An inter-disciplinary approach for earthquake vulnerability assessment in urban areas: A case study of Central District, Yalova

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Abstract

Most of the existing earthquake vulnerability assessment procedures concentrate on structural loss assessment and the resulting indirect economic losses. However, in addition to their destructive effect on the building stock, earthquakes also have a substantial potential in degrading an urban area’s economy, cultural heritage, and social structure. Thus, in order to be effectively used by decision makers, a robust assessment procedure should at least integrate socio-economical, structural and geological vulnerability components of an urban area.

In this study, an inter-disciplinary approach is presented to assess urban earthquake vulnerability at household to neighborhood scale. The proposed methodology introduces a technique for measuring certain attributes of individuals living within a household that contribute to their vulnerability to earthquake impact. At this stage, the overall vulnerability at household scale is “measured” considering physical, social, and economical components of vulnerability. Then, each component is analyzed in broad categories of indicators respective of the component in question. The physical fragility is estimated through a walk-down evaluation approach, whereas the social and economic components are determined through statistical surveys and specifically developed questionnaires. This information is then combined with the geological vulnerability to assess the average vulnerability at neighborhood scale. Conclusively, each indicator of a component is given a value to reach a final vulnerability assessment notwithstanding the effects that combinations of components will have on a person’s vulnerability. Within an undergraduate capstone design project course, a comprehensive application of the methodology is performed for the nine neighborhoods of the central district in Yalova province in the north-west Turkey, which experienced considerable damage in the 1999 Izmit Earthquake.

1. Introduction

Policies on natural hazards becoming disasters are moving from a culture of reactive response and recovery to proactive risk reduction and safety. This is a significant change from a mindset of crisis to one of resilience, vulnerability analysis appearing to be the key concept with the common objective of preventing and mitigating shared risks. Considering the increasing levels of risks originating from natural hazards, recent literature also points to a better understanding of physical, social, economic and political/institutional vulnerabilities to natural hazard impacts for the development of comprehensive and integrated risk models and risk management strategies (Blaikie et al., 1994 in CapHaz-Net, 2010).
As Dwyer et al. (2004) state, while natural hazards will continue to occur, their capacity to become a disaster or merely a manageable event depends on many factors, including the magnitude of the hazard, the vulnerability of people and their communities, the built environment and political systems. Thus place-specific risk assessment and mapping should be the first step in preventive efforts in order to improve the resilience of societies.

Researches should develop new probabilistic hazards and risk scenarios and improve the methodologies for risk assessment and for estimating disaster impacts. On this basis, researches should elaborate improved risk governance and management responses depending on the resilience of societies. This will contribute to produce innovative risk management solutions combining a cost-effective variety of risk reduction measures such as risk transfer and financing, adaptation and mitigation.

This study aims to contribute to the development of an integrative quantitative methodology of identifying, measuring aspects of vulnerability to earthquake hazards, evaluating all factors and indicators of vulnerability on risk maps in the case of central Yalova, Turkey. It gives emphasis to the concept of vulnerability within the perspective of a broad analysis and evaluation of vulnerability factors affecting the levels of earthquake disaster impacts. Some of the key questions that prepared the necessary grounds for the research are as such:

- What factors contribute to the vulnerability of individuals to earthquake impact?
- Can an approach be developed that is comparable from one place to another?
- Can a single personal attribute determine vulnerability, or is vulnerability dependent on certain combinations of numerous attributes?
- Can combinations of vulnerability attributes of individuals be mapped?

These questions are some of the key drivers behind the selection of methodologies, measurement processes and applications. The method is specific to earthquake disasters, however minor changes and the use of different data would make it possible for various hazard types. Therefore, one of the main objectives of this study is to contribute to the ongoing global development of vulnerability assessments that significantly value-add to total risk assessments. The progress this study will enhance is it’s developing a new methodology for an integrated analysis of hazard assessment and vulnerability assessment in the way to give root to place-specific risk maps.

Place-specific risk maps that will give important clues about the effects of physical/built-environment, social, economic and political and/or institutional factors of vulnerability on the levels of exposure and disaster impacts, will prepare the necessary grounds of coherent methods for national risk assessments. Place vulnerabilities are analyzed and evaluated with respect to their mutual interrelationships in increasing the level of disaster impacts that can be presented on risk maps performing different risk scenarios for different locations. This will conclusively give important clues for the improvement of resilience of societies and development of risk management strategies specific to the risks and disaster impacts of a given locality.

The objectives are:

1. To develop a methodology of an integrated analysis of place vulnerability with the elements of earthquake hazard assessment (geophysical) and vulnerability assessment (physical-built environment, economic, social and political);
2. To explore the mutual relationship between different indicators of vulnerability. To understand whether a combination of quantitative and qualitative indicators, based on the likelihood of one indicator being associated with others, will provide a more accurate representation of vulnerability.

3. To develop risk maps based on place-specific risk assessments and disaster impacts giving the necessary roots of new probabilistic hazards and risk scenarios that will contribute to the development of knowledge-based disaster impacts at different levels of government and among different policy competencies, as national risk assessments involve the integration of risk information from multiple sources.

2. Background

Risk assessment and mapping are the central components of a more general process which furthermore identifies the capacities and resources available to reduce the identified levels of risk, or the possible effects of a disaster (capacity analysis), and considers the planning of appropriate risk mitigation measures (capability planning), the monitoring and review of hazards, risks, and vulnerabilities, as well as consultation and communication of findings and results (Commission Staff Working Paper, 2010).

Risk is a combination of the consequences of an event (hazard) and the associated likelihood/probability of its occurrence (ISO 31010 in Commission Staff Working Paper, 2010). Risk assessment is the overall process of risk identification, risk analysis, and risk evaluation (ISO 31010 in Commission Staff Working Paper, 2010).

In Commission Staff Working Paper (2010) it is stated that in situations where the likelihood of occurrence of a hazard of a certain intensity can be quantified we refer to the term probability of occurrence. When the extent of the impacts is independent of the probability of occurrence of the hazard, which is often the case for purely natural hazards, such as earthquakes or storms, risk can be expressed algebraically as:

\[ \text{Risk} = \text{hazard impact} \times \text{probability of occurrence} \]

Thus the overall risk assessment process of national risk assessments is taken in two stages: (1) risk identification and (2) risk analysis. Risk identification is the process of finding, recognizing and describing risks. It is a screening exercise and serves as a preliminary step for the subsequent risk analysis stage (Commission Staff Working Paper, 2010). At this stage each risk factor based on geophysical data got from hazard assessment and vulnerability criteria got from vulnerability assessment, are listed to be mutually evaluated at the stage of risk analysis.

Risk analysis is the process to comprehend the nature of risk and to determine the level of risk (Commission Staff Working Paper, 2010) in accordance with the risk factors identified at the former stage. Thus all risk factors are mutually and comparatively evaluated at this stage to be presented on risk maps establishing the geographic scope of the risk scenario and of the impacts.
a. Hazard Assessment

Hazard is a dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage (ISO Guide in Commission Staff Working Paper, 2010). Earthquakes are one of the most important types of hazards having the greatest impacts in becoming disasters. According to EM-DAT, for the period 1998–2009, earthquakes in Europe rank second in terms of fatalities and third in terms of overall losses. The event that caused the largest number of fatalities took place in İzmit (Turkey) in August 1999, with more than 17 000 people killed and overall losses exceeding EUR 11 billion. Other significant events include the Düzce earthquake (Turkey) in the same year, resulting in about 845 fatalities, and the earthquake in L’Aquila (Italy, 2009), with 302 fatalities and the overall losses of at least EUR 2 billion. In contrast to the period 1998–2002, there were no events with a magnitude of more than 6.4 on the Richter scale recorded during the period 2003 and 2009 (European Environment Agency, 2010).

b. Vulnerability Assessment

The potential for a hazard to cause a disaster mainly depends on how vulnerable an exposed community is to such hazards. Disasters normally occur when hazards meet vulnerability (Wisner et al., 2004 European Environment Agency, 2010), and the potential for a hazard to become a disaster mainly depends on a society’s capacity to address the underlying risk factors, reduce the vulnerability of a community and to be ready to respond in case of emergency. It is important to note, however, that there are no internationally agreed minimum criteria for an event to be classified as a disaster (DFID, 2006). This is due to the variable manner in which hazardous events impact on population, economies or ecosystems. As Davidson demonstrates, even in urban regions with low seismicity, an earthquake could turn into a major disaster depending upon other characteristics of that city, such as population, use of adequate building codes, national GDP and housing vacancy rate (Dwyer, et al., 2004).

Thereby, even events which do not reach a certain ‘disaster-threshold’ and thus do not appear in global disaster databases, may in fact account for a considerable proportion of losses or of the impact in general (e.g. if there are many of these events) (European Environment Agency, 2010). So levels of vulnerability become very important in addition to the potential of hazard in risk assessment.

The United Nations International Strategy for Disaster Reduction UNISDR (2010a, 2010b in European Environment Agency, 2010) defines vulnerability as the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard. This definition proves the fact that actions and measures, if well implemented, can reduce the human health and economic impact of a hazardous event (European Environment Agency, 2010). Thus vulnerability reduction is related to the concept of resilience.

c. Factors of Vulnerability

Factors of vulnerability are categorized as physical (built-environment), social, and economic. Political/institutional factors are beyond the scope of this study. Macroform structure, risks of productive loss (working areas such as industry, commerce, transporation points such as
harbors and the like) and hazard evaluation are taken as the factors of preparedness and recovery.

Scholars have found that vulnerability may be increased due to factors such as a person’s age, gender, social class, race, and ethnicity (Aptekar and Boore, 1990; Morrow and Enarson, 1998; Peacock et al., 1997 in Fothergill, 2004). Some disaster researchers now use a “socio-political ecology of disasters” as a theoretical framework to study disasters, as such an approach includes the critical analysis of minority, gender, and inequality issues in disasters (see for example, Bates, 1993; Hewitt, 1983; Peacock with Ragsdale, 1997). Fothergill and Peek (2004) reviewed the literature on poverty, inequality, and disasters. Cutter et al (2008) state that those components that consistently increased social vulnerability for all time periods were density (urban), race/ethnicity, and socioeconomic status.

Cutter et al (2003) describe biophysical vulnerability and the vulnerability of the built environment (Mileti, 1999) and puts forward the social aspects of vulnerability. They state that socially created vulnerabilities are largely ignored, mainly due to the difficulty in quantifying them, which also explains why social losses are normally absent in after-disaster cost/loss estimation reports. Instead, social vulnerability is most often described using the individual characteristics of people (age, race, health, income, type of dwelling unit, employment). Social vulnerability is partially the product of social inequalities—those social factors that influence or shape the susceptibility of various groups to harm and that also govern their ability to respond (Cutter et al., 2003). They also suggest that the term also includes place inequalities—those characteristics of communities and the built environment, such as the level of urbanization, growth rates, and economic vitality, that contribute to the social vulnerability of places (Cutter et al., 2003)- which will be taken as physical vulnerability related with the built-environment in this study, besides social, economic and political vulnerabilities. Physical vulnerabilities and/or place inequalities are partially related with the social environment, they are also affected by political and economic consequences and interventions, such as planning decisions, building codes, and the like. So it will be more useful to take the vulnerabilities related with the built-environment as separate and consider its relations with the other types of vulnerability.

Physical vulnerability factors are related with the indicators of built-environment. Social vulnerability is a measure of both the sensitivity of a population to natural hazards and its ability to respond to and recover from the impacts of hazards (Cutter, et al, 2008). Race/ethnicity, socioeconomic class, and gender are among the most common characteristics that define vulnerable populations, along with age (elderly and children), migration, and housing tenure (renter or owner) (Cutter, et al, 2008), lack of access to resources (including information, knowledge, and technology), limited access to political power and representation, social capital, including social networks and connections, beliefs and customs, building stock and age and frail and physically limited individuals, (Cutter, 2001a; Tierney, Lindell, and Perry, 2001; Putnam, 2000; Blaikie et al., 1994 in Cutter et al., 2003).

3. Proposed Methodology

The proposed methodology considers vulnerability in four main categories. In the first category, the vulnerability is based mainly on the structural characteristics of the buildings. This involves the evaluation and mapping of the building stock fragility for a given neighborhood. In addition, due to the massive amount of liquefaction-induced damage in the 1999 earthquakes, geological vulnerability is included as a second category. Estimation of this
includes gathering of necessary geotechnical information to map the liquefaction-prone soil deposits in the area under consideration. Categories 1 and 2, which are mainly related to the structural elements of the urban area, can be classified as Type I vulnerability, according to the definition given by Düzgün et al. (2011). Once Type I vulnerability is computed, the next step is to evaluate the social and economic vulnerabilities, i.e., Categories 3 and 4. These are classified within Type II vulnerabilities (Düzgün et al., 2011), and are not dependent on seismic fragility analyses. Evaluation of Categories 3 and 4 necessitates obtaining information on income level, employment rate, relative economic contribution, dependency rate, car ownership, demographic structure, education level, access to social security and similar other variables for each neighborhood considered, as a minimum.

In the proposed methodology, the indexes of the four categories of vulnerabilities are evaluated for the nine neighborhoods of the central district of Yalova. Then, Type I and Type II vulnerability indexes are combined to determine an overall urban vulnerability index using simple additive weighting method. Note that the vulnerability indexes are given weights according to their importance. The overall vulnerability index (V) is computed using Equation 1:

\[ V = w_1V_s + w_2V_g + w_3V_e + w_4V_s \]

in which, \( V_s \) = structural vulnerability, \( V_g \) = geological vulnerability, \( V_e \) = economic vulnerability, \( V_s \) = social vulnerability, and \( w_i \) = weights for each vulnerability component.

Based on the experience of the authors, the weights for Type I vulnerabilities, i.e., \( w_1 \) and \( w_2 \) are selected as unity, whereas those for Type II, i.e., \( w_3 \) and \( w_4 \), are both taken to be equal to 0.5.

4. Implementation of the Proposed Methodology to the City of Yalova

a. Assessment of Type I Vulnerabilities

Yalova, with an urban population reaching more than 200,000 people, is an important city in the Marmara Region. According to data from the Ministry of Development, it is ranked as 13\textsuperscript{th} within the 81 provinces of Turkey, in terms of socio-economic development. According to the current seismic zoning map of Turkey (Figure 1), the province of Yalova is completely located in Zone I (Figure 2), due to its proximity to the notorious North Anatolian Fault (Figure 3). The seismic zoning map of Turkey contains five zones with Zone I being the seismically most active one.

![Figure 1. The Seismic Zoning Map of Turkey](image)
The 1999 İzmit earthquake (also known as the Kocaeli or Gölcük earthquake) that was a 7.6 magnitude earthquake that struck northwestern Turkey on August 17, 1999, was heavily felt in the city of Yalova. The 2,504 of the 17,480 official casualties were in Yalova (Figure 4), in addition to heavy structural damage. A reconnaissance survey indicates that 10,189 buildings suffered complete damage, while the corresponding numbers for medium and light damage states were 8953 and 14566, respectively. These figures made Yalova a natural choice for the implementation of the proposed methodology.
Estimation of structural vulnerability is based on a methodology named as “walk-down evaluation” due to its relative easiness and speed in application. This methodology enabled a survey of 943 apartment buildings within a duration of one week. It is based on observing and recording a number of structural properties for a given structure, which are determined according to the experience and behavior of reinforced concrete structures in previous earthquakes. These properties, or factors, also take into account the deficiencies in the existing building stock, and each are associated with “penalty” points according to their relative importance. The following are observed for any structure within the walk-down evaluation method:

- The number of storeys
- Existence of soft storey
- Existence of cantilevers or heavy architectural elements
- Relative quality / maintenance state of the structure
- Existence of hammering effect
- Topographic effects
- Local geotechnical conditions / amplification effects (excluding liquefaction)

A survey form that facilitates the evaluation of above-mentioned criteria was produced (Figure 5). The vulnerability of each building could easily be determined in a numeric format using this form, which later was digitized along with the photographs of the structure.

![Figure 5. Walk-Down Evaluation Form](image-url)
The initial scores were allocated to each structure according to local seismic hazard, i.e., the peak ground velocity (PGV) and the number of storeys (Table 1). The city of Yalova consists of three regions with different PGV values. Then, within the context of walk-down evaluation, these starting scores are reduced through observation of factors that were mentioned before (Table 2). Thus, a lower resulting score would mean a structure with higher vulnerability.

**Table 1. Initial Scores Allocated to Structures**

<table>
<thead>
<tr>
<th>No. of Storeys</th>
<th>PGV&gt;60</th>
<th>40&lt;PGV&lt;60</th>
<th>PGV&lt;40</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,2</td>
<td>100</td>
<td>130</td>
<td>150</td>
</tr>
<tr>
<td>3</td>
<td>90</td>
<td>120</td>
<td>140</td>
</tr>
<tr>
<td>4</td>
<td>75</td>
<td>100</td>
<td>120</td>
</tr>
<tr>
<td>5</td>
<td>65</td>
<td>85</td>
<td>100</td>
</tr>
<tr>
<td>6,7</td>
<td>60</td>
<td>80</td>
<td>90</td>
</tr>
</tbody>
</table>

**Table 2. Reduction Scores**

<table>
<thead>
<tr>
<th>No. of Storeys</th>
<th>Soft Storey</th>
<th>Heavy Cantilever</th>
<th>Apparent Quality</th>
<th>Short Column</th>
<th>Hammering</th>
<th>Topography</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,2</td>
<td>0</td>
<td>0</td>
<td>-10</td>
<td>-5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>-10</td>
<td>-5</td>
<td>-10</td>
<td>-5</td>
<td>-2</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>-15</td>
<td>-10</td>
<td>-10</td>
<td>-5</td>
<td>-3</td>
<td>-2</td>
</tr>
<tr>
<td>5</td>
<td>-20</td>
<td>-10</td>
<td>-10</td>
<td>-5</td>
<td>-3</td>
<td>-2</td>
</tr>
<tr>
<td>6,7</td>
<td>-20</td>
<td>-10</td>
<td>-10</td>
<td>-5</td>
<td>-3</td>
<td>-2</td>
</tr>
</tbody>
</table>

The results of structural vulnerability assessment are shown in Figure 6. Note that, the scores in the figure indicate weighted relative structural vulnerabilities, with a score 100 indicating the highest vulnerability. Bahçelievler and Rüstempaşa neighbourhoods appear to be having the highest structural vulnerabilities.

![Figure 6. Structural Vulnerability Scores for Nine Neighborhoods of Yalova](image-url)
A study based on collecting local geotechnical reports and borehole data was utilized to estimate the other component of Type I vulnerability, i.e., the geological vulnerability. This study is mainly based on estimating whether the first 18 m of local soil deposit is prone to liquefaction hazard. Note that, it was not possible to consider whether a liquefaction hazard would create structural damage through differential settlements, since the foundation system type should be incorporated into the analysis to do so. The results are given in Figure 7, in terms of liquefaction vulnerability value, with a score 100 indicating liquefaction prone soils. These scores indicate that Yalova was settled in an area having high liquefaction potential.

![Geological Vulnerability Map](image)

**Figure 7.** Liquefaction Vulnerability for Centeral Neighborhoods of Yalova

### b. Assessment of Type II Vulnerabilities

Type II vulnerability includes economical and social vulnerabilities, and are characterized by dimensions such as:

**Economic Vulnerability:**
- The level of income
- Employment rate
- Economic contribution
- Dependency rate
- Poverty rate
- Car ownership level

**Social Vulnerability:**
- Age distribution
- Gender
- Family size
- Education level
- Social security
To develop a robust feel for the social and economic vulnerability levels, a representative database and necessary statistical data is needed. A field research was conducted to reach representative and space-based data in the neighborhood level. 420 families were interviewed for this purpose in addition to data from Turkish Statistical Office (TUIK). An example result about education level is shown in Figure 8 giving education levels in different neighborhoods.

The results of economic and social vulnerability assessments are shown in Figures 9 and 10, respectively. Note that, the scores in the figure indicate weighted relative structural vulnerabilities, with a score 50 indicating the highest vulnerability. As this study is focused on developing a methodology at the first stake, some of the social and economic vulnerability factors are not used in order to simplify the process. This study gives important clues in the use of this methodology. So the next step will be to enlarge the process with all of the factors mentioned above.

Figure 9 shows that İsmetpaşa neighbourhood has the highest degree of economic vulnerability. Süleymanbey, Fevzi Çakmak and Kazım Karabekir neighbourhoods follow İsmetpaşa neighbourhood. Gaziosmanpaşa, Bağlarbaşı and Dere neighbourhoods has the lowest degrees in economic vulnerability. As for the social vulnerability Kazım Karabekir neighbourhood has the highest degree, followed by Bağlarbaşı and Dere neighbourhoods, as shown in Figure 10. These evaluations show that Bahçelievler neighbourhood which has the highest degrees of liquefaction and structural vulnerability, has low degrees of economic and social vulnerability. Dere neighbourhood on the other hand has the lowest degrees of liquefaction and structural vulnerability but it has high degrees of economic and social vulnerability.
c. Assessment of Overall Vulnerability

As stated previously, Type I and Type II vulnerability indices are combined to determine an overall urban vulnerability index using simple additive weighting method. The result is shown in Figure 11. Also, the numerical values of resulting overall vulnerability indices are tabulated in the form of a histogram in Figure 12. The results indicate that Bahçelievler is the most vulnerable neighborhood against earthquakes, whereas Dere and Bağlarbaşı are the most resilient ones.
5. Summary and Conclusions

An easy to apply interdisciplinary vulnerability assessment procedure is proposed for urban areas. Its application is demonstrated for Yalova, an earthquake prone city in North-Western Turkey. Although based on limited data, the obtained results are promising. The results indicate that the resilience of neighborhoods varies significantly for different vulnerability categories. The methodology allows indication of vulnerability in different categories such as economical and structural, thus, through its use, resilience of urban areas can be more effectively increased by correct prioritization of limited resources by decision makers. This will help enable robust implementation of risk reduction strategies.

REFERENCES


Cutter, S.L., Boruff, B., Shirley, W.L., (2003), Social Vulnerability to Environmental Hazards, Social Science Quarterly, Volume 84, Number 2, June 2003


Klein, R.J.T., Nicholls, R.J., Thomalla F., (2004), Resilience To Natural Hazards: How Useful Is This Concept?, Global Environmental Change Part B Environmental Hazards , Elsever LTD.


Timmerman, P., (1981), Vulnerability, Resilience And The Collapse Of Society Institute For Environmental Studies, University Of Toronto In Toronto.

UN/ISDR, (2009), Terminology on Disaster Risk Reduction, Geneva.