The 14th World Conference on Earthquake Engineering
October 12-17, 2008, Beijing, China

A NEW RAPID SEISMIC VULNERABILITY ASSESSMENT METHOD FOR TURKEY

H. Kaplan[1], S. Yilmaz[2], E. Akyol[3] and G. Sen[4]

[1] *Professor, Dept. of Civil Engineering, Pamukkale University, Denizli, Turkey*
[2] *Assist. Professor, Dept. of Civil Engineering, Pamukkale University, Denizli, Turkey*
[3] *Assist. Professor, Dept. of Geological Engineering, Pamukkale University, Denizli, Turkey*
[4] *Research Assistant, Dept. of Geological Engineering, Pamukkale University, Denizli, Turkey*
Email: hkaplan@pau.edu.tr, syilmaz@pau.edu.tr, eakyol@pau.edu.tr, gsen@pau.edu.tr

ABSTRACT:

It is crucial to estimate seismic performance of buildings in tectonically active areas for seismic hazard mitigation. For this purpose, many rapid evaluation methods have been developed for seismic evaluation of existing building stocks. However, those methods usually require giant sources for mid to large size cities. Properties of the structural system, seismic quality of construction and geotechnical properties of soil are important parameters, which have to be collected by costly field investigations. On the other hand, each method reflects the characteristics of building stock, for which it was developed. In this study, a HAZUS based rapid evaluation method using building census data is used for rapid assessment. Validation of the method and building grading system is presented. Bingöl Earthquake data is utilized for this purpose. It is found out that proposed method can be used for seismic assessment of mid to large size cities. However, some modifications are also needed for modeling parameters of masonry structures especially.

KEYWORDS: Earthquake Damage, Loss Estimation, Rapid Assessment Method, Bingöl

1. INTRODUCTION

The excessive number of fragile buildings against lateral loads is of major importance for Turkey. Erzincan Earthquake of 1992 (Ersoy, 1992) revealed that building stock in Turkey had many seismically vulnerable buildings. This fact has been also proved by a large number of damaged and collapsed buildings in 1995-Dinar (Kaplan, 1996), 1998-Ceyhan (Kaplan et al., 1998), 1999 Marmara (Sucuoglu et al., 2000), and 2003-Bingöl earthquakes (Kaplan et al., 2004). Due to this fact, public awareness on seismic safety of buildings has an increasing trend. This figure also makes seismic mitigation works more crucial than ever before.

In general, disaster losses may be reduced by simple and economical precautions before any destructive event. Based on that modern disaster management is composed of four main stages, namely: loss reduction, preparedness, action and recovery. Loss reduction studies are one of the most important parts of mitigation works. Preparation of a probable risk/damage/loss map is an important issue in these works. Rapid seismic vulnerability evaluation methods are utilized for the production of such data.

Current approaches in seismic vulnerability evaluation follow three main stages: walk-down, preliminary and final evaluations (Ozcebe et al., 2003). All these stages require time and financial sources. Even in the walk-down stage, many engineers need to be employed for a long period of time depending on the size of the building stock. On the other hand, there are number of studies and methods for rapid structural evaluation. However these methods are generally based on nonlinear performance analysis and they give satisfactory results only for the building stocks used for the development. For example, HAZUS and JICA rapid evaluation methods are widely used in Turkey for capacity estimation of buildings, but those methods cannot represent Turkish Building Stock.

In this study, building database derived from results of Building Census is utilized for rapid seismic assessment. Main advantage of the method is the minimized requirement of time and financial sources. EDMPI (2000) method, which was adopted from HAZUS (1997) is utilized for the performance assessment. Injury matrices are adapted to cases in Turkey Earthquakes. As a case study, earthquake loss statistics of 2003 Bingöl Earthquake is used for validation of the proposed data source, method and injury matrices.

2. SEISMICITY OF THE BINGOL AND 2003 EARTHQUAKE

2.1. Seismicity

Bingöl city center and nearby is located on East Anatolian Fault System (EAFS) which is second major fault system of Turkey. The EAFS has about 600 km length and moves 1 cm/year. It is because the research area close to the junction of East and North Anatolian Fault Systems, a number of conjugate faults have been developed parallel and normal to the EASF (Figure 1). Any activity has not been observed on the EAFS for more than a century except 1971 Bingöl and 1975 Lice earthquakes although it is a main fault system.

Some historical earthquakes have reported in the area. The earthquake activity has been recorded since 1930s. The active faults have caused a number of casualties during this period and they are listed in Table 1. As it is seen tens of thousands of people dead and/or injured and tens of thousands of building damaged and/or collapsed.

Table 1. Major recorded earthquakes around Bingöl City.

Date	Magnitude (Ms)	Area	Dead	Injured	Heavily Damaged
21.11.1939	5.9	Tercan	43	-	500
26.12.1939	7.9	Erzincan	32962	-	116720
12.11.1941	5.9	Erzincan	15	-	500
31.05.1946	5.7	Varto-Hınıs	839	349	1986
17.08.1949	7.0	Karlıova	450	-	3000
05.02.1949	5.2	Harmancık	-	-	150
04.02.1950	4.6	Kiğı	20	-	100
25.10.1959	5	Hınıs	18	-	300
31.08.1965	5.6	Karlıova	-	-	1500
07.03.1966	5.6	Varto	14	75	1100
12.07.1966	4.0	Varto	12	-	90
19.08.1966	6.9	Varto	2394	1489	20007
26.07.1967	6.2	Pülümür	97	268	1282
24.09.1968	5.1	Bingöl	2	40	-
22.05.1971	6.7	Bingöl	878	700	5617
13.03.1992	6.8	Erzincan-Tunceli	653	3850	6702
27.01.2003	6.1	Pülümür	1		50
01.05.2003	6.4	Bingöl	176		6000

2.2. Geotechnical Data

Physical and mechanical characteristics of the Bingöl city center vary in very wide perspective. Early settlement of the city was around the Çapakçur and Gayt Brooks which are of loose deposits with high water content. After heavy damages of the early earthquakes the settlement has moved to higher level of the area which are consist of Plio-Quaternary terrace deposits and partly to the alluvium plain (Figure 1). The terrace deposits include block, gravel sand and silt with satisfactory bearing capacity for the ordinary buildings. In these areas, the underground water is deep enough to affect the structure foundations. In the light of a large number of drill holes and observation pits in the city center, all the soils of the quarters have been classified based on the Turkish Building Codes (MPW, 1997) as shown in Table 2. In some parts of the city, particularly in SW of the city, all the soils marked as Z2 although it was rock. It is because of loose alluvium on the surface and shallow foundation depth. Soil amplification factor (calculated from SPT) varies from 2 to 3.7.

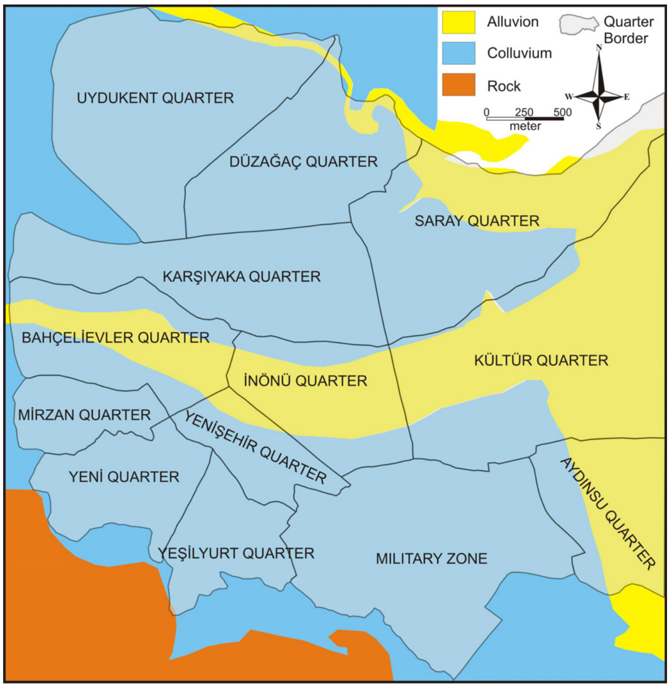

Figure 1 Simplified geological map (modified from Seymen and Aydın, 1972) and the quarter borders of Bingöl Municipality

Table 2 Soil classifications in Bingöl quarters based on Turkish Building Codes (%)

Quarter Name	Soil classification (%)			
	Z1*	Z2*	Z3*	Z4*
Uydukent	-	100	-	-
Düzağaç	-	90	10	-
Saray	-	70	15	15
Kültür	-	35	35	30
Aydınsu	-	40	50	10
İnönü	-	55	10	35
Karşıyaka	-	75	15	10
Bahcelievler	-	75	15	10
Mirzan	-	100	-	-
Yeni	-	100	-	-
Yesilyurt	-	100	-	-
Yenisehir	-	100	-	-

*Characteristic periods of the soil types are as follows: T_b=0.3 (Z1), 0.4 (Z2), 0.6 (Z3), 0.9 (Z4)

2.3. 2003 Bingöl Earthquake

Bingöl City has been greatly affected by May 2003 Earthquake, which has a distance of 13 km from the city center. A single strong motion record is obtained at the city from the recorder at the Building of Bingöl Office Branch of Ministry of Settlement and Public Works. Two horizontal component of the record and elastic acceleration spectrums (%5 damped) of these records are given in Figure 2.

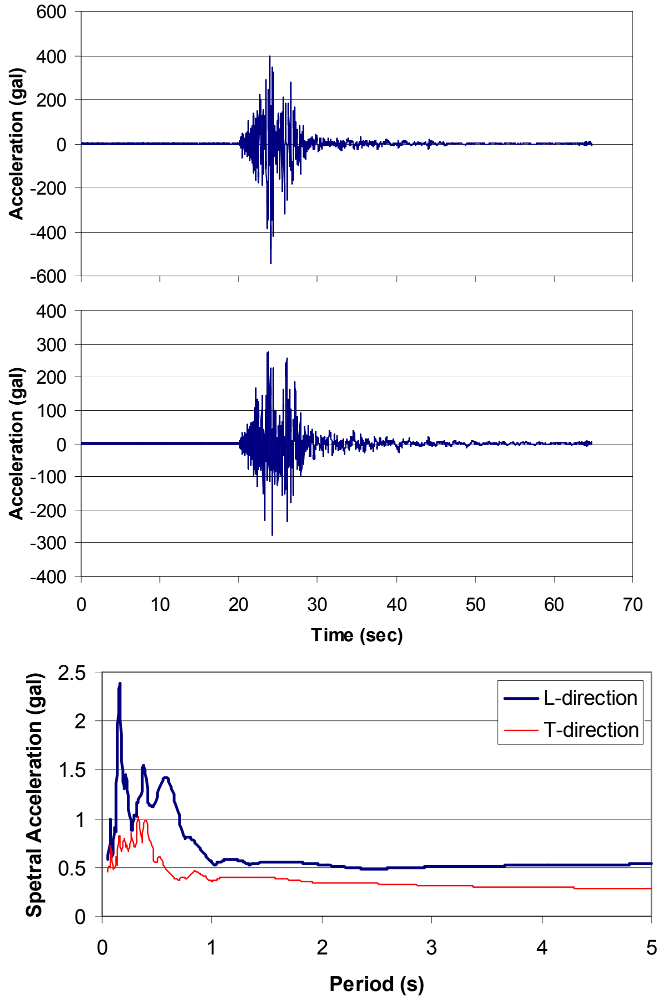

Figure 2 Strong ground motion components and acceleration spectrums of the record (DAD)

3. METHOD

3.1. Evaluation of the Building Inventory

Statistical building data are collected by TUIK that makes building inventories periodically in Turkey. The last one was carried out in 2000. The data, taken directly from administrators/owners of the buildings, are collected to prepare economical plans and to make clear demographic structure. Database includes the followings: quarter of the building, date of construction, usage type of the building, constructer of the building, owner of the building, structural system and wall material, floor area, land area, number of storeys, number of flats, number of commercial spaces in ground floor and other floors, number of industrial spaces, physical condition of the building and some other information about installations.

Some of the information, listed above, have not any influence for seismic risk assessment while some ones are of importance. Inventory data have converted into a format that can be used for building damage assessment. Three parameters, namely structural system (I), date of construction (J) and building quality (K), are obtained for the rapid evaluation purposes. Different values of parameters I, J, K are explained in Table 3. I and J can be obtained directly from statistical data. To determine the building quality, each building is graded and classified. All of the buildings are classified as either poor, fair or good according to their building quality grade. Buildings, which have 40 points or less are classified as poor. Those have 70 points or more are classified as good. Buildings between these limits are qualified as fair. Table 4 shows the main points of the grading system. Details of the grading system can be found in previous studies (Kaplan et al., 2007).

Table 3 Building classification system

Parameter	Value	Description
Structural System (I)	1	1-2 storey RC
	2	3-5 storey RC
	3	6+ storey RC
	4	1-2 storey masonry
	5	3+ storey masonry
	6	Other
Date of Construction* (J)	1	Constructed after 1975
	2	Constructed after 1975
Building Quality (K)	1	Good
	2	Fair
	3	Low

**Turkish Building Codes have been changed in 1975*

Table 4 Grading parameters.

Parameter	RC	Masonry
Date of Construction	20	20
Resonance Risk	25	—
Number of Storey	—	25
Soft Storey	15	—
Wall Material	—	25
Pounding Effect	10	—
Quarter	15	15
Physical Condition	15	15
Total	100	100

3.2. Damage Estimation Methodology

Nonlinear static (pushover) analysis is a popular and efficient analysis method used in structural engineering. Building capacity against lateral loads can be calculated by pushover analysis without nonlinear dynamic analysis. Capacity spectrum method (CSM) is an efficient tool that is used to determine a building's displacement level (performance) for a given earthquake demand. Details of the method can be found in ATC-40 (1996). Procedure B of CSM is utilized in this paper as it is more appropriate for programming.

Capacity of a building may change significantly with changes in material quality, lateral and longitudinal reinforcement ratios, structural system type, structural irregularities and some other factors. Although there are many factors affecting building capacity, it can be defined by base shear coefficient and ductility in a simple way. Certainly, this approach may introduce some errors but it is very simple and time-efficient. Coefficients that define building capacity were modified to reflect building stock in Turkey. These parameters have been tailored from HAZUS (1997) and EDMPI (2000). The capacity curve is obtained using 3 parameters (I, J, K) of each building. Demand Spectrum is constructed from May 1, 2003 Bingöl Earthquake. Smoothed spectrum is used for the assessment procedure. Throughout the city the same demand spectrum is used since no other strong motion record is available.

Building damages are classified into 4 categories: light, moderate, heavy, very heavy. Buildings, not included in any one of these, are considered as non-damaged. Definitions for these damage states are given in HAZUS (1997) and EDMPI (2000). Each damage state is characterized by median and standard deviation of earthquake damage. Injury matrices given in HAZUS (1997) to estimate the number of injuries and deaths are adapted to Turkey in a previous study by authors (Kaplan et al., 2007).

4. COMPARISON OF THE RESULTS WITH 2003 EARTHQUAKE DATA

After the seismic evaluation, number of lightly, moderate, heavily and very heavily damaged buildings are obtained. However, official records have a different structure. Local government collected data for number of damaged flats. During that, all flats in a building are assessed as the same damage level. Therefore, number of damaged buildings converted to number of damaged flats using inventory data. Moreover, official records, does not have a distinction between heavy and very heavy damage. For this reason, those 2 damage levels are presented together (and will be mentioned as heavy damage). Estimated and observed values of damaged flats are compared for heavy and moderate damage levels in Figure 3. Every point represents a different district of the city. District numbers (given in Table 5) are also associated with the points for some of the bad estimates.

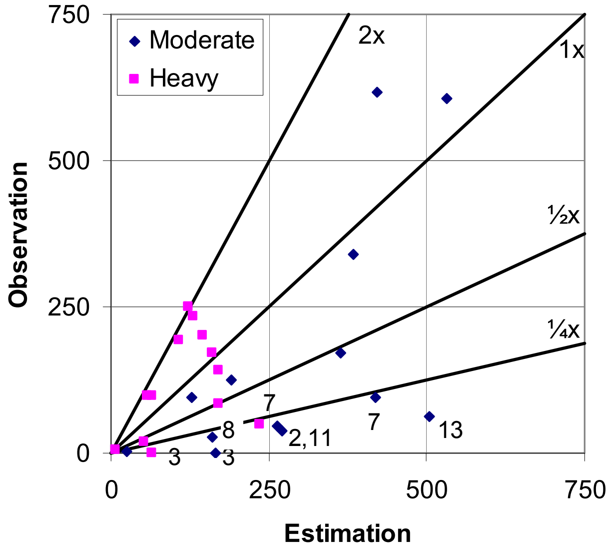

Figure 3 Estimated vs. observed values of number of flats with heavy/very heavy and moderate damage

The proposed method well estimates heavy damage cases except two districts (Duzagac and Kultur). The other districts fall between ½x and 2x lines. For the moderate damage case number of over-estimates increases significantly. Duzagac and Kultur are again in the list. Bahcelievler, Mirzan, Yesilyurt and Yenisehir are the other bad estimates for moderate damage. The common point of these districts is that dominant type of buildings is masonry except Yenisehir (Table 5). It is also remarkable that dominant soil type of Bahcelievler, Mirzan, Yesilyurt and Yenisehir are Z2. However, the only strong ground motion record of the earthquake is recorded on a softer soil. Therefore, the over-estimations in these districts may be due to over estimation of the corresponding seismic demands.

Addition to damage estimation death and injury estimations are carried out. Injuries are categorized into 4 groups as follows:

- 1st degree injuries : Medical treatment on foot.
- 2nd degree injuries : Short term treatment in hospital.
- 3rd degree injuries : Long term treatment in hospital.
- 4th degree injuries : Injury results in death.

According to this classification estimated and observed injuries are given in Table 6. Number of deaths is under-estimated, whereas case is vice versa for number of injuries. This over estimation might be due to some unrecorded minor injuries. It is possible to conclude that both estimated number of deaths and injuries are sensible.

Table 5.Some characteristics of the districts of the Bingöl City

District No	District Name	Dominant I-J-K	Dominant construction year	% of Z2 type soils
1	Aydınsu	2-1-3	60s	40
2	Bahcelievler	4-1-1	70s	75
3	Duzagac	4-1-1	80s	90
4	Inonu	2-1-3	70s	55
5	Kaleonu	4-1-1	80s	70
6	Karsiyaka	2-1-3	70s	75
7	Kultur	4-2-1	70s	35
8	Mirzan	4-1-1	60s	100
9	Saray	2-1-2	70s	70
10	Uydukent	1-1-2	60s	100
11	Yesilyurt	4-2-1	60s	100
12	Yeni	1-1-2	70s	100
13	Yenisehir	2-1-3	70s	100

Table 6 Estimated and observed injuries

<table>
<tr><th>Injury type</th><th>Estimation</th><th>Observation</th></tr>
<tr><td>1st degree</td><td>386</td><td rowspan="3">370</td></tr>
<tr><td>2nd degree</td><td>174</td></tr>
<tr><td>3rd degree</td><td>35</td></tr>
<tr><td>4th degree</td><td>35</td><td>54</td></tr>
</table>

5. RESULTS AND CONCLUSION

Current approaches in seismic vulnerability evaluation methods include three main stages: walk-down, preliminary and final evaluations, which require abundant time, qualified workmanship and financial sources. In this study, a new stage that does not need giant sources has been employed before starting the other stages for optimized planning.

Proposed method is previously used for seismic assessment of another city, Denizli. However, it is needed to be validated the method before common usage. For this purpose, validation is carried out by using 2003 Bingöl Earthquake, which has been occurred 13 km away from Bingöl City center. Building inventory of Bingöl City, collected at 2000 is used as input data. Demand is assumed to be uniform in the city, as there is only one strong motion record.

Estimations on damages and losses are reasonable on city scale. However, dealing with each district separately on micro scale there are quite significant misestimates. These are primarily because of uniform modeling of the demand throughout the city and over-punishment of masonry buildings. Although, method needs to be improved, the results showed that data collected by TSI can be used for damage estimation. Districts of the city having primary importance can be determined easily. This data is very valuable for optimum use of sources for detailed assessment.

Most important advantage of the method is its speed. For a mid-size city, after determination of the soil properties seismic assessment can be completed within a day. It is also possible to carry out calculations for different scenario earthquakes.

ACKNOWLEDGEMENTS

The authors would like to sincerely express their thanks to Civil Engineer Ahmet Hülakü, Survey Engineer Şerafettin Kaldık and Survey Technician Selim Boydaş of Bingöl Municipality for geotechnical reports, maps and all digital data.

REFERENCES

ATC (1996). Applied Technological Council, ATC-40 Seismic Evaluation and Retrofit of Concrete Buildings, Redwood City, California, USA.

DAD, Earthquake Research Center, www.deprem.gov.tr

EDMPI (2000). Earthquake Disaster Master Plan for the City of Izmir, www.koeri.boun.edu.tr

Emre, Ö., Herece, E., Doğan, A., Parlak, O., Özaksoy, V., Cıplak, R ve Özalp, S. (2003). 1 May 2003 Bingöl Earthquake, p. 17 (unpublished report, in Turkish).

Ersoy, U. (1992). Erzincan earthquake and RC structures–technical report on 13 March 1992 Erzincan earthquake. TMMOB-Association of Civil Engineers, Ankara, Turkey.

HAZUS (1997). Earthquake loss estimation methodology technical manual prepared by the National Institute of Building Sciences for Federal Emergency Management Agency (FEMA).

Kaplan, H. (1996). Damages of Dinar earthquake in 1st october 1995 and their prevention. *Journal of Engineering Sciences* **2,** 25-34 (in Turkish).

Kaplan, H., Binici, H., Un, H. (1998). The Ceyhan earthquake of june 27, 1998 and design of earthquake resisting buildings. *Journal of Engineering Sciences* **4,** 853-863 (in Turkish).

Kaplan, H., Yilmaz, S., Binici, H., Yazar, E., Cetinkaya, N. (2004). May 1, 2003 Turkey-Bingöl earthquake: damage in reinforced concrete structures. *Engineering Failure Analysis* **11,** 279-291.

Kaplan, E., Yilmaz, S., Akyol, E., Sen, G., Dayanir, N. (2007). Preliminary seismic vulnerability asssessment of urban building stocks: A case study for Denizli-Turkey. *Journal of Science and Technology* **1,** 106-124.

KOERI, Kandilli Observetory and Earthquake Research Institute, www.koeri.boun.edu.tr

MPW (1997). Ministry of Public Works and Settlement, Turkish Earthquake Code, Ankara.

Ozcebe, G., Yucemen, M. S., Yakut, A., Aydogan, V. (2003). Seismic vulnerability assessment procedure for low- to medium-rise reinforced concrete buildings. METU, Ankara, Turkey.

Seymen, İ. and Aydın, A. (1972). Bingöl earthquake fault and its relation with eastern Anatolian Fault Zone, *MTA Journal* **79,** 1-8.

Sucuoglu, H., Gulkan, P., Yilmaz, C., Bakir, S., Ozcebe, G., Ersoy, U., Tankut, T., Gur, T., Akkar, S., Erberik, A., Yilmaz, T. (2000). Technical Report on Marmara and Duzce Earthquakes. METU- EERI, Ankara.

TUIK, Turkish Statistical Institute, www.turkstat.gov.tr