DEVELOPMENT OF RAPID EARTHQUAKE LOSS ASSESSMENT METHODOLOGIES for EURO-MED REGION

M. Erdik[1], Z. Cagnan[2], C. Zulfikar[3], K. Sesetyan[1], M. B. Demircioglu[1], E. Durukal[1], C. Kariptas[3]

[1]Bogazici University, Department of Earthquake Engineering, Istanbul, Turkey
[2] Middle East Technical University, Department of Civil Engineering, Cyprus.
[3]GRM Bilisim Company
Email: erdik@boun.edu.tr, zcagnan@gmail.com, can.zulfikar@boun.edu.tr, karin@boun.edu.tr, betul.demircioglu@boun.edu.tr, durukal@boun.edu.tr, , ckariptas@grmbilisim.com

ABSTRACT :

For almost-real time estimation of the ground shaking and losses after a major earthquake in the Euro-Mediterranean region the JRA-3 component of the EU Project entitled “Network of research Infrastructures for European Seismology, NERIES” foresees:

1. Finding of the most likely location of the source of the earthquake using regional seismotectonic data base, supported, if and when possible, by the estimation of fault rupture parameters from rapid inversion of data from on-line regional broadband stations.
2. Estimation of the spatial distribution of selected ground motion parameters at engineering bedrock through region specific ground motion attenuation relationships and/or actual physical simulation of ground motion.
3. Estimation of the spatial distribution of site-specific ground selected motion parameters using regional geology (or urban geotechnical information) data-base using appropriate amplification models.
4. Estimation of the losses and uncertainties at various orders of sophistication (buildings, casualties)

Main objective of this study is to develop a methodology for real time estimation of losses after a major earthquake in the Euro-Mediterranean region. The multi-level methodology being developed together with researchers from Imperial College, NORSAR and ETH-Zurich is capable of incorporating regional variabilities and sources of uncertainty stemming from ground motion predictions, fault finiteness, site modifications, inventory of physical ane social elements subjected to earthquake hazard and the associated vulnerability relationships. Within the scope of this paper, results obtained from a pilot application of this methodology for the 1999 Kocaeli earthquake are presented and comparisons with the observed losses are made.

KEYWORDS: **Earthquake Loss Assessment, ShakeMap**

1. INTRODUCTION

The Joint Research Activity 3 of the EU Project NERIES aims at establishing rapid estimation of earthquake damages, casualties, shelters and food requirements throughout the Euro-Med Region. Within the scope of this activity, a rapid loss estimation tool is being developed with researchers from Imperial College, NORSAR and ETH-Zurich The European rapid loss estimation (or LossMap) tool will enable effective emergency response and public information.

Available near real time loss estimation tools can be classified under two main categories depending on the size of area they cover: (1) Local Systems and (2) Global Systems. Several local systems capable of computing damage and casualties in near real time already exist in the Euro-Mediterranean region. The Istanbul Rapid Response System constitutes an example of the urban loss assessment systems (Erdik et.al. 2003). This System consists of 100 accelerograms distributed in the Metropolitan area of Istanbul in dial up mode. After triggered by an earthquake, each station processes the streaming strong motion to yield the spectral acceleration at specific periods and sends these parameters in the form of SMS messages to the main data center at Kandilli Observatory and Earthquake Research Institute (KOERI) through available GSM network services. A shakemap and damage

distribution map is then automatically generated based on the spectral acceleration data received, building inventory and the vulnerability relationships. In addition to several systems in Japan and Taiwan, the local systems that exist in the Euro-Mediterranean region are: the rapid response systems in the Eastern Pyrenees area at the French – Spain border, in Bucharest-Romania and the system in Naples region - Italy.
For the global near real time loss estimation efforts, Global Disaster Alert and Coordination System (GDACS), World Agency of Planetary Monitoring Earthquake Risk Reduction (WAPMERR) and the Prompt Assessment of Global Earthquakes for Response (PAGER) system of USGS can be listed. GDACS (http://www.gdacs.org) is based on issuing a three level alert based on the reported earthquake parameters, Landscan population dataset and the population vulnerability (from European Commision Humanitarian Aid Department Global Needs Assessment Indicator) of the region of interest. .
The PAGER system of USGS is designed to distribute three level alarms via internet similar to GDACS, in addition to information on the earthquake location, magnitude, depth, number of people exposed to varying levels of shaking, and region's fragility. This system uses the ground motion and intensity distribution maps that are produced by the USGS Shakemap system (http://earthquake.usgs.gov/eqcenter/shakemap) as input in addition to a three level approach for casualty and loss estimation. PAGER relies on empirical correlations between casualties and intensity to estimate number of fatalities.

2. EARTHQUAKE LOSSMAP METHODOLOGY FOR EURO-MED REGION

The methodology being developed for near real time estimation of losses after a major earthquake in the Euro-Mediterranean region consists of the following 4 main components:

1. Finding the most likely location of the earthquake source using regional seismotectonic data-bases
2. Estimation of the spatial distribution of selected site-specific ground motion parameters using attenuation relationships and geology or topographic slope based estimates of average shear wave propagation velocity in the upper 30m.
3. Incorporation of the available macroseismic and strong motion data with the estimated ground shaking
4. Estimation of physical damage and casualty distributions in different levels of sophistication that commensurate with the availability of inventory of human built environment.

This methodology, elaborated in Figure 1, will culminate in the development of the software, entitled Earthquake Loss Estimation Routine (ELER) which will constitute the deliverable of the NERIES project JRA3 component. The ELER tool will be open source and will allow community based maintenance and further development of the database and earthquake loss estimating procedures. The software will provide an estimation of losses in three levels analysis, as illustrated in Figure 1. These there levels of analysis are designed to commensurate with the available building inventory and demographic data.

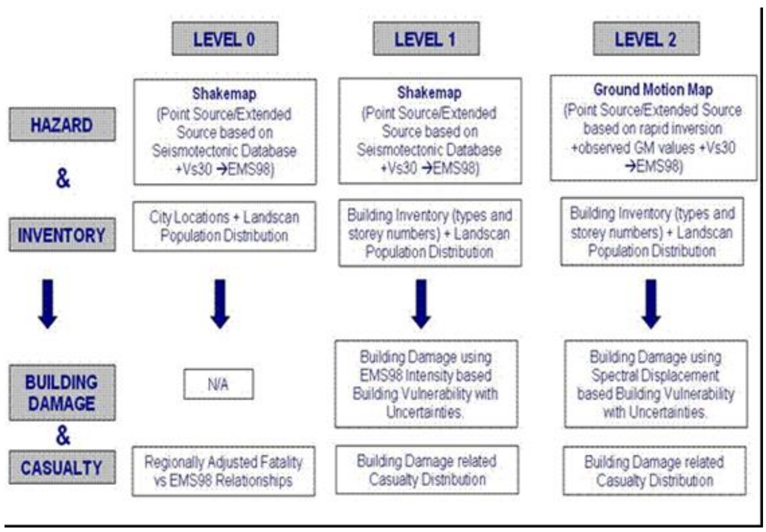

Figure 1. The levels of analysis to be incorporated in the ELER software.

3. ASSESSMENT OF SHAKEMAPS

As the flow chart shown in Figure 1 indicates level 0 type analysis is based on obtaining intensity distributions analytically and estimating total number of casualties using regionally adjusted intensity-casualty correlations. This level of analysis will be used at locations where instrumentation is rather scarce and building inventory databases are not available. In Level 0 analysis, epicenter locations obtained from EMSC are used as the earthquake sources for the case of magnitude <6.5 earthquakes. However for magnitude >6.5 earthquakes, based on seismotectonic databases and rupture length-magnitude relationships (i.e. Wells and Coppersmith, 1994), fault ruptures are estimated with the assumption that earthquake epicenters are at the mid points of corresponding fault ruptures. The intensity distributions are then computed using the three alternatives listed below:

a) Local and regional one- and two-dimensional intensity attenuation relationships
b) Tectonic regime specific ground motion attenuation relationships and various intensity correlations with PGV, PGA, and Response Spectrum (Wald et al. 1999, and Atkinson and Kaka, 2007)
c) Synthetic strong ground motions and available intensity correlations with Fourier Amplitude Spectrum (Sokolov, 2002)

Level 1 type analysis is based on obtaining intensity distributions analytically as well, however uses EMS98 based building vulnerability relationships (Lagomarsino and Giovinazzi, 2006) to estimate building damage and casualty distributions. This type of analysis will be employed at locations where instrumentation is rather scarce and region specific spectral displacement based vulnerability relationships are not available for various building types that exist in the region of interest. In level 1 type analysis, for the estimation of intensity distributions the methods listed above are used. Level 2 type analysis corresponds to the highest sophistication level in the loss estimation methodology being developed. This level of analysis is based on obtaining fault rupture parameters from rapid inversion of online regional broadband data. Selected ground motion parameters are then estimated using tectonic regime specific ground motion attenuation relations at engineering bedrock. These values are later amplified where necessary by employing geology databases. In level 2 type analysis, by enriching the estimated ground motion information with the available on-line strong motion data, the error level in the computed ground motion information is reduced. Finally, building damage and casualty distributions are then obtained using spectral displacement based vulnerability relationships and building damage related casualty vulnerability models respectively.

4. ASSESSMENT OF BUILDING DAMAGE

The vulnerability relationships and the building damage assessment methodologies that are identified for utilization in the ELER software development can be studied under the different levels of analysis.

Methodology for Building Damage Estimation in Level 0

For this level of analysis the inventory (default) will consist of population density (LandScan Population Distribution Data, 30 Sec-arc), city names, locations and populations. The level of analysis will not normally include any building damage assessment. The damage to physical elements can be roughly inferred through the intensities given through the Shakemaps. If a grid based (about 5km x 5km) distribution of the number of buildings can be inferred from the population distribution, number of people per building (as a function of the land use and income level) can be constructed (as elaborated in Section 0) then a very coarse estimate of number of damaged buildings can be given using EMS-1998 stipulations for different (region dependent) vulnerability classes.

Methodology for Building Damage Estimation in Level 1

In addition to the default data provided for Level 0 analysis, the building inventory data for the Level 1 analysis will consist of grid (geo-cell) based building distribution based on Risk UE Building Typology. Data from Turkey will be provided to set an example for other regions and countries to develop/incorporate their own inventory data. The intensity based empirical vulnerability relationships developed by Lagomarsino and Giovinazzi (2006).

Methodology for Building Damage Estimation in Level 2

Level 2 analysis is essentially intended for earthquake risk assessment (building damage and consequential human casualties) in urban areas. As such, the building inventory data for the Level 2 analysis will consist of grid (geo-cell) based urban building (RISK-UE typology) and demographic inventories. Sample data for Istanbul based on 150 sec-arc grids will be made available. Building damage assessment will be based on the following vulnerabilities and methodologies:

a). The empirical vulnerability relationships developed by Lagomarsino and Giovinazzi (2006)

b) The analytical vulnerability relationships based on the Coefficient Method, Equivalent Linearization Method and the Reduction Factor Method.

5. ASSESSMENT OF CASUALTIES

For the assessment casualties the following levels of analysis are foreseen:

Methodology for Casualty Estimation in Level 0

Loss estimation at Level 0 basically involves the estimation of casualties directly from the calculated Shakemap. In other words, building inventory and building damage assessment is not an ingredient of the casualty estimation at Level 0. As such, casualty vulnerabilities relating casualties directly to the earthquake magnitude and intensity distribution will be used at this level.

The regional variability of the earthquake vulnerabilities and casualty rates can also be associated with the social wealth of a country. In this context economical indicators such as the Gross Domestic Product (GDP) for different regions of the world will be analyzed with the aim of introducing the economic wealth as a parameter in the assessment of casualties.

Two approaches will be used in Level 0.

Samardjieva and Badal (2002) and Badal et al. (2005) Approach

The following procedure will be used for Level 0 casualty estimation.

1. Obtain the intensity distribution resulting from the earthquake (ShakeMap).
2. Obtain grid based population distribution and average population density (D_I) for zones of intensity I.
3. Obtain the distribution of the casualties in different intensity zones from the model suggested by Christoskov et al. (1990). This model assumes that the number of casualties decreases proportionally with the square of the epicentral distance, R, similar to the attenuation of the seismic energy, $N \sim 1/R^2$. A factor W_i, depending on the radii R_I of the areas of intensity I was introduced. For example, in the case of observed intensities I = VII, VIII, VIX (MSK), the weighting coefficients W_I are:

$$W_i = 1/\left[R_I^2 \sum_j \left(1/R_j^2\right)\right], j = \text{VII, VIII, IX} \qquad (5\text{-}1)$$

Then, the number of people killed within the area of intensity I can be determined by the equation:

$$N_k^I = W_I \cdot N_k(D_I) \qquad (5\text{-}2)$$

where the value of $N_k(D_I)$ is estimated from equation (101) for the average population density D_I in the area intensity I. The total number of human losses is the sum of the values N_k^I.

4. Obtain the grid based casualty distribution from:

$$Deaths\ per\ unit\ area_I = N_k^I \cdot \frac{Population\ per\ unit\ area_I}{Total\ population_I} \qquad (5\text{-}3)$$

$$Injuries\ per\ unit\ area_I = N_{inj}^I \cdot \frac{Population\ per\ unit\ area_I}{Total\ population_I} \qquad (5\text{-}4)$$

Casualty estimation procedure based on building damage

This procedure is based on the estimation of number of buildings damaged beyond repair in settlements affected by an earthquake and the assessment of casualties accordingly. As the number of buildings in a settlement is not known in Level 0 assessments, this procedure will encompass the following steps.

1. Obtain the intensity distribution resulting from the earthquake (ShakeMap).
2. Obtain grid based population distribution.
3. Estimate and/or assign number of buildings in a unit area (e.g. 5 km x 5 km grids) based on population distribution and land use information (urban vs. rural) and regional correlation studies on population per building.
4. Assignment of EMS-98 vulnerability classes for the building stock in a region, depending on the level of development or GDP.
5. Conduct a damage assessment study based on intensities as in Level 1.
6. Estimate the number of fatalities based on the number of buildings damaged beyond repair together with the error bounds.

Methodology for Casualty Estimation in Level 1

Casualties in Level 1 will be estimated based on the assessment of number of buildings damaged beyond repair Intensity Based Building Damage Assessment. Regional casualty models correlating number of fatalities and injuries with the number of damaged building will be utilized together with the error bounds.

Methodology for Casualty Estimation in Level 2

Casualties in Level 2 will be estimated based on the assessment of number of buildings in different damaged states, obtained in Level 2 Building Damage Assessment based on analytical methods. The methodology of HAZUS99 and HAZUS-MH will be used in the estimation of casualties. Modifications in the casualty rates will be proposed if necessary.

Within the scope of this study, we applied the methodology explained above to 1999 Kocaeli earthquake. The sophistication level employed is level 1 in this test run. The methods used to develop analytical intensity distribution maps for 1999 Kocaeli earthquake, and the building inventory and population databases employed for loss estimations are discussed in detail below. Comparison of results with the observed building damage and casualty distributions are also provided.

6. APPLICATION OF EARTHQUAKE LOSSMAP METHODOLOGY TO 1999 KOCAELI EARTHQUAKE

The analytical intensity distribution maps corresponding to 1999 Kocaeli earthquake were obtained by both using PGA, PGV-intensity correlations (Figure 2a and Figure 2c) and Fourier Amplitude Spectrum-intensity correlations (Figure 2b). The fault rupture solution obtained from broad band data was used (Figure 2a and Figure 2b) as well as the fault rupture surface obtained empirically using the regional seismotectonic database and empirical magnitude – rupture length relation given in Wells and Coppersmith (1994) (Figure 2c). Figure 2a and Figure 2c were obtained by computing the PGA, PGV distributions for Kocaeli earthquake using Boore and Atkinson (2006) attenuation relationships. The QTM map developed by the Turkish Republic's General Directorate of Mineral Research and Exploration was used in addition to Vs30-QTM correlations given in Wills and Silva (1998) to obtain site specific PGA and PGV values. Figure 2b was obtained using the FAS computed at various locations throughout the area of interest based on the functional forms provided by Boore (2003) and FAS-intensity correlations give in Sokolov (2002). In Boore (2003), the radiated spectrum is described with Eqn. 3.2 where S(f) is the source spectrum, D(f) is the diminution factor, and G(f) is the site amplification factor. For S(f), D(f) and G(f) the models developed for California region in Frankel et al. (1996), Boore (1984), and Boore and Joyner (1997) was used respectively. For the los assessment, year 2000 population and building census tracks of the State Statistical Institute were utilized. These data were first geocoded in district base. However as the district size throughout the study area had large variability (from a few to more than one thousand square kms) a grid based damage assessment was thought to be more approriate. As such, a grid size of 0.05° x 0.05° (4km by 5.5km) was chosen and the data were aggregated to these geocells. The geographical distribution of the population and building inventory within a district was obtained based on the Landscan population distribution data and lumped to the geocells accordingly. The population thus obtained represented the cell based nighttime distribution and the buildings were grouped according to the construction type as well as the number of stories for the reinforced concrete structures. This building typologies coincided well with those covered by the vulnerability relationships considered for damage assessment. The EMS98 based building vulnerability relationships developed for adobe, rubble, masonry, moderate earthquake resistant design (ERD) lowrise, midrise and highrise reinforced concrete buildings by Lagomarsino and Giovinazzi (2007) were employed in this study. Two different casualty models were used in this study. The first model is the empirical relationship developed by JICA (2003) between number of heavily damaged buildings and number of fatalities (Figure 3). The second model is developed by Coburn and Spence (1992). For the three analytical intensity distributions given in Figure 2a-Figure 2c and the observed intensity distribution of 1999 Kocaeli earthquake, mean, upper and lower bound estimates of number of D1 to D5 buildings and fatalities were computed in this study. D1-D5 are EMS98 damage grades; 1 being negligible to slight damage and 5 being destruction. Due to space limitations only mean results are shown; upper and lower bounds are excluded. Figure 3a- Figure 3d illustrate distribution of very heavly damaged buildings as a result of observed intensity distribution and analytical intensity distributions in Figure 2a-Figure 2c respectively. As it can be seen although the distribution varies, all methods are capable of identifying the regions that suffered very heavy damage after the Kocaeli earthquake (Adapazari, Kocaeli, Izmit, and Golcuk). According to Erdik et al ,2003, 19,355 buildings collapsed, 14,626 buildings sustained damage beyond repair and 17,439 people died as a result of the 1999 Kocaeli earthquake. Although the number of very heavily damaged buildings and fatalities corresponding to different computation methods vary considerably between each other; in comparison to observed values they are within acceptable limits applicable to such estimations.

7. CONCLUSIONS

A near real time earthquake loss estimation tool is being developed for the Euro-Mediterranian region. This tool is expected to enable effective emergency response, both local and global level, and public information. As the density of instrumentation, quality of building inventory and population databases vary throughout the region of interest, a multi sopistication level methodology is forseen to fullfill the task. Within the scope of this study, the second sophistication level of this methodology was applied to the case of 1999 Kocaeli earthquake. In comparison to observed number of very heavly damaged buildings and fatalities, the computed values with various methods were found satisfactory. It should be underlined once again that this tool is still under development and is expected to be available for the first estimation of damage immediately after an earthquake in Turkey by the end of 2007 and for the whole Euro-Med region by the end of 2009.

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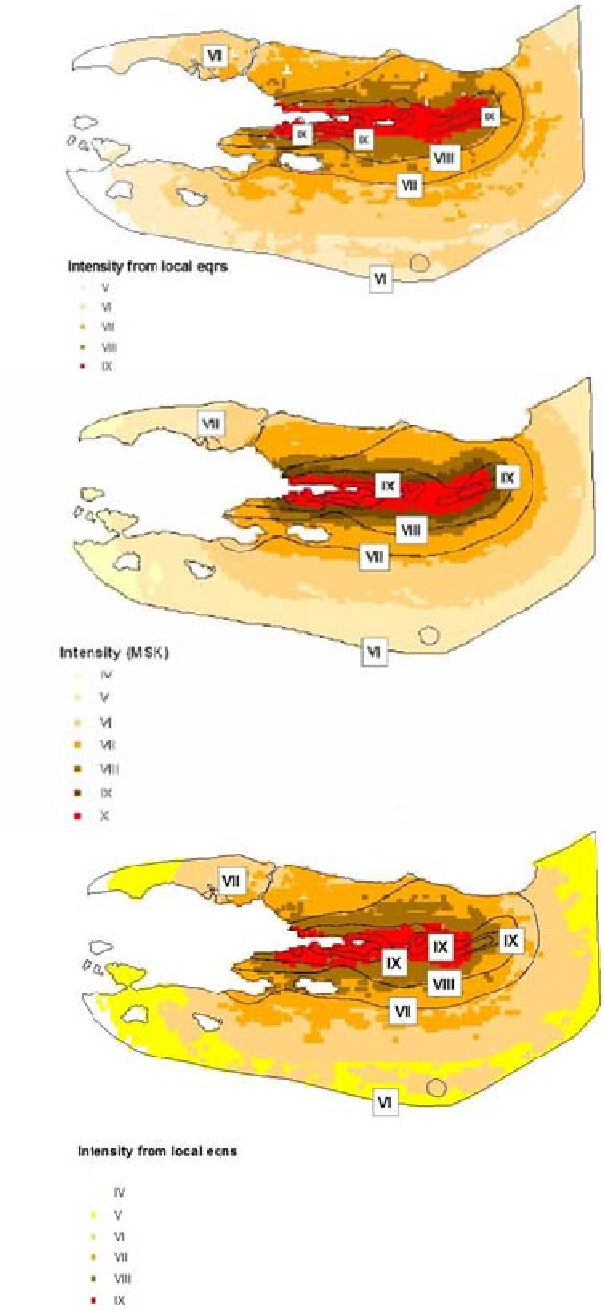

Figure 2. Comparison of Analytical Intensity Distributions computed by (a) PGA/PGV-Intensity Correlations,

(b) FAS Method, (c) PGA/PGV-Intensity Correlations Using Estimated Fault Length, with the Observed Intensity Distribution for Kocaeli Earthquake.

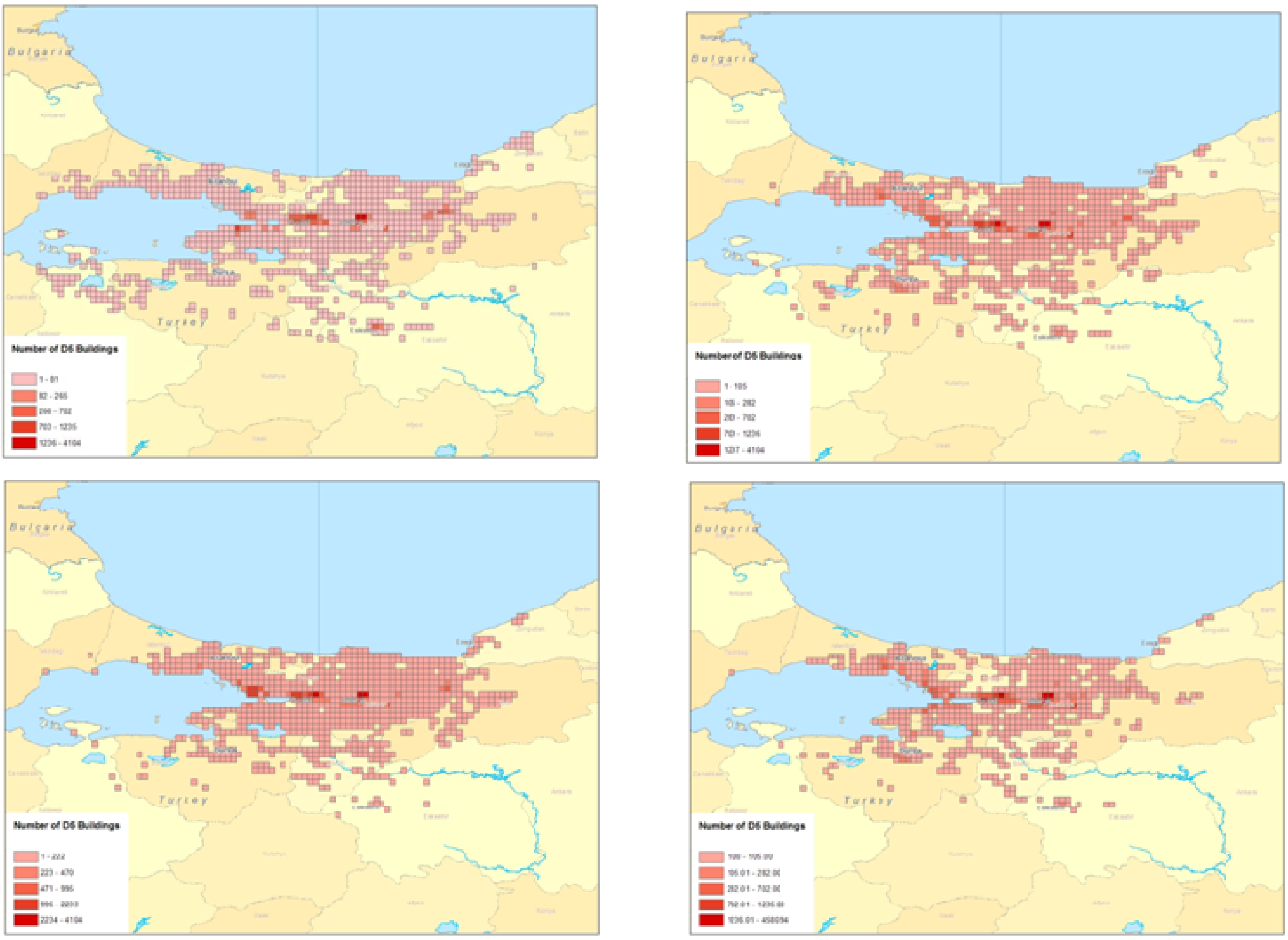

Figure 3. Mean Number of Very Heavily Damaged Buildings: (a) for Observed Intensity Distribution, (b) for Analytical Intensity Distribution Computed by PGA/PGV-Intensity Correlations, (c) for Analytical Intensity Distribution Computed by the FAS Method, (d) for Analytical Intensity Distribution Computed by PGA/PGV-Intensity Correlations Using Estimated Fault Rupture Length.