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Urban Earthquake Risk

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Abstract

The impact of earthquakes in urban areas is a complex problem compounded by multi-hazard and consequential risk issues, enormous inventory of vulnerable physical elements and the attendant socio-economic problems. A review of our state-of-knowledge and applications on the assessment of urban earthquake risk is provided. Rational urban risk predictions and expected losses from major earthquakes in the future serve the basis and also provide strong reasons for the pro-active risk mitigation activities.

Introduction

In recent decades, earthquake disaster risks in cities have increased mainly due to a high rate of urbanization, faulty land-use planning and construction, inadequate infrastructure and services, and environmental degradation. Thus for urban centers under possible exposure to large earthquakes, it is imperative that certain preparedness and emergency procedures be contrived in the event of and prior to an earthquake, which in turn requires quantification of the effects of the earthquake on the physical and social environment. The main element of such quantification is the building losses, which is directly related to casualties, planning of emergency response, first aid and emergency shelter needs.

A compilation of worldwide investigations on urban earthquake risk is presented in Tucker and Erdik (1994). In Japan, Oyo Corporation has produced an earthquake damage scenario development methodology (Komaru et al. 1995) that has found application in several cities (e.g., Kawasaki City, Saitama Prefecture, Kanagawa Prefecture, Quito, Tehran) as well as in the IDNDR RADIUS (http://geohaz.org/radius/) Project. EPEDAT (The Early Post-earthquake Damage Assessment Tool) (Eguchi et al. 1997) is a GIS-based system capable of modeling building and lifeline damage and estimating casualties in near real-time given the source parameters of an earthquake. HAZUS (http://www.fema.gov/hazus/) is a standardized earthquake loss estimation methodology intended for national application in the U.S. (Whitman and Lagorio 1999). A number of cities worldwide (Addis Ababa, Antofagasta, Bandung, Guayaquil, Izmir, Tashkent, Skopje, Tijuana and Zigong) were engaged in risk modeling in the UN-IDNDR program RADIUS (http://geohaz.org/radius/). Several earthquake loss scenario assessment studies at various levels of sophistication have also been carried out in Europe (ENSeRVES 2000); Basel (Faeh et al. 2001); Barcelona (Barbat et al. 1996); Catania (Faccioli et al. 1997); Quito (Fernandez et al. 1994); Istanbul (Erdik et al. 2004; JICA 2002); Izmir (Erdik et al. 2000) and; Bucharest (Wenzel et al. 1998). A EC-funded research project, RISK-UE (http://www.chez.com/riskue /scope.htm) has developed a general and modular methodology for creating earthquake-risk scenarios that concentrates on the distinctive features of European towns, including both current and historical buildings. Also, within the EU-funded Safety Assessment for Earthquake Risk Reduction Project (SAFERR - http://www.saferr.net/index.htm), several European research groups have undertaken investigations characterization of seismic hazard and risk assessment systems to provide tools for application of risk assessment.

Earthquake Hazard

Earthquake hazard assessments, conducted in connection with risk analysis in urban centers can be conducted using probabilistic or deterministic approaches. To obtain the probable losses in a given urban subdivision or geo-cell probabilistic approach would be appropriate. However, since all the probabilistic losses at a given geo-cell cannot take place simultaneously the sum of these individual losses will overestimate the total loss in the urban area. Furthermore for assessment of lifeline damages, where a spatial system-based approach is needed, the probabilistic approaches may also be inadequate. As such urban earthquake loss assessments have been traditionally linked to a (or set of) scenario earthquake in a deterministic manner. The scenario earthquake can be assessed through de-aggregation of the probabilistic hazard to find the source that contributes most to the overall hazard (Thenhaus and Campbell 2003; Somerville and Moriwaki 2003; Faccioli and Pessina 2003).

Topics associated with the evaluation (probabilistic or deterministic) of ground motion involve consideration of:

- Earthquake Source Process
- De-aggregation of Probabilistic Hazard
- Empirical Attenuation Relationships
- Near Fault Effects (Radiation Pattern and Directivity)
- Site Response
- Analytical Simulation Procedures

Currently reliable empirical models exist in terms of peak ground acceleration, velocity and displacement (PGA, PGV and PGD) and, pseudo spectral velocity (PSV), at specific frequencies and damping ratios, for given earthquake magnitude, distance, fault mechanism and local geology (e.g. Boore et al. 1993; Campbell and Bozorognia 1994; Gregor 1995; Fukushima and Tanaka 1990;

Ambraseys and Bommer 1995; Campbell 2003a, 2003b). Although the data are biased towards well instrumented regions of the world (e.g. California, Japan and Italy) recent comparisons indicate that, with identical definitions of input parameters, the difference amongst Western USA, Japanese and European based attenuation relationships are less than the scatter in any one of them (Fukushima and Tanaka 1990; Ambraseys and Bommer 1995). This finding enhances their utilization in other parts of the world with limited strong motion data. Although highly complex numerical simulation procedures exist for the determination of ground motion on the basis of fault rupture mechanism and wave propagation, problems associated with the parameterization will preclude their routine use in future earthquake loss scenario developments.

In Istanbul, the earthquake hazard has been assessed using deterministic (Mw=7.5 earthquake on the Main Marmara Fault) means. The site-dependent spectral accelerations, provided in Fig. 1, are used in the construction of the so-called "Uniform Hazard Response Spectrum" (NEHRP 1997) to model the earthquake demand for spectral displacement-based vulnerability assessments (Erdik et al. 2004). The spectral accelerations for the periods T=0.2s. and T=1s, calculated for NEHRP B/C boundary site class, are modified using the site coefficients presented in the 1997 NEHRP Provisions.

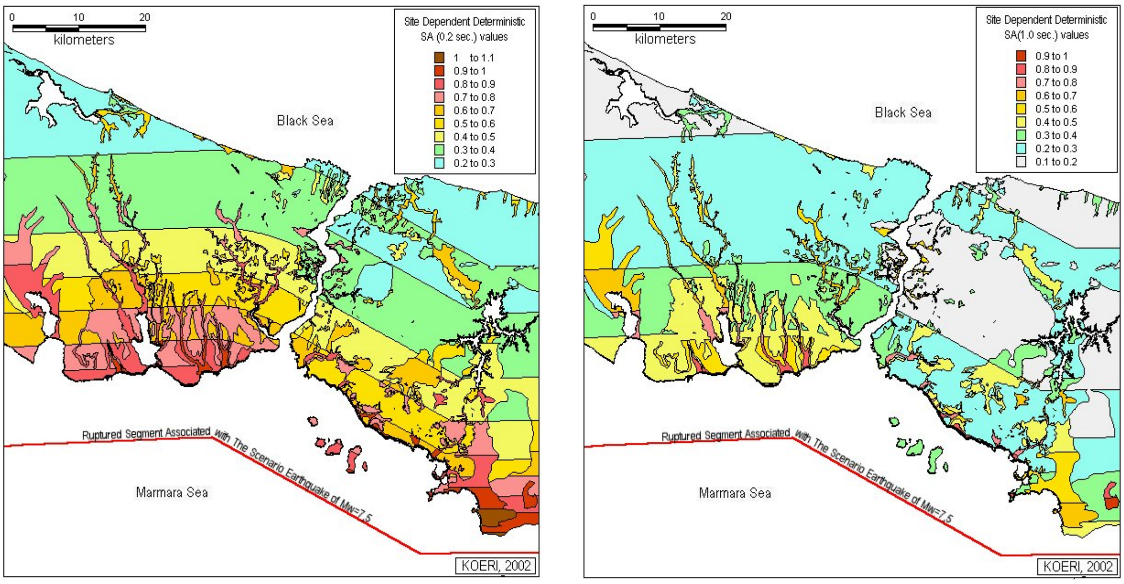

Figure 1. Site dependent spectral acceleration (T=0.2s, in g for the figure at left; T=1.0s, in g for the figure at right) distribution in Istanbul.

Elements at risk

In urban areas the population, structures, utilities, systems, and socio-economic activities constitute the "Elements at Risk". Buildings and lifeline systems are generally termed "Built Environment". The physical losses to elements at risk that would result from a specified earthquake scenario necessitate an extensive and comprehensive collection of their inventories. Preparation of urban earthquake damage/loss scenarios encompass involve compilation of information on: Demographic structure for different times of the day; building stock and its typification; lifeline and infrastructure (major roads, railroads, bridges, overpasses, public transportation, power distribution, water, sewage, telephone, and natural gas distribution systems) including their nodal points (stations, pumps, switchyards, storage systems, transmission towers, treatment plants, airports, marine ports etc.); major and critical facilities (dams, power plants, major chemical and fuel storage tanks) in the form of GIS databases.

In HAZUS (1999) the general building inventory includes residential, commercial, industrial, agricultural, religious, government, and educational buildings. A building inventory classification system is utilized to group buildings with similar damage/loss characteristics into a set of pre-defined building classes to commensurate with the relevant vulnerability relationship classes. For earthquake loss estimation purposes, the building inventory in Istanbul was divided into three main groups based on the construction type, number of stories and construction date (Erdik et al., 2004). To provide an example the distribution of post-1980 mid-rise reinforced concrete buildings are illustrated in Fig. 2 (Erdik et al. 2004).

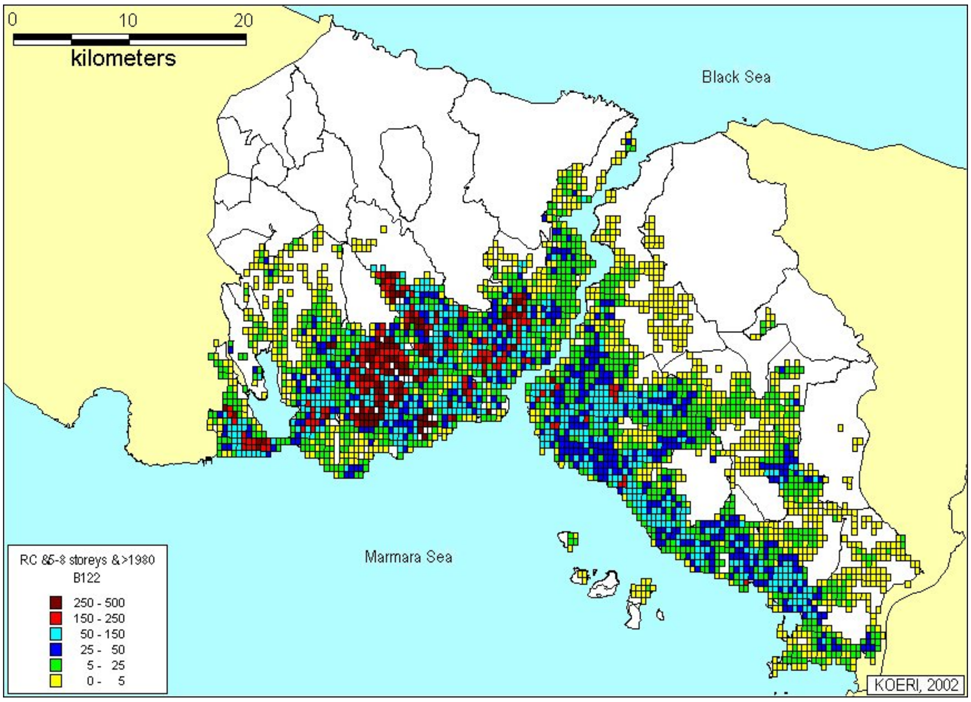

Figure 2. Distribution of (numbers per cell) mid-rise reinforced concrete buildings (post-1980) in Istanbul.

Earthquake Vulnerabilities

Vulnerability functions (or fragility curves) of an element at risk represent the probability that its response to earthquake excitation exceeds its various performance limit states based on physical and socio-economic considerations. Vulnerability assessments are usually based on past earthquake damages (observed vulnerability) and on analytical investigations (predicted vulnerability). Primary physical vulnerabilities are associated with buildings, infrastructure and lifelines. These vulnerabilities are agent- and site-specific. Furthermore, they also depend on design, construction and maintenance particularities. Secondary physical vulnerabilities are associated with consequential damages and losses. Socio-economic vulnerabilities include casualties, social disruption and traumas and economic impacts.

Physical Vulnerabilities

Almost all of the earthquake loss scenario developments have used building vulnerability matrices that relate descriptive damage classes to earthquake motion intensities. Coburn and Spence (1992) provide observed vulnerability functions (percent of buildings damaged) for common building types. ATC-13 (1985) provides loss estimates for 78 different building and facility classes for California. The analytical estimation of structural damage has been recently standardized (HAZUS 1999), where the vulnerability relationships (also called fragility curves) are described in terms of spectral displacements, which in turn are calculated from the estimated mean inelastic drift capacities of buildings for various damage states. Modern buildings can suffer major functional and economic loss by damage to the equipment and furniture in their house, even though the structures experience little damage. Especially in research laboratories, hospitals and offices, unanchored equipment is highly vulnerable to earthquake damage. The same also applies to exhibited pieces in museums and in art galleries.

A compilation of lifeline vulnerability functions and estimates of time required to restore damaged facilities are provided in ATC-25 (1991). The vulnerability functions are based on the review of existing models and the expert opinion in ATC-13(1985) supplemented by an expert technical advisory group.

Only limited vulnerability models exist for secondary damages for secondary hazards, such as: post-earthquake fire, hazardous material release, explosions and water inundation. Recent developments in fire following earthquake models include three stages: ignition, spread and suppression, and provide first-order estimates of total losses as functions of intensity, wind, building density and fire engine number.

Socio-Economic Vulnerabilities

The socio-economic vulnerability of the urban system also needs to be assessed in terms of casualties, social disruption and economic loss for a comprehensive earthquake damage and loss scenario. Casualties in earthquakes arise mostly from structural collapses and from collateral hazards. Lethality per collapsed building for a given class of buildings can be estimated by the combination of factors representing the population per building, occupancy at the time of the earthquake, occupants trapped by collapse, mortality at collapse and mortality post-collapse.

Production and/or sales lost by firms due to damaged lifelines, losses arising from tax revenues and increased unemployment compensations. Partial quantification of these indirect economic losses can be found in ATC-25 (1991). More than detailed economic models, practical rules need to be incorporated in the loss assessments for the evaluation of complex economic impacts.

Urban Earthquake Risk Results

In the context of damage scenarios risk can be defined as the losses to the elements at risk that can result from the occurrence of scenario earthquake(s). Damage scenarios are the vehicles to portray these risks. Following is a brief review of current developments in earthquake damage and loss scenarios:

In Japan, Oyo Corporation (1988) has produced an earthquake damage scenario development methodology (Komaru et al. 1995) that has found application on several cities (e.g. Kawasaki City, Saitama Prefecture, Kanagawa Prefecture, Quito-Equator and Tehran-Iran) as well as in the IDNDR RADIUS Project. The methodology encompasses: Identification of disaster prevention problems in the objective area; postulation of the kinds of earthquakes that may affect the area; mapping the distribution of their seismic intensities and assessing the probable effects of their seismic motion; estimation of damage to structures, lifeline facilities; estimation of fires, casualties and time to restoration of normal conditions.

Under the general title of "Planning Scenario", California Department of Conservation-Division of Mines and Geology has prepared earthquake damage scenarios for several areas in California (Toppozada et al. 1988, 1993, 1994). The seismic shaking intensity maps were developed on the basis of an Evernden et al. (1981) type model where various geologic units are assigned intensity adjustment factors relative to the bedrock. Assessment of the building damage was limited to public high schools and hospitals. Damage, loss of service to highways, airports, marine facilities, railroads, electric power (plants and facilities), natural gas (storage, transmission and distribution pipelines), water supply (source, transmission, treatment, distribution), dams and reservoirs, waste water (collection, treatment, discharge), telephone systems have been assessed and the restoration periods have been estimated by treating these elements as parts of a network as well as on nodal point basis.

HAZUS, a standardized nationally applicable earthquake loss estimation methodology implemented through PC-based geographic information system software (Whitman and Lagorio 1999). HAZUS provides quantitative estimates of losses in terms of direct costs for repair and replacement of damaged buildings and lifeline system components; direct costs associated with loss of function (e.g., loss of business revenue); casualties; people displaced from residences; quantity of debris; regional economic impacts; functionality losses in terms of loss-of-function and restoration times for buildings, critical facilities such as hospitals, and components of transportation and rudimentary analysis of loss-of-system-function for utility lifeline systems.

KOERILoss is software developed by the Earthquake Engineering Department of Bogazici University, Kandilli Observatory and Earthquake Research Institute (KOERI). The software applies a loss estimation methodology (Probabilistic vs Deterministic) developed by KOERI to perform analyses for estimating potential losses from earthquakes. A code to evaluate seismic scenarios has been developed by the Italian National Seismic Service (SSN) (Di Pasquale and Orsini 1997). In this tool, intensity is used for loss estimate. The seismic demand over the urban region (municipality) is assigned an average intensity.

Example: Urban Earthquake Loss Assessments from Istanbul

The results from the earthquake risk assessment in Istanbul conducted by the Department of Earthquake Engineering of Bogazici University (Erdik et al. 2003 and 2004) will be used to provide illustrative examples of urban earthquake loss assessment. Under exposure to the scenario earthquake (Mw=7.5 on the Main Marmara Fault) the expected number of buildings damaged beyond repair (i.e. EMS'98 damage grade > D3), calculated both by the intensity-based and the spectral displacement-based approaches, are provided in Fig. 3 and Fig. 4. The expected scenario earthquake casualties in Istanbul were estimated using both the intensity-based and the spectral displacement-based approaches. The results for nighttime population obtained for severity level 4 (death) from the spectral displacement-based approach is given in Fig. 5. To provide an example for the assessment of urban lifeline losses the distribution of "High Risk" bridges and viaducts in Istanbul overlaid with the peak ground velocity map resulting from the scenario earthquake is provided in Fig. 6.

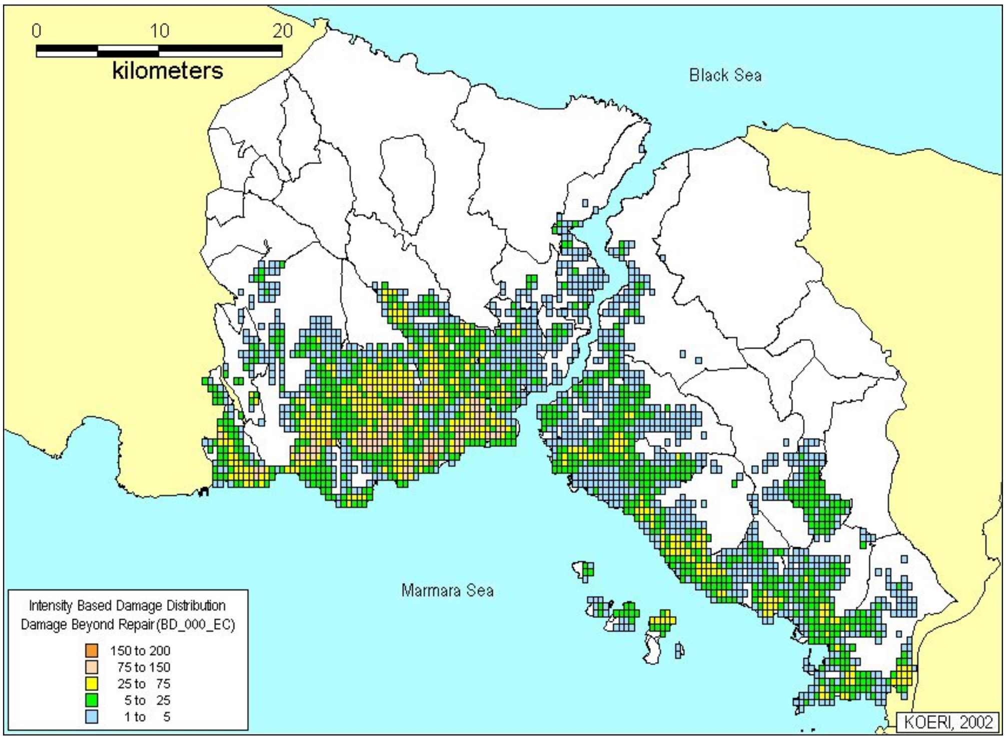

Figure 3. Distribution of all buildings damage beyond repair under exposure to scenario earthquake (intensity-based loss assessment approach)

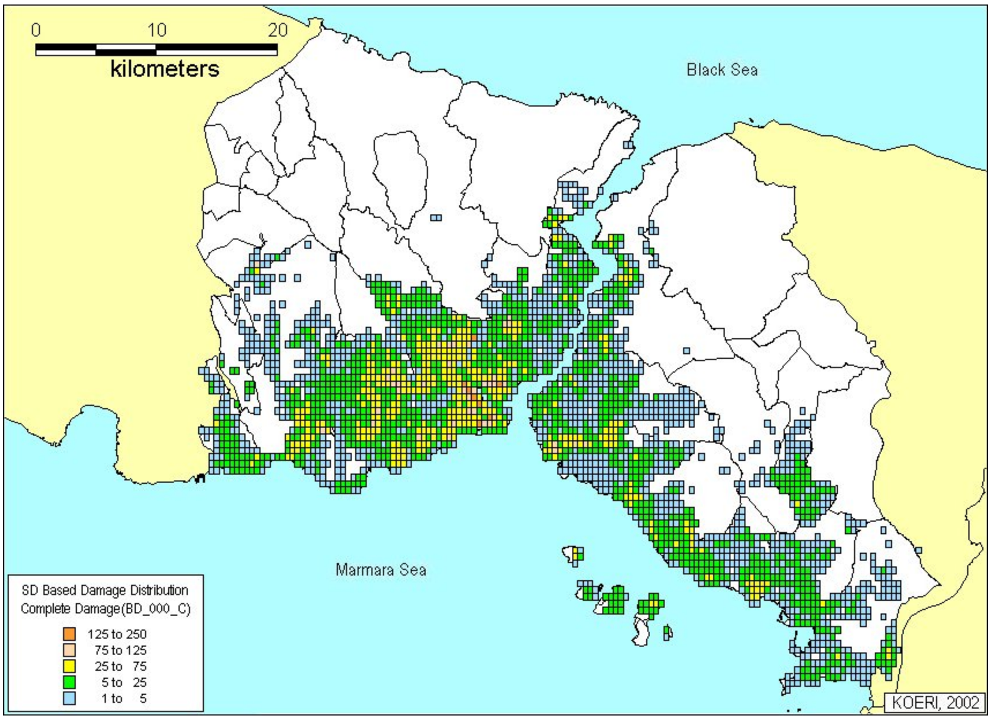

Figure 4. Distribution of all buildings damage beyond repair under exposure to scenario earthquake (spectral displacement – based loss assessment approach).

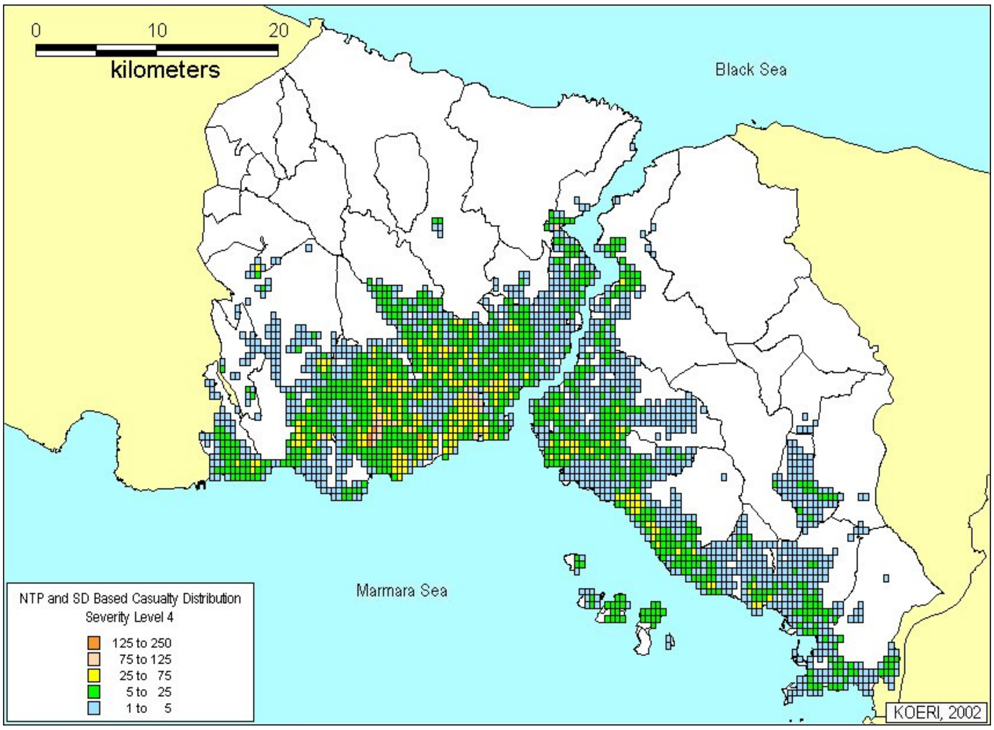

Figure 5. Distribution of casualties (severity level -4) under exposure to scenario earthquake (spectral displacement – based loss assessment approach).

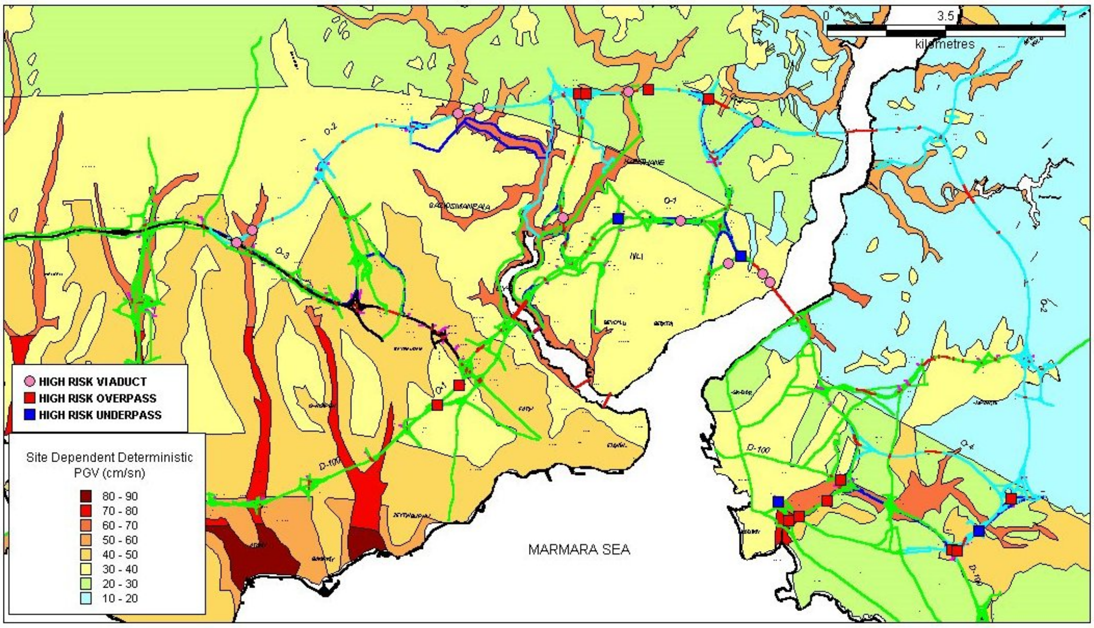

Figure 6. Distribution of the "high risk" bridges and viaducts based on the ATC6-2 method, overlaid with the peak ground velocity map resulting from the scenario earthquake.

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