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Development of Building Damage Functions for Big Earthquakes in Turkey

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Abstract

The current work is an attempt to predict building reactions to big earthquakes using real data collected from surveys carried out after the occurrence of earthquakes. With the development of building damage functions for big earthquakes in Turkey one can predict the damage levels as a function of earthquakes' intensity and the building parameters. Our model is based on neural networks techniques which allow for the non-linear correlations to be taken into account. We analyse data collected for damaged buildings after the following three big earthquakes: Afyon (2002; Mw = 6.0), Bingöl (2003; Mw = 6.4) and Düzce (1999; Mw = 7.2). The current model includes some of the main important factors affecting the health of any structure, namely, age, number of stories, floor areas, and the column areas. Our method of damage prediction is based on several earthquakes and buildings with different damage levels. The obtained results show that there is a strong correlation between the strength of the earthquake, the basic building parameters and the damage level. The obtained building damage function is essential for future plans and regulations for new constructions and can be considered as an essential module for hazards mitigation systems.

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Keywords: earthquakes; neural networks; structural health monitoring; estimation methods

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1. Introduction

Turkey has been witnessing earthquakes of large magnitudes that often result in loss of property and life. On August 17, 1999 a massive earthquake measured 7.4 on the Richter scale and 7.6 on the Moment Magnitude scale (MW) in Izmit area killed over 18,000, injured some 44,000, and destroyed 300,000 homes and 40,000 business premises. After three months later on November 12th 1999, another strong earthquake measured 6.8 on the Richter scale (MW 7.4) in Duzce area killed over 800 and injured some 5000 people. Similar devastating earthquakes were reported from the area. For example, over 30,000 casualties were reported from the earthquake on December 26, 1939 that devastated Erzincan and 15000 deaths from the Oct 15, 1883 earthquake that hit the western part of Izmir. The most recent major earthquake with a magnitude of 6.6 on the Richter scale (MW 7.1) was on October 23, 2011 in eastern part of the Turkey near Van province and killed more than 600 and injured around 2500 people.

Anatolia (Asian Turkey) is a big block of crust moving to the west towards lower-stress domains far from the high-stress area of the Arabian-Eurasian collision as can be seen in Figure 1. This setting is a classic example of “tectonic escape” (Burke and Sengor, 1986), where Turkey is moving out of the way of Arabia as it impinges into Iran. As the Anatolian block moves, earthquakes are generated. Two of the biggest active fault zones in Turkey are the East Anatolian Fault (EAF), which bounds southeastern Anatolia, and the North Anatolian Fault (NAF), which strikes east-west across northern Anatolia. The reasons for such huge damage of buildings have been associated with different parameters; mainly the geological conditions beneath buildings and the rest are related to the structures themselves.

Many international and national hazard mitigation projects have been initiated to estimate responses and losses of buildings (e.g., PAGER (Wald et al. 2008); HAZUS (FEMA 2006); and HAZTURK (ISTABIS)). Both global and local systems are usually combined with geographical information systems (GIS). These systems mostly require information about the building functions and are based on probabilistic models. Studies show the importance of including hazards mitigation systems into land use planning (e.g., Hamilton, 2000). In the current study we try to understand the relation between the different parameters affecting the building’s strength against big earthquakes in Turkey. The past collected information are used to construct and to train our neural network – based model for future predictions. The current study constitutes the first step towards building a self-consistent disaster management system.

It is important to mention here that the current approach is different from the other existing global and local systems (e.g., GDACS; QLARM; NERIES-ELER) in that it depends on real data collected from infected regions and not on probabilistic models.

2. Methodology

2.1. Earthquake management system

The main aim of our research work is the development of a self-consistent and real-time based natural disaster management system for Turkey. The proposed system as shown in Fig.1 is divided into three main time based modules: before, during and after the occurrence of the disaster. They involve generating real-time rescue plans and loss calculations. The system will also allow the comparison of previous scenarios that support decision makers.

The real-time data collection module will involve different monitoring and communication techniques that transfer the actual status of buildings and the number of people under debris as a function of time. One will have complete view about the number of people inside buildings shortly before the occurrence of the natural disasters (Fawzy & Sahin 2011; Fawzy & Sahin 2013). With this system we aim to efficiently direct the rescue teams and a faster relief after natural disasters.

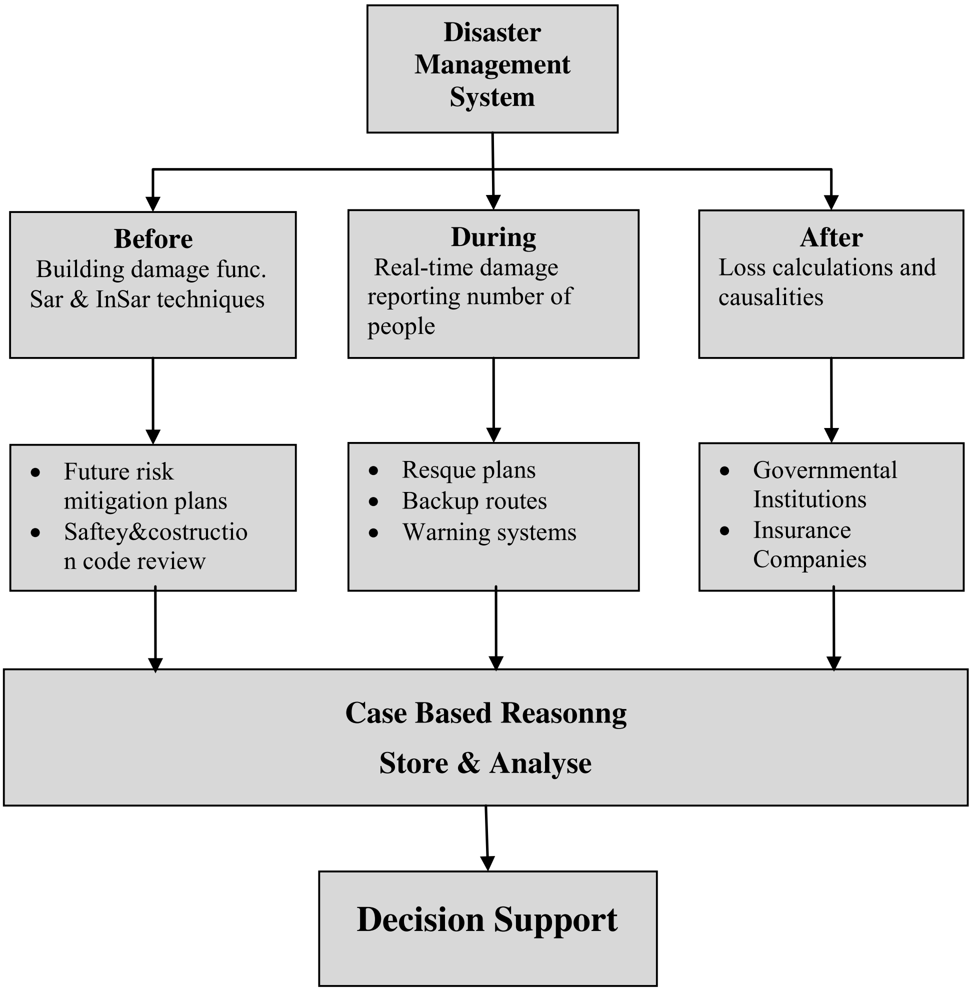

Fig. 1. A summary of the proposed disaster management system

2.1. Damage prediction methods

Damage forecasting and detection for buildings is still a difficult task to be fully achieved. Harsh environments are main sources for the undetected time accumulation of damages. In the current study, we take only sudden disasters into account (i.e, earthquakes).

From seismic side, there are many Bayesian probabilistic, Monte-Carlo simulations, stochastic, and remote-sensing based models and techniques developed for forecasting the occurrence of earthquakes. In the current study, we focus on the reaction of buildings and public structures to earthquakes. The prediction of damage levels are studied through different approaches. A common approach is the vibration-based one, the reaction of buildings to different levels of seismic shocks are translated into a self-property of the building's natural frequency (Doebling et al. 2001). These types of models show good success in simple structures, and their success rate decreases in predicting the place of the damage in complex structures due to the increase in noise level.

2.2. Properties of buildings and parameters

The integrity of any building structure is governed by some key parameters and the related prediction model used to describe it. The current model is based on parameters, which are chosen from data for damaged buildings. The data were collected from different regions after the three big earthquakes mentioned above. Using these considerations, the following parameters were considered in this study:

1. Intensity of earthquake
2. Age of the building
3. Number of stories
4. Average floor area
5. Column area

2.3. Damage levels

The current model is based on the classification of damage levels is based on the European Macroseismic scale and shown in Table 1.

Table 1. The damage degrees and their descriptions. The classification is based on the European Macroseismic Scale.

D_i	Damage Level	Description
0	undamaged	No structural damage
1	Slight damage	Small cracks or loss of doors or windows – possible replacement
2	Moderate damage	Damage of non-supporting elements
3	Heavy damage	Major cracks or complete damage of supporting elements, collapse of supporting elements
4	Partial-total damage	Partial or complete due to collapse of one or more walls which led to collapse of the roof or collapse of one or more stories

2.4. Data sources and preparation

The process of evaluating buildings after earthquakes and extracting the damage information is not straightforward. The key problem in the current work lies in the collection of complete, reliable and consistent data sets directly after the earthquakes. The collected data should include the main parameters we found vital to the health of any structure. Very high resolution remote-sensing-based applications are accurate but they require field justifications and are sometimes limited by some factors as weather condition and rescanning period. Table 2 contains a set of 38 building types with different damage levels.

Table. 2. The available data for past earthquakes in Turkey (source: Anatolianquake.org).

#	Intensity	Stories	Year	Avg_area	Col_area	Col_index	Damage D_i
1	6,0	5	1997	417,3533	7,65	0,78	3
2	6,0	4	2002	235,13	3,79	1,58	3
3	6,0	3	2002	265,1	3,3	1,82	4
4	6,0	3	2002	111,3833	1,58	3,80	3
5	6,0	3	1985	165,98	2,63	2,28	3
6	6,0	3	1976	197,03	1,36	4,41	3
7	6,0	3	1976	344,22	6,37	0,94	1
8	6,0	4	1975	129,975	2,16	2,78	3
9	6,0	4	1985	140,36	1,6	3,75	2,5
10	6,0	4	1994	235,44	5,28	1,14	1
11	6,0	3	1990	118,63	1,6	3,75	2
12	6,4	3	1975	306,06	6,72	0,95	2
13	6,4	4	1998	787,2	10,5	0,61	2
14	6,4	4	1988	827,78	16,42	0,39	1
15	6,4	4	2002	550,2	5,37	1,19	0
16	6,4	5	1990	646	5,31	1,21	1
17	6,4	4	1989	138,515	2,13	3,00	3
18	6,4	4	1996	467,23	5,25	1,22	0
19	6,4	3	2003	110,7833	1,8	3,56	1
20	6,4	4	2003	148,2333	1,9	3,37	4
21	6,4	4	1976	602	13,7823	0,46	1
22	6,4	3	1991	260,05	3,78	1,69	2
23	6,4	4	1997	145,78	3	2,13	1
24	6,4	3	1995	117,3467	2	3,20	0
25	7,2	4	1990	206	3,2	2,25	3
26	7,2	4	1987	245,3333	5,26	1,37	1
27	7,2	5	1985	157	3,22	2,24	3
28	7,2	4	1975	254,6	3,58	2,01	3
29	7,2	4	1975	130	2,06	3,50	1
30	7,2	3	1981	127	2	3,60	1
31	7,2	4	1980	135	2	3,60	2
32	7,2	5	1993	578,6667	11,71	0,61	2
33	7,2	5	1996	210	4,49	1,60	2
34	7,2	4	1995	358,3333	5,78	1,25	3

35	7,2	2	1970	147	3,08	2,34	1
36	7,2	3	1974	173	2,3	3,13	1
37	7,2	5	1991	306	4,98	1,45	3
38	7,2	5	1988	204	4,3	1,67	3

2.5. Neural network models

Neural networks are used in many areas of science because of their flexibility to model nonlinear systems where other approaches are difficult to use or implement. With the available, the neural network can be trained by appropriate learning algorithms. The performance of the network will critically depends on the type of neural network and on its topological structure. In the current study we used a simple feed forward neural network with two layers. As learning algorithm, the resilient and back propagation algorithms have been applied in training the network. We have used the Encog Machine Learning Framework for the computations.[4]

3. Results

The following feed forward 2-layer neural (4-3) network (Fig. 2) with 4 and 3 neurons in the second and third layers, respectively, was trained using different learning algorithms such as resilient and back propagation algorithms. In both cases the error rate for the training set was obtained as 1.44% (see Fig. 3).

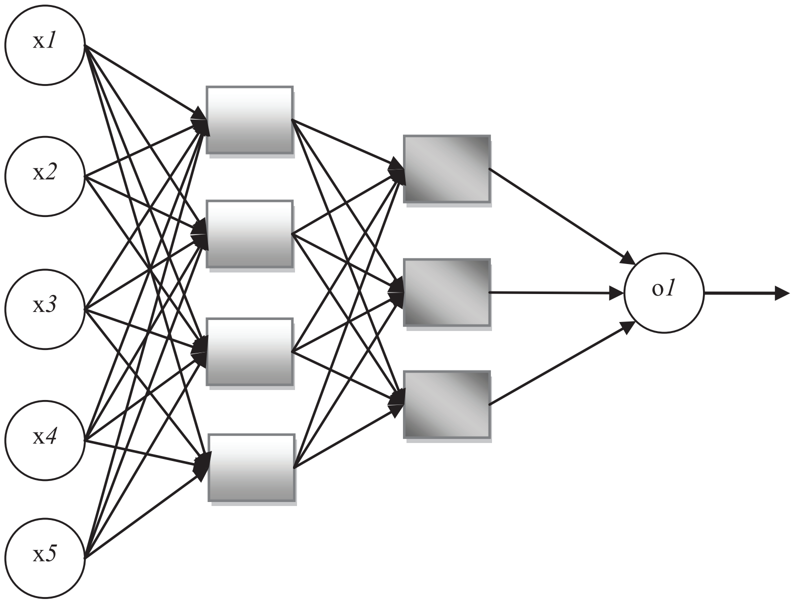

Fig. 2. Two-layer feed forward network

The input layer consists of the parameters considered for the model; x1: intensity of earthquake, x2: age of building (w.r.t. earthquake date in years), x3: number of stories, and x4: column index. Other variations such as two-layer networks with 5 neurons in the first layer and 3 neurons in the second layer (4-3) have also been tried but they resulted in poorer performance.

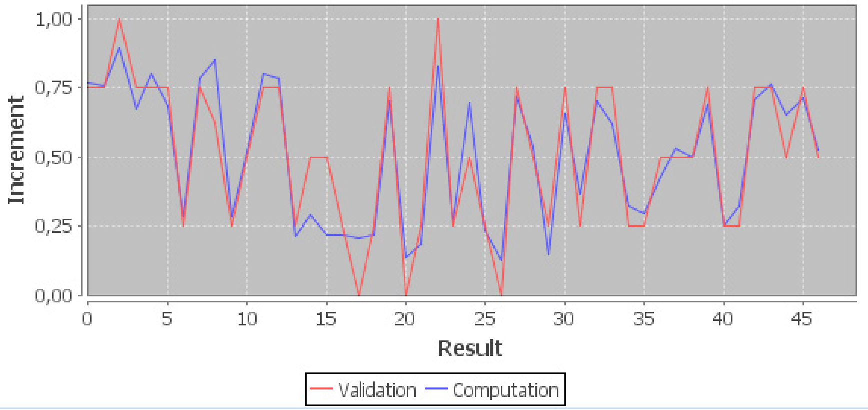

Fig. 3. Training error for network model; 1.0%

In addition to the data set we also used a separate data set for validation purposes, which consists of 3 additional real building examples from each of the three regions. The error rate for the validation set was obtained as 0.47% (see Fig. 3).

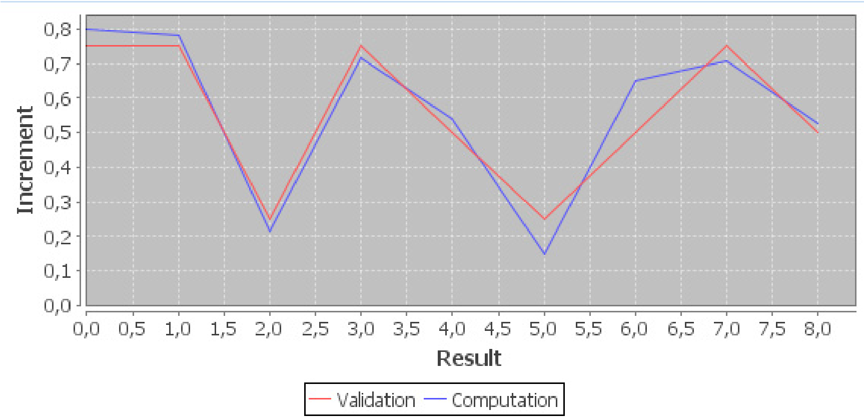

Fig. 4. Validation error for network model; 0.47%

We note that in this initial study we worked with a limited number of parameters and also a limited number of examples. Nevertheless, it can be seen that the results are promising and need further investigation. As mentioned before, we also tried alternative network models. For example, a similar network structure but with 3 neurons in the first and second layers (3-3) resulted in a training error of 3.85% but improved validation error of 10.94%.

4. Conclusion

The process of evaluating and predicting the reactions of buildings after strong earthquakes is a vital task to minimize future losses. Manual investigations by experts are sometimes not fast due to the limited resources. In the current study we suggest a supportive method for pre-earthquakes evaluation that helps accelerating the evaluation process.

The prediction process is very complicated task, mainly due to the large number of parameters and the non-linear coupling among them. The current method is based on artificial neural network technique that considers the non-linear correlations between buildings' parameters. In the current study we concentrate on understanding the effects of structural main elements, namely the design parameters. We plan to extend these parameters in future studies to build more complicated model.

Our analysis started with some basic descriptive statistics and correlations between the parameters, no simple linear dependence has been found. This supported the idea of using neural network models. The current data set consisting of 38 training examples and a separate data set consisting of 6 test samples, the neural network approach gives surprisingly good results. The error rates for training as well as validation (test) are both below 1%. It important to mention here that the current data set is collected after the occurrence of three big earthquakes in Turkey that may reflect a narrow range of shaking intensities and thus further research is required with a wider data range.

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