Safe Cities

Case Studies

Earthquake Risk to Buildings in Istanbul and a Proposal Towards its Mitigation
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1 Background and General Considerations

Turkey ranks high among countries that have suffered losses of life and property due to earthquakes over many centuries. So far in this century there have been earthquakes that caused loss of life in Turkey with total of over 110,000 deaths, about 250,000 hospitalised injuries and close to 600,000 destroyed housing units.

Following the losses suffered during the two major earthquakes that struck Turkey in 1999, there has been a broad recognition among Turkey's governmental, non-governmental and academic organizations of the need for extensive response planning based on detailed risk analyses of likely seismic hazards in Turkey general and, Istanbul, in particular.

In recent decades earthquake disaster risks in urban centers of Turkey have increased mainly due to very high rate of urbanization, faulty land-use planning and construction, inadequate infrastructure and services, and environmental degradation. Several studies conducted (Erdik and Aydinoglu, 2002) has shown that the vulnerabilities of Turkish building stock are at least an order of magnitude higher than their counterparts in California, which shares comparable level of earthquake hazard. The reasons for this high vulnerability can be traced back to several reasons. Essentially the building development system was conducive to poor construction due to high (chronic) rate of inflation (consequently very limited mortgage and insurance, impediment to large scale development and industrialization of the construction sector), high rate of urbanization (which created the demand for inexpensive housing), ineffective control/supervision of design/construction, regulations with limited enforcement, no accountability and government acting as a free insurer of earthquake risk.

The other important source of the increased risk in Istanbul is the unprecedented increase of the probability of occurrence of a large earthquake (which stands at about 65% during the coming 30 years).

The inevitability of the occurrence of such a large earthquake in Istanbul makes it imperative that certain preparedness and emergency procedures be contrived in the event of and prior to an earthquake disaster, which in turn requires the quantification of effects of the earthquake on physical and social environment and subsequently, the development of urban earthquake risk mitigation master plans that develops and elaborates on short and long term strategies.

This study first summarizes the study conducted by the Department of Earthquake Engineering with support from American Red Cross (BU-EQE, 2002) on the assessment of building losses in Istanbul as a result of a major earthquake. The second part of the paper elaborates on a building retrofit strategy that can be adopted for cost-effective mitigation of life losses. The metropolitan municipality of Istanbul has recently (October, 2002) signed a memorandum of agreement with the Bogazici, Istanbul Technical, Middle East Technical and Yildiz Technical Universities to develop a comprehensive earthquake risk mitigation master plan that encompasses technical, legislative, administrative, social and economical issues and strategies of large scale retrofit, renewal and relocation campaigns.

2 Estimated Building Losses and Casualties in Istanbul

Earthquake Hazard

For Istanbul, a worst-case scenario earthquake of Magnitude 7.5 is assumed to take place on the Main Marmara Fault. Figure 1 provides a map of earthquake intensities that would result from the scenario earthquake. Using the damage definitions of 1998 European Macroseismic Scale (EMS), a general understanding of damage under exposure to these intensity levels can be gained. For the vulnerability class where the general reinforced concrete multi-story building stock in Istanbul is located, EMS-1998 provides the following damage definitions.

Intensity VII:	A few buildings sustain moderate damage
Intensity VIII:	Many buildings suffer moderate damage; a few substantial to heavy damage
Intensity IX:	Many buildings suffer substantial to heavy damage; a few very heavy damage

“Few” describes less than 20% and “Many” describes between 20% and 60%.

Inventory of Elements at Risk

In urban areas, buildings, population, lifeline systems and socio-economic activities constitute the “elements at risk”. Buildings and lifeline systems are generally termed “Built Environment”. Building inventory data is compiled from Istanbul Metropolitan Municipality and State Statistical Institute complemented by Turk Telekom analog maps, imagery from helicopter flights and aerial and satellite imagery. Classification of buildings in Istanbul is essential to ensure a uniform interpretation of data and results. The building inventory is classified using three basic categories on Structural Systems, Number of Stories and Year of Construction. Each category is further subdivided into groups to yield 24 different building classes. Istanbul Metropolitan Area was divided into grids as 0.005° x 0.005° (approximately 400 m x 600 m) cells for aggregation of hazard and physical inventory data. The day and night time population of 28 districts were determined, and then assigned to the geo-cells in order to calculate the human losses in Istanbul due to a major earthquake. The population and building data for Istanbul have been obtained from the State Statistics Institute. For the determination of day population, Istanbul Transportation Master Plan, which is prepared by Municipality of Istanbul Metropolitan in 1997, is been utilized.

Vulnerabilities

There are two main approaches for generating vulnerability relationships. The first approach is based on damage data obtained from field observations after an earthquake or from experiments. The second approach is based on numerical analysis of the structure, either through detailed time-history analysis or through simplified methods.

In the earthquake loss scenario developed for Istanbul have used building vulnerability relationships that express the percentage damage for each typified building group and in certain damage classes against the EMS-1998 (European Macroseismic Scale) intensity ranges and Spectral Displacements. The intensity–based vulnerability relationships are empirical in nature and are based on damage data from local earthquakes. The spectral displacement-based building vulnerabilities (also called as “fragility curves”) relate the probability of being in, or exceeding, a building damage state to for a given spectral displacement demand parameter using the methodology developed in HAZUS (http://www.fema.gov/hazus/).

The most vulnerable building group is found to be medium-rise (4-7 storey) reinforced concrete frame buildings built prior to 1975. These are cast-in-situ reinforced concrete frame buildings with unreinforced masonry infill walls designed on the basis of outdated codes and generally suffering from reinforcement corrosion problems. In majority, the ground floors are often left open for shops and irregular plan shapes are common due to irregular land lots and urban congestion.

Death tolls in earthquakes arise mostly from structural collapses and to a lesser degree from collateral hazards. In this study casualties per damaged building for a given class of buildings is obtained on the basis of data obtained from local earthquakes.

Risk Assessment Methodology

Several methodologies and attendant software (such as, HAZUS, EPEDAT and NHEMATIS) exist for computation of urban earthquake risk using hazard, inventory and vulnerability inputs through a GIS engine for the manipulation data and display of results. The KOERILoss software developed by the Earthquake Engineering Department of Bogazici University, Kandilli Observatory and Earthquake Research Institute (KOERI), applies a loss estimation methodology (Probabilistic vs Deterministic) developed by KOERI to perform analyses for estimating potential losses from earthquakes. In order to perform building damage and loss analysis, the building inventory stock database should be provided for each geo-cell. The seismic hazard information in terms of: Intensities for intensity based-analysis and Spectral accelerations for spectral displacement-based analysis should also be aggregated at the center of geo-cell. To compute the damage probability ratios intensity based vulnerabilities and/or spectral displacement based fragility curves for each building class type vulnerabilities should be specified. Economic losses associated with the general building stock is estimated using the building damage losses and costs for different structural damages of each building group. In order to estimate the number and the severity of the casualties, the day and night time population for each building type in geo-cells should be provided together with the casualty rates for each building class and damage grade. The software provides the building damage loss, economic loss and the number of casualties in terms of Geo-cells, which can then be integrated into sub-districts (Mahalle) and districts (İlçe), as MapInfo Output tables.

Building Losses and Casualties

The study culminates with maps depicting the distribution of building losses, lifeline facilities overlaid on intensity maps, distribution of casualties, temporary shelter needs and expected financial losses due to building damage. The resolution of these maps is the geo-cell (400m by 600m) scale. All the digital data, some subject to security classification, will be made available to professional users that can build any information they need at any scale and with any overlay desired using the GIS software of their choice. The expected building damages, calculated by the intensity based deterministic approach, is provided in Figure 2. Results indicate that, on the basis of two independent approaches (intensity based and spectral displacement based approaches), a total of about 35,000 to 40,000 buildings (about 5% of the total building stock) were estimated to be damaged beyond repair (complete damage). Most of casualties are expected in this damage group, especially in a subset of this group where the collapse will be of the worst “pancake” form. In pancaked buildings the floors pile up on top of each other rendering very difficult conditions for search and rescue. Our estimate for pancaked buildings will be in the vicinity of 5,000 to 6,000.

Furthermore about 70,000 buildings will receive extensive damage and about 200,000 buildings will be moderately damaged. Both of these damage groups are repairable. The total monetary losses due to building damages caused by the scenario earthquake are estimated to be in the range of about USD 11 Billion (Figure 3). Building damages are mostly concentrated in the densely populated districts located in the southwestern part of the city, such as Eminönü, Fatih, Zeytinburnu, Bakırköy, Bahçelievler, sourhern part of Küçükçekmece and Avcılar, and to a lesser degree, in districts such as Kadıköy, Maltepe and Kartal located on the southestern part of Istanbul. Although situated in relatively farther locations from the causative fault, due to the building density and vulnerability conditions, districts of Beyoğlu, Eyüp and Bayrampasa are also expected to undergo high levels of damage. As the result of the analysis conducted for various structure types, the mid-rise reinforced concrete structures constructed before 1980 are found to constitute the most vulnerable building class. The expected casualties were calculated using both the intensity based and the spectral displacement based approaches. The results for both the nighttime and daytime population are obtained for the four levels of casualty severities from the spectral displacement based approach. Thus, on the basis of these two independent approaches it is estimated that the death would vary between 30000 and 40000. How many of the casualties in serious injury class would be lost is difficult to estimate since it would depend on the post earthquake emergency services. If we assumed that about 1/3 would be lost, that would bring the total estimate of deaths to about 40,000-50,000 level. Death distribution based on intensity approach is presented in Figure 4. As the result of the intensity based analysis a total of about 600,000 households and from the spectral based analysis a total of about 430,000 households were assessed to be in need of shelters following the scenario earthquake. This amount constitutes an upper bound limit for the expected shelter needs, since the conversion of this number to total number of households is subject to some discussion and the vacancy of some dwelling units should also be considered. It should again be noted that these values are the estimates for a Mw=7.5 earthquake at closest position to Istanbul, that one can provide in the absence of detailed building inventory and geotechnical data. Especially the death figures entail large uncertainties arising from the time and date of the earthquake.

3 Risk Mitigation

General Mitigation Options

The basic tenets of mitigation are: Do not increase the existing risk (i.e. build proper); Decrease the existing risk (i.e. retrofit) and; Transfer the risk (i.e. insurance). Reduction of the structural vulnerability, siting and land-use regulations, design and construction regulations, relocation of communities, and public education/awareness programs are viable measures for the mitigation of earthquake risk. Urban settlements can be improved by changing the functional characteristics of the settlements through land-use planning and increasing the redundancy of the infrastructure, such as building an additional bridge at a strategic crossing.

The new buildings in Istanbul are in general being built much better than the existing building stock. The reasons for this improvement are: Application of new (1998) earthquake resistant design code; Increased public awareness and demand for earthquake safety; Various training and education programs for engineers; Better zoning regulations and enforcement by municipalities and; Control by private construction supervision firms. New legislation (Revision Of Law On Engineering And Architecture, Building Design and Construction Control and, Standard Development Regulations for Municipalities) enacted after the 1999 earthquakes provided help in this regard. For Istanbul the most important and complex issue in mitigating earthquake casualties is the retrofit of existing buildings.

Retrofit of the Existing Building Stock

It is clear that the greatest impact to the reduction of human casualties can be affected through retrofit of the existing building stock. Although several assessment and retrofit applications are in place for public and commercial buildings, serious initiatives have yet to be taken for the strengthening of residential building stock. A comprehensive retrofit campaign will be a formidable task that would involve the earthquake performance screening of about 800,000 buildings, prioritisation based on the exhibited risk, analysis of options and market study, development of retrofit alternatives; development engineering capacity for retrofit and finally creation of public / private incentives.

The full retrofit (i.e. in compliance with latest code requirements) of a residential building costs about 40% of replacement value and the building has to be vacated for several months. In addition to this high cost and the inconvenience of moving out, for residential buildings there are strong impediments for retrofitting. The retrofit decision is difficult to reach since these buildings are multi-family owned/rented apartments with tenants having different expectations, budgets, and constraints. Due to the high residential mobility (desire for better housing in better neighbourhoods) there does not seem to be any sense in spending money for something that is expected to be changed. Furthermore, there is evidence that retrofitting will not increase the sales value or rental fee of the property as such it is being viewed as an investment with no financial return. Under these conditions, no conceivable reduction in insurance premium (or property tax) would be sufficient to create an incentive for retrofitting.

Even neglecting the social and legal constraints of retrofit actions to be taken in apartment complexes and the highly distressed real estate market in Istanbul, on the average the structural retrofit is not cost effective. For a mid-rise R/C MRF building in Istanbul the average loss (mean damage ratio - MDR) in intensity IX region will be 62%. For a mid-rise reinforced concrete frame building in Istanbul the average loss (MDR) in intensity VIII region will be 40% (CAR and BU, 2000). If these buildings are retrofitted to meet the current earthquake resistant design code to its full extent the MDR's will be respectively 16% and 11% in intensity IX and VIII regions. Thus retrofit actions will save 46% and 29% of the cost of construction of the building. The average cost of full retrofit is about 40% of the cost of construction of the new building. For probabilistic earthquake occurrences (even with average return periods as low as 50year, as is the case for Istanbul) it is almost impossible to be cost effective in full-scale (meeting code criteria) retrofit applications. Only for short-horizon deterministic cases (say, in 5 years) we can barely be at the break-even point of cost effectiveness in intensity IX regions. In intensity XIII (or less) regions retrofit can never be cost effective. Thus, if life loss and the other social costs associated with an earthquake are taken out of account, the expected future losses are small by comparison with the immediate cost of retrofit, which translates to no economic feasibility.

Possible incentives for retrofit are being discussed all over the world. These include: Earthquake retrofit grants by government or compulsory insurance agencies; Below-market interest rates on loans for earthquake retrofit; Insurance premium discounts to policyholders upon completion of the retrofit and; financial incentives to property owners of properties, such as: waiving of building permit fees, city property tax and easing of sitting and geometric regulations.

It should be noted that the direct use of Turkish Catastrophe Insurance Pool (TCIP) in earthquake risk mitigation, such as funding of retrofit applications, does not seem to be realistic. The premiums are far short of the actual risks (about 0.2% per annum, 2% deductible for a flat in Istanbul). These rates should be compared with 0.5% premium rate and 10-15% deductible in San Francisco. In Istanbul, with a cap of about USD 17,500, the premium is about USD 35. For comparison, in San Francisco average premium is between 600-800 USD. In Istanbul, with such low rates, no risk-based adjustment of this premium, can serve as an incentive to structurally upgrade one's property. The market forces require that for retrofit actions and campaigns to be successful the insurance premiums should be high (or realistic), such that property owners can see that it would be profitable to retrofit their premises instead of waiting for damage and reimbursement for damages. Currently (October, 2002) the penetration of compulsory earthquake insurance in Istanbul is about 30% and the pool has a capacity of about 1 Billion USD (including the 0.85 Billion USD re-insurance) for settlement of the claims in case of an earthquake (Information from Milli-Re). There is stagnation in the market since the number of new policies is almost equal to the non-renewals of existing policies. In case of a large earthquake the TCIP today can be barely enough to cover claims (about 1 Billion USD capacity versus about 3 Billion USD estimated insured losses and 1.5 Billion USD claims, using a cap of USD 17,500 per housing units, in Istanbul earthquake). Thus it is not reasonable to use the pool for funding retrofit at its current financial level.

Although building owners will find the future property losses small by comparison with the cost of full retrofit and cannot visualize the benefit, at the macro scale, the society in general will greatly benefit from a retrofit campaign through the reduction of physical, social and consequential societal losses, that will eventually be covered by the public. The load imposed on the public finance by 1999 Kocaeli earthquake was about 6.2 Billion USD (Erdik, 2001). About 3.5 Billion USD of this amount was utilized for post-earthquake housing construction. The special earthquake taxes and paid military service scheme introduced by the government have generated about 3 Billion USD in one year after the earthquakes. Foreign finances (World Bank, European

Union and others) contributed another 2.5 Billion USD. Although steps are taken, such as TCIP, the public funds will continued to be used for rehabilitation after earthquake disasters in Turkey. As such, the use of public funds can be justified for retrofit purposes under a strategy that is designed to maximize benefits with well prioritized and fairly distributed minimum expenditures. Such a strategy can lead us to the concept of minimum retrofit.

Prioritization in Retrofit of Residential Buildings

Under the circumstances and issued discussed above, what seems to be rational is to provide rehabilitation (strengthening or retrofit) to the most vulnerable building stock in Istanbul. The objective of the retrofit will be to avoid total collapse where most of the deaths are associated (fatality ratio is about 10%). The earthquake performance criteria will be the prevention of total collapse and saving lives at minimum cost. The avoidance of total and especially pancake-type collapses is also important for facilitating search and rescue operations and reducing the road closures. However, it should be noted that the boundary between upgrades to the “collapse prevention” and “life safety” performance criteria is fuzzy and more research is needed to assess the amount of retrofit consistent with the objective of saving lives at minimum cost.

The first priority in the use of public funds will be the upgrading of the seismic performance levels of the most vulnerable buildings to collapse prevention performance level. These are the buildings that are expected to collapse in “Pancake” manner. Somewhat crude, screening criteria for the identification of these most vulnerable residential buildings in Istanbul can be set as follows:

Buildings with and greater than 5 stories, built before 1970 (pre-1975 code, poor concrete quality and corrosion issues), located in zones with PGA >=0.25g or SA (0.2) >= 0.60g or EMS-I >= VIII.

Similar buildings with added floors (with no engineering services) and buildings that have received structural damage in 1999 Kocaeli Earthquake but not retrofitted properly can also be considered. Initial assessments indicate that about 5,000 buildings fall in this first priority group. The cost of minimum retrofit is estimated to be on the average USD 40,000 per building with a total cost of about USD 200 million. Upon proper implementation of this retrofit scheme it is expected that about 20,000 lives can be saved. On the technical side intelligent retrofit scheme(s) that are suitable for general campaign-type applications needs to be developed.

A possible mode of operation for this minimum retrofit campaign can be as follows:
After the identification process the Municipality will declare the buildings as “Hazardous” and legally enforce that unless “Minimum Retrofitting” is done within a prescribed time the occupancy permit (if any) will be cancelled, the tenants evicted and building will be sold on behalf of the owners. For financing each household will need to have access to a credit of about USD 5,000. Such a credit scheme has precedent in Turkey. After the Kocaeli Earthquake Turkish government had extended about USD 5,000 low interest credit with long payment terms to eligible owners of medium damaged housing units.

The second priority can be the retrofit of about 40,000 buildings that were assessed to be damaged beyond repair (greater D3 damage level). These are mid-rise R/C frame buildings located in zones with EPGA>=0.2g or SA(0.2) >= 0.50g or in zones with EMS-I >= VIII. The retrofit performance criteria will be life safety. The approximate cost of this retrofit will be 1.6 Billion USD

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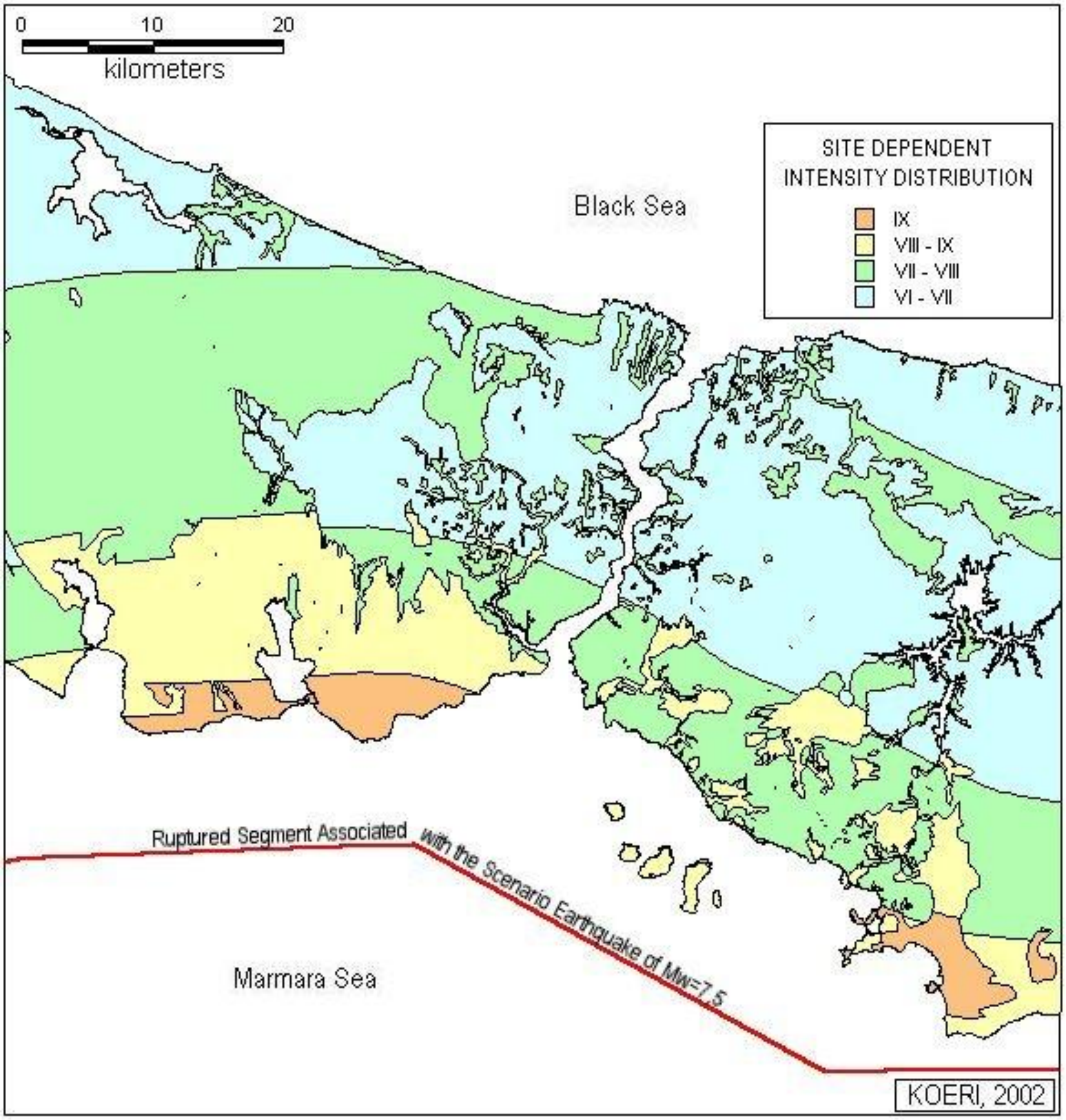

Figure 1. Site dependent deterministic intensity distribution.

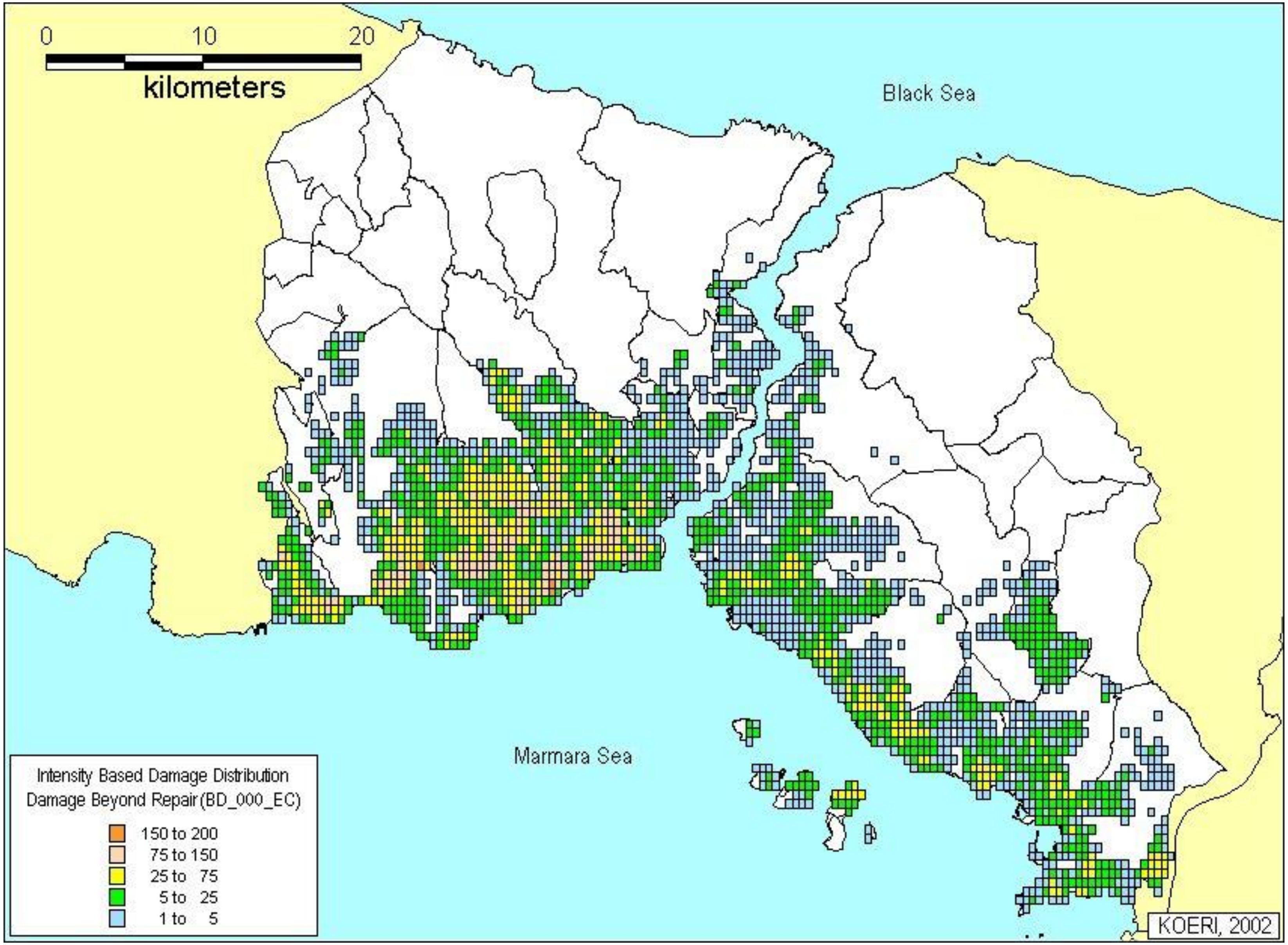

Figure 2. Intensity based distribution of all buildings damaged beyond repair (complete damage).

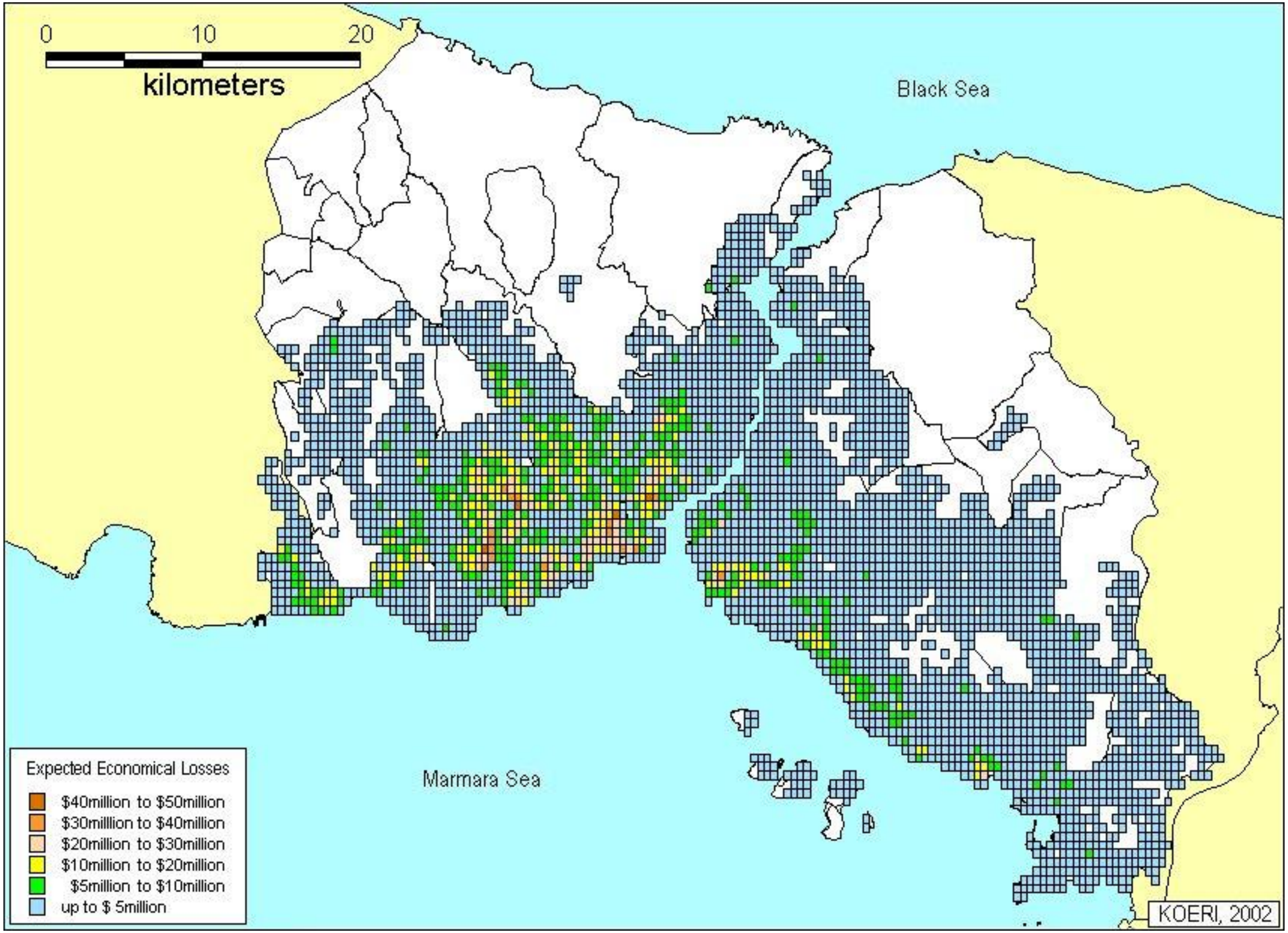

Figure 3. Distribution of Direct Financial Losses due to Building Damage

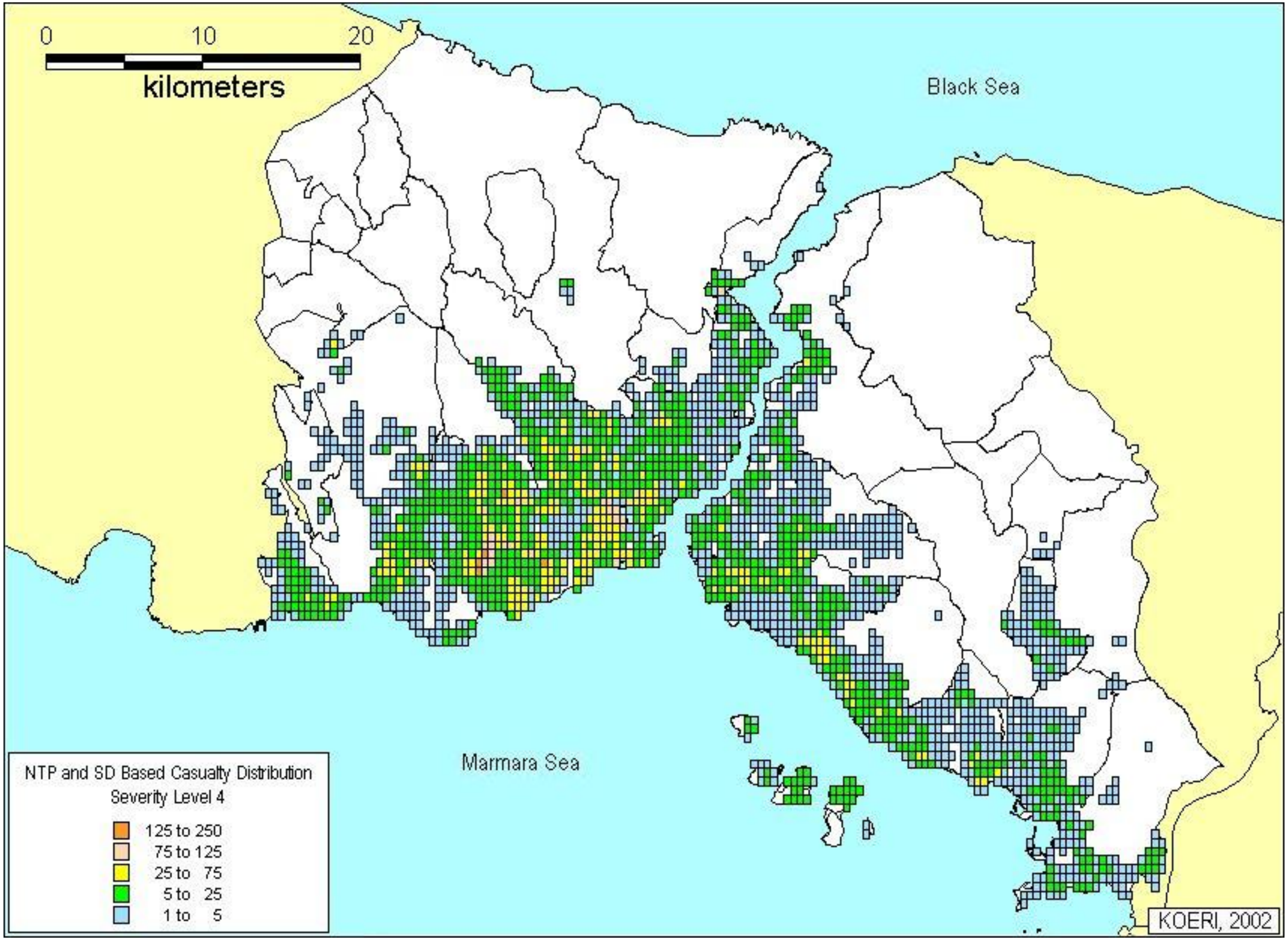

Figure 4. Distribution of Deaths for a Night-Time Scenario Earthquake.