COMPARISON OF THE ISTANBUL EARTHQUAKE LOSS ASSESSMENT STUDIES

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Abstract

Earthquakes caused tens of thousands of life losses, billions of dollars of economic losses and fear for the next one and the impact of it. The fear and the desire to be prepared for the next earthquake developed the loss assessment studies. People who are responsible for the economic and social wellness of the cities and the countries desired to know what will be the impact of the next earthquake and how can they mitigate it. The first studies included the impact of the past earthquakes and the extrapolation of the previous ones to possible earthquakes. Then, several assessment methodologies used to estimate. Following the 1999 earthquakes in Kocaeli and Duzce, several earthquake loss assessment studies carried out for the long expecting possible Istanbul earthquake. All those studies contain different approaches, methods, calculations and estimations. Except from the earthquake loss estimation systems and studies in Turkey, there are also several earthquake loss assessment systems around the world. The estimation results changes with respect to hazard assumptions like, earthquake scenarios that are used, fault mechanism definitions, attenuation models, liquefaction effects, vulnerability functions like, fragility definitions, and inventory classifications like, data models and types, data resolution and reliability, and inventory detail. Except from the differences given above, the assessment calculations may also change based on the calculation methodologies. This paper compares the earthquake loss assessment systems and studies firstly, with respect to basic components of those systems. The second comparison is made based on the differences of the estimation results of the earthquake loss assessment studies, which are made for City of Istanbul and Zeytinburnu District.

Introduction

The earthquake loss assessment studies all over the world are constituted because of the damages caused by the earthquakes. One of the most destructive disasters all over the world is the earthquakes with an average of 10000 loss of life each year, while accompanying billions of dollars of economic losses (Table 1). Earthquakes caused development of several disciplines concerning earthquakes like seismology, geosciences, structural and geotechnical engineering, earthquake engineering, information technologies, disaster and emergency management over the past century. However, it is understood that, to achieve more satisfying research results interdisciplinary studies are required. Loss assessment studies of last few decades carried out interdisciplinary.

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Table 1 Losses of the earthquakes around the world

Location	*Date*	*Mw*	*Economic Loss*	*Loss of Life*	*Reference*
Loma Prieta, USA	October 17, 1989	6.9	$10 billion	62	EQE Report, 1989
Northridge, USA	January 17, 1994	6.7	$20 billion	60	SSC Report No. 95-01, 1995
Kobe, Japan	January 17, 1995	6.9	$150 billion	6000	EQE Report, 1995
Kocaeli, Turkey	August 17, 1999	7.4	$13 billion	20000	Bibbee et al., 2000
Bhuj, India	January 26, 2001	7.9	$5 billion	18600	EERI Report, 2001
Bam, Iran	December 26, 2003	6.6	$1.5 billion	43000	EEFIT Report, 2004
Kashmir, Pakistan	October 8, 2005	7.6	$5.2 billion	80000	MAE-Center Report No. 05-04, 2005
Sichuan, China	May 12, 2008	8.0	$146 billion	69000	Miyamoto, 2008

The disciplines included within the loss assessment studies also use several methodologies and approaches to derive the consequences of the earthquake related to that single discipline. Results of the disciplines are used by the other disciplines to derive their results or estimations. This loop generates the assessment of the earthquake losses. If the variations of every single discipline's methodologies, approaches and the resulting estimations are to be considered, it can be clearly realized that, the possible consequences of the loss assessment studies are infinite.
By comparing the loss assessment studies, it can be understand that, because of the variations of the approaches and the methodologies, the estimation results of the studies can be varied heavily. This paper compares the methodologies, approaches, inventories and results of the remarkable loss assessment studies for Turkey. The classifications of the comparison are done by four classes as hazard, fragility, inventory and results.

Theory and Method

The loss assessment studies all over the world constituted within the general headings of hazard, fragility, inventory and estimation results. So, it can be said that, the ingredients of seismic loss assessment are hazard (exposure), vulnerability or fragility (sensitivity), inventory (value) and integrated visualization (losses). Hazard is described as an input ground motion parameter or a spectral response value. Vulnerability or fragility is given as a conditional probability of an asset (inventory unit) reaches or exceeds a damage threshold. Inventory data describe the location and characteristics of the assets of interest to the decision-maker seeking the loss assessment results. Integration and visualization is an essential framework to use hazard, fragility and inventory to evaluate physical and economical impact, given the loss functions that translate damage into loss of value.

Hazard

As described above the hazard is about the earthquake impact on the region of interest and consists from focal mechanism to topography and geology of the study region. The main ingredients of the hazard are focal mechanism, earthquake scenario, attenuation models, soil classification, liquefaction susceptibility, and topography of the region. All of the above have influence on the impact of the earthquake on the study region. The methods that were used to derive the data or the approaches that were followed could diverse the results of the hazard. For example, use of an attenuation model with the same earthquake scenario, with the same focal mechanism, can give different results if, the soil classification, or liquefaction or topographic effects are given different weights or vice versa. Even the change on the smallest weighted ingredient gives a different result for the hazard.

Vulnerability

Amongst the above ingredients of loss assessment, the definition of reliable vulnerability functions poses a number of challenges such as: (i) the dearth of statistically-viable damage data across the range of limit states and ground motion shaking severity and (ii) the difficulties associated with defining analytical limit state indicators that can be monitored in dynamic analysis. Each of the two challenges poses further questions and dictates research agendas. The selection of the input motion data set, definition of the response parameters and the analysis method used as well as the random parameters selected to represent the response of the population can also change the estimated response of the structure (Elnashai, 2007).
Relationships between shaking intensity, or system demand, and the conditional probability of the same system reaching or exceeding a response limit state are referred to as vulnerability or fragility functions. Derivation of useful vulnerability functions requires the definition of limit states that are meaningful in the context of loss assessment. Selection and quantitative definition of limit states is therefore central to the derivation of system vulnerability.
Existing uncoupled vulnerability curves can be classified into the four generic groups of empirical, judgmental, analytical and hybrid according to whether the damage data used in their generation derives mainly from observed post-earthquake surveys, expert opinion, analytical simulations, or combinations of these respectively. Each data source has associated advantages and disadvantages. In Table 2, a summary of existing approaches for empirical, judgmental and analytical fragility derivation are summarized and their relative accuracy and required computing effort are compared (Elnashai, 2007).

Table 2 Comparison of fragility assessment methods (Elnashai, 2007)

Methods	***Empirical***	***Judgmental***	***Hybrid***	***Simple analytical model***	***Detailed analysis procedure***
Effort		*increasing time and computation effort* →			
Precision		*accuracy of the assessment* →			
Application	building stock				individual building

Inventory

The reliability of the loss assessment analysis can be reached only if the input data is of high quality. The accuracy of the estimation results of an earthquake loss assessment process depends on the accuracy and the detail of the data used for the analyses. This dependency forces loss assessment studies to acquire all available data for the study region. The date, resolution, accuracy, format, type, classification, datum and projection, reliability and renewability of the inventory directly affect the estimation results.

Loss Assessment Software Around the World

There are several loss assessment tools existing worldwide. However, most of them are proprietary, closed code, region-specific or all the above. The use of a loss assessment tool of another country constrains the data usage, classification, and units. Besides, tools constrain the administrative units for aggregation, earthquake source and path features, vulnerability of the inventories, and the cost functions and other socio-economic parameters, which must be specified for the region of interest (Karaman et al., 2008). Most of those tools use the Geographic Information Systems (GIS) to visualize the inventory, hazard, and the estimation results.

The pioneer and the leader of these tools are HAZUS (Hazards-U.S.), which was developed by National Institute for Building Science (NIBS) and Federal Emergency Management Agency (FEMA). The initialization of the HAZUS started in 1992, resulting from a study of National Science Foundation (NSF) in 1989 following the 1989 Loma Prieta Earthquake in United States.

KOERILoss software is developed by the Kandilli Observatory and Earthquake Research Institute (KOERI) of Earthquake Engineering Department of Bogazici University. The software applies a loss estimation methodology (Probabilistic vs. Deterministic) developed by KOERI. This tool can work through Geo-cells system, which does not apply the analyses to every single structure but, to minimum defined region (KOERI, 2002).

Using the core of HAZUS capacity spectrum method method (FEMA 1999, 2004) within a logic-tree computation scheme in order to account for epistemic uncertainties, an open-source tool was developed under MATLAB and called SELENA (SEimic Loss EstimatioN using a logic tree Approach; Molina and Lindholm, 2006) by the International Centre for Geohazards, through NORSAR and the University of Alicante (Spain). SELENA can compute the probability of damage in each one of the four damage states (Slight, Moderate, Extensive and Complete) for defined building types (Lang et al., 2008).

ESCENARIS has been developed for application in Barcelona and the surrounding Catalonia region by the Institut Geologic de Catalunya (IGC). The software includes two levels of complexity. In Level 0, inbuilt EMS-98 vulnerability classes are used in conjunction with a built-in statistical vulnerability classes distribution developed for the Catalonia region (Roca et al., 2006). The Level 1 approach is based on the vulnerability index method with the vulnerability indexes and structural typologies defined within the RISK-UE project (Mouroux and Le Brun, 2006). The ESCENARIS software is integrated with a rapid response system operating over the eastern Pyrenees (Dominique et al., 2007). The software tool used by the Spanish Civil Protection for the assessment of potential earthquake losses in any municipality in Spain, SES 2002 (Simulacion de Escenarios Sismicos), is based on the Level 0 ESCENARIS software (Strasser et al., 2008).

An Italian tool of SIGE is the Emergency Management Information System developed by the Italian Department of Civil Protection in 1995. SIGE includes a seismic scenario analysis module (Di Pasquale et al., 2004). The SIGE-DPC tool is currently under development for the characterization of earthquake sources and the treatment of uncertainties. Intensity-based loss estimation is used in SIGE. However, Sabetta et al. (1998)'s empirical fragility curves for PGA and spectral response ordinates can be used (Strasser et al., 2008).

DBELA (Displacement-Based Earthquake Loss Assessment) is a new methodology for loss estimation that is currently under development. Predictions of the degree of structural and non-structural damage to building classes under both ground shaking and liquefaction-induced ground failure can be carried out with this method. Building classes might encompass reinforced concrete buildings, buildings with structural walls or dual (wall-frame) system buildings (Pinho and Crowley, 2007).

Another extensive and significant loss assessment tool is the MAEviz, which has been developed by the Mid-America Earthquake Center. MAEviz is a broadly extensible, open source platform for earthquake hazard risk management. MAEviz is a model cyber environment that provides

practical capabilities for researchers through decision-makers to model earthquake events, develop risk reduction strategies, and implement mitigation plans to minimize the impact of earthquake disasters while also providing a pathway for researchers to quickly add new algorithms and data to assure that decisions are based on state-of-the-art engineering understanding (Elnashai et al., 2008).
The objective of the HAZTURK system is to provide a reliable loss estimation analysis that can be used by a region or municipality for earthquake hazard preparation and mitigation. These practices will help to secure Turkey's communities, businesses, housing, and infrastructure from earthquake disasters. This system can manage geological, seismological, geotechnical, structural, and geodetic approaches in a single tool. HAZTURK (MAEviz-Istanbul) 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 (Karaman et al., 2008).

Loss Assessment Studies for Istanbul

The latest study for the loss assessment of Istanbul is HAZTURK (2008). This study represents the estimations for the damage on the structures with respect to several earthquake scenarios that were estimated by the HAZTURK software, which is a modified version of the MAEviz for Turkey.
Another important study for Istanbul building damage is carried out by Bal et al., (2008) by using the DBELA software for Istanbul. With a Mw = 7.5 scenario earthquake.
JRA3 of the NERIES (2007) Project present a series of comparative results for Istanbul by using different five loss assessment software with respect to Mw = 7.5 earthquake scenario in main Marmara fault.
Project NERIES has also includes studies for the loss assessment of Istanbul by using four different tools. The results of the estimations are also presented by the Strasser et al., (2008).
Istanbul Metropolitan Municipality's company BIMTAS (2007) has also conducted a loss assessment study on Zeytinburnu district with judgmental approach.
Kucukcoban (2004) estimate a series of results for Istanbul for a Mw = 7.5 scenario earthquake for the master of science thesis.
Yakut et al. (2006) presented a procedure developed for the seismic performance assessment of low- to mid-rise reinforced concrete buildings in Turkey by using a damage index derived from spectral displacements. The scenario earthquake of Mw = 7.5 was applied for only 3,036 buildings with a range from one to seven stories.
The most comprehensive study for the region is carried out by The Pacific Consultants International and OYO Corporation as JICA for IMM. This study offered 4 scenario earthquakes but used just two of them as the most probable (Mw = 7.5) and the worst case (Mw = 7.7) scenarios.
Another detailed study for Istanbul was carried out by the Kandilli Observatory and Earthquake Research Institute of Bogazici University in 2002 with the name of ''Earthquake Risk Assessment for Istanbul Metropolitan Area.'' The expected building damages are given by intensity based and spectral displacement based deterministic approaches.
The study conducted by a consortium of leading universities in Turkey is named as ''Earthquake Master Plan for Istanbul.'' This study used Model A, which is the most probable scenario from the JICA (2002) study,

Results

The comparisons between the loss assessment studies of Istanbul are made through the hazard, fragility, inventory and estimation result classes. The differences between the study methodologies, approaches, calculations, data and estimation results are given in tables. The approaches and the methods used within the analyses are also denoted to separate the details of the systems.

Hazard

Hazard studies of the loss assessment projects are compared in focal mechanism, earthquake scenario, attenuation models, soil classification, liquefaction susceptibility, and topography of the region. Table 3 presents the comparisons for the hazard studies of Istanbul.

Table 3 Comparisons for the ingredients of the hazard studies

	Earthquake Scenario	*Focal Mechanism*	*Attenuation Models*	*Soil Classification*	*Topographic Effect*	*Liquefaction Effect*
JICA (2002)	7.5 Mw 7.7 Mw	Strike Slip	Boore et al., (1997) Campbell (1997) Spudich et al., (1999)	NEHRP	Slope Failure Slope Stability	TC4, ISSMFE(1993)
KOERI (2003)	7.5 Mw Deterministic Probabilistic	Strike Slip	Boore et al., (1997) Sadigh et al., (1997) Campbell (1999) Erdik et al., (1985) Özbey (2001)	NEHRP	Slope Gradient	Youd & Perkins (1978)
IDMP (2003)	7.5 Mw	Strike Slip	JICA (2002) KOERI (2003)	NEHRP	Judgmental	None
Kucukcoban (2004)	7.5 Mw	Strike Slip	Gülkan & Kalkan (2002) Abrahamson & Silva (1997) Sadigh et al., (1997) Boore et al., (1997)	NEHRP TEC	None	None
Yakut et al., (2006)	6.0-7.5 Mw	Strike Sllip	Boore et al., (1997) Gülkan & Kalkan (2002) Abrahamson & Silva (1997)	Turkish Seismic Codde	None	None
HAZTURK (2008)	User Defined	User Defined	Kalkan & Gülkan (2004) Özbey et al., (2004) Ulusay et al., (2004) Boore et al., (1997) Sadigh et al., (1997) Spudich et al., (1999) Boore & Atkinson (2006) Campbell & Bozorgnia (2006) Chiou & Youngs (2006)	NEHRP	Eurocode 8	Youd & Perkins (1978)
Bal et al., (2008)	7.5 Mw	Strike Slip	Erdik et al., (1985) Evernden & Thomson (1985) Boore et al., (1997) Campbell (1997) Sadigh et al., (1997)	NEHRP	None	None
Bimtas (2007)	N/A	None	None	None	None	None
ESCENARIS (2008) - a	7.5 Mw	Strike Slip	Erdik et al., (1985) Evernden & Thomson (1985) Boore et al., (1997) Campbell (1997) Sadigh et al., (1997)	NEHRP	None	None
ESCENARIS (2008) - b	7.5 Mw	Strike Slip	Erdik et al., (1985) Evernden & Thomson (1985) Boore et al., (1997) Campbell (1997) Sadigh et al., (1997)	NEHRP	None	None
SIGE-DPC (2008)	7.5 Mw	Strike Slip	Erdik et al., (1985) Evernden & Thomson (1985) Boore et al., (1997) Campbell (1997) Sadigh et al., (1997)	NEHRP	None	None

Vulnerability

Vulnerability studies of the loss assessment projects are compared in damage states, analysis method for determining the damage on the structures, input motion datasets for simulating the response of the structures of the study region, demand type and units of the fragility or capacity curves and update possibility of the vulnerabilities. The comparison can be seen in Table 4 for the vulnerability studies.

Table 4 Comparisons of the ingredients for the vulnerability studies

	Update Possibility	*Damage States*	*Analysis Methods*	*Input Motion Dataset*	*Demand Type and Units*
JICA (2002)	N/A	Heavily Moderately Partly	Empirical	None	Sd (cm)
KOERI (2003)	N/A	Complete Extensive Moderate Slight	Empirical Analytical	None	Sd (cm) MSK-81 Intensity
IDMP (2003)	No	N/A	N/A	None	N/A
Kucukcoban (2004)	Yes	Heavy Moderate Light	Demand Spectrum Capacity Spectrum	None	Sd (cm)
Yakut et al., (2006)	N/A	Severe Collapse Moderate Light	Damage Indexes	None	Sd (cm)
HAZTURK (2008)	Yes	Complete Heavy Moderate Insignificant	Empirical Analytical	42 Strong Ground Motions from San Andreas North Anatolian Zone	PGV (cm/s) PGA (g) Sd (in) Sa (g)
Bal et al., (2008)	Yes	Collapse Extensive Moderate	Displacement Capacity	None	Sd (cm) Sa (g)
Bimtas (2007)	N/A	Heavy Moderately Partly	Judgmental	None	None
ESCENARIS (2008) - a	Yes	Heavy Beyond Repair	Judgmental, Statistical Vulnerability Class	Catalonia Strong Motions	MSK-76 Intensity
ESCENARIS (2008) - b	Yes	Heavy Beyond Repair	Judgmental, Vulnerability Index	Catalonia Strong Motions	N/A
SIGE-DPC (2008)	Yes	Collapse D5 … No Damage D0	Damage Probability Matrices	None	MSK-76 Intensity

Inventory

The possibility to update the data of the region of interest is one of the most important characteristic of the loss assessment studies. Because of the development on the cities all the estimation needs to be updated with respect to new inventory of the region of interest. Other important features for the inventories are the type and format of the data used, types of the buildings accepted within the analyses, resolution of the data that can be put into the analyses, date of the data, and one of the most important feature datum and projection of the datasets that can be ingested into the system and analyses. Below in Table 5, the comparison for the inventories of the loss assessment studies are represented.

Table 5 Comparisons of the inventories for the loss assessment studies

	Update Possibility	*Data Type*	*Data Format*	*Building Types*	*Data Resolution*	*Date of the Data*	*Datum and Projection*
JICA (2002)	No	Regional	ArcGIS	5 Types	Sub-district	2001	ED50 UTM 3°
KOERI (2003)	Slightly	Regional	MapInfo	4 Types	0.005x0.005° Geo-cells	2001	N/A
IDMP (2003)	No	N/A	None	N/A	N/A	2001	N/A
Kucukcoban (2004)	Yes	Regional	ArcGIS Excel	6 Types	0.005x0.005° Cells	2001 2004	N/A
Yakut et al., (2006)	N/A	N/A	N/A	1 Type	N/A	2005	N/A
HAZTURK (2008)	Yes	Point Polygon Polyline Regional	ArcGIS Raster Excel XML	12 Types HAZUS	User Defined	2007 2001	WGS84 - GCS
Bal et al., (2008)	Yes	Regional	ArcView	4 Types	0.005x0.005° Cells	2001	N/A
Bimtas (2007)	N/A	N/A	N/A	12 Types	Building Based	2007	ED50 UTM 3°
ESCENARIS (2008) - a	Yes	Regional	ArcView	4 Types	0.005x0.005° Cells	2001	N/A
ESCENARIS (2008) - b	Yes	Regional	ArcView	4 Types	0.005x0.005° Cells	2001	N/A
SIGE-DPC (2008)	Yes	Regional	ArcView	4 Types	0.005x0.005° Cells	2001	N/A

Discussion

It is determined that the estimation results of different studies vary within a wide range. If the big differences between the estimation results neglected, the range get smaller. It is also realized from this study that the variety of the results are resulting from the differences in approach for the determination of the vulnerabilities, analysis methods, acquisition of the input data, and use of the datum and projection for the inventory. The small differences are resulting from the selection of the attenuation relations, data types and resolutions, focal mechanism definitions, and inclusion of the amplification effect of topography and liquefaction. Consequently, if the subject is estimation it must be denoted that the results of the loss assessment studies only represents the possibilities of the damages on the structures in the region of interest. However, the results must be controlled with the previous studies and disasters' results to check whether the analyses and the methodologies are giving reasonable results or not. The unreasonable results and methods can be clearly recognized by comparisons. Comparing for one region is also not enough for assuring the reliability of the analyses. The results should also be compared for different regions and datasets to notice if the loss assessment system is credible or not. The next step for earthquake loss assessment studies can be denoted as a "single out of the box GIS software", which stores, analyze, query and present the estimations for the possible earthquake scenarios to the emergency managers.

Estimation Results

BIMTAS (2007)	***Partly***	***Moderately***	***Heavily***	
Judgmental	53.0	31.2	15.8	
SIGE-DPC (2008)	***D0+D1***	***D2***	***D3***	***D4+D5***
			40.00	3.64
ESCENARIS (2008)			***Heavy***	***Beyond Repair***
Level 0			13.80	7.80
Level 1			9.09	4.36
Bal et al., (2008)		***Moderate***	***Extensive***	***Collapse***
		27.24	11.05	6.37
Kucukcoban (2004) Mw 7.5	***Insignificant***	***Moderate***	***Heavy***	
IBB-New	0.02	82.79	17.20	
JICA-New	0.00	3.57	96.43	
JICA-Check	0.00	17.90	82.10	
HAZTURK Mw 7.5	***Insignificant***	***Moderate***	***Heavy***	***Complete***
Boore and Atkinson (2006)	43.78	35.60	16.40	4.22
Ozbey et al., (2004)	43.69	35.02	16.63	4.66
Boore et al., (1997)	36.12	36.99	20.14	6.75
Kalkan & Gulkan (2004)	30.91	37.69	22.74	8.66
JICA (2002) Mw 7.5	***H+M+P***	***H+M***	***Heavily***	
Boore et al., (1997)	61.2	34.0	16.6	
KOERI (2002) Mw 7.5		***Moderately Damaged***	***Extensive Damage***	***Complete***
Spectral Displacement Based		26.45	9.14	4.72
Intensity Based			***Heavy***	***Damage Beyond Repair***
			10.43	5.5
Yakut *et al.*, (2006)	***Low Risk***	***Moderate Risk***	***High Risk***	
	10	21	69	
EDMI (2003)			***Heavily Damaged Building Ratio***	
			13.22	

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