (DesRoches et al., 2003; DesRoches et al., 2006), as well as the number of spans, total length, and width.

Results

In order to reveal road functionality in Küçükçekmece because of the earthquake, debris spreading distance of potential collapse building in Küçükçekmece and bridge damage in Küçükçekmece were calculated then the results combined to assess together.

According to GIS studies, building age distribution for Küçükçekmece buildings were given at figure 6. There are 14488 buildings that were built before 1982, 15468 buildings that were built between 1983 and 1996, 3249 buildings that were built between 1997 and 2004 and 2384 buildings that were built between 2005 and 2014 in Küçükçekmece (Figure 7).
Building damage analysis in Küçükçekmece was made using HAZTURK program. There are 35589 building in Küçükçekmece and 1897 of them have the possibility of more than 30% complete damage according to Sa (Figure 8). The buffer analysis was made by using these buildings and it was accepted that these collapsed buildings would create a 17.45 m debris site around them. Because of this debris, the road around the potential collapsed building could lose their functionality.

The length of current road in Küçükçekmece is 714743 meters. Because of the debris, 91787 meters road lose their functionality (Figure 9).

There are 9 overpass bridges, 6 underpass bridges, 1 viaduct related to road in Küçükçekmece. Bridge damage analyses were made by using HAZTURK program. According to this damage analysis, functionality of bridges was revealed immediately after an earthquake (Figure 10). Figures 11 represents the functional and non functional bridges in Küçükçekmece immediately following an earthquake. These results show that most of the bridge will not be used after a potential earthquake in Istanbul.
| Name                                      | Abbreviation | Material                          | Type                          | Spans |
|-------------------------------------------|--------------|-----------------------------------|-------------------------------|-------|
| Multi-Span Continuous Concrete Girder     | MSC Concrete | Concrete Continuous, Prestressed Concrete Continuous | Stringer, Tee-Beam, Floor Girder, Channel Beam | >1    |
| Multi-Span Continuous Steel Girder        | MSC Steel    | Continuous Steel                  | Stringer, Tee-Beam, Floor Girder, Channel Beam | >1    |
| Multi-Span Continuous Slab                | MSC Slab     | Concrete Continuous, Prestressed Concrete Continuous | Slab                          | >1    |
| Multi-Span Simply Supported Concrete Girder| MSSS Concrete| Concrete Continuous, Prestressed Concrete Continuous | Stringer, Tee-Beam, Floor Girder, Channel Beam | >1    |
| Multi-Span Simply Supported Steel Girder  | MSSS Steel   | Steel                             | Stringer, Tee-Beam, Floor Girder, Channel Beam | >1    |
| Multi-Span Simply Supported Slab          | MSSS Slab    | Concrete Prestressed Concrete     | Slab                          | >1    |
| Multi-Span Simply Supported Concrete Box Girder | MSSS Concrete-Box | Concrete Prestressed Concrete     | Box Beam - Multiple           | >1    |
| Single – Span Concrete Girder             | SS_Concrete  | Concrete Prestressed Concrete     | Stringer, Tee-Beam, Floor Girder, Channel Beam, Slab, Box-Beam - Multiple | <2    |
| Single – Span Steel Girder                | SS Steel     | Steel                             | Stringer, Tee-Beam, Floor Girder, Channel Beam, Slab, Box-Beam - Multiple | <2    |
Fig 8. Buildings that have the possibility of complete damage more than 30% according to Sa

Fig 9. Road blockage in Küçükçekmece
Fig. 10. Transportation structure functionality in Küçükçekmece

Discussion and Conclusion

Road functionality in Küçükçekmece is revealed with figure 12 by using debris spreading of collapsed building in Küçükçekmece and related post-earthquake functionality of transportation structures damage. This figure shows that most roads in Küçükçekmece district lose their functionality during the potential earthquake because of the collapsed buildings debris. Also most of transportation structures functionality is lower immediately after an earthquake.

The occurrence of earthquakes cannot be prevented by human efforts. If an earthquake were to occur in a populated area, especially one covered with vulnerable building stock such as the city of Istanbul, it could cause a serious impact on human life. Besides this, if the road’s functionality decreases due to damage to the transportation structures, the level of damage gets even higher and earthquake impacts may not be managed properly. Therefore, road network also plays an important role in activities of search and rescue, evacuation, firefighting operations and medical services after an earthquake.
Fig 11. Bridge functionality distribution in Küçükçekmece

Fig 12. Road functionality according to building collapse direction and transportation structure damage
If the roads lose their functionality because of the earthquake effects, the necessary activities could be impractical during the response and recovery time. It could cause an increase in earthquake damage.

As a conclusion, the results and the proposed methods in this study represent important contributions that can be used as a database for decision makers to develop important strategies for risk reduction, to prevent a hazard from becoming a disaster and to transform the urban areas based on the earthquake risk. Another important outcome of this study is to enable the decision makers to optimize the resources that will be used in the response and recovery phases of the integrated disaster management cycle.

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