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EARTHQUAKE DAMAGE SCENARIOS FOR URBAN AREAS

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ABSTRACT

The first stage of an earthquake damage scenario involves generation of microzonation maps with respect to ground motion parameters based on regional seismic hazard analysis. The effects of local geological and geotechnical site conditions are taken into account using representative soil profiles with shear wave velocities extending down to the engineering bedrock. 1D site response analyses are conducted to calculate an average site specific peak ground acceleration and elastic acceleration response spectrum on the ground surface. In the second stage, vulnerability of the building inventories is estimated using site-specific ground shaking parameters and empirical relationships. Recently an extensive site investigation study was carried out on the European side of Istanbul as part of a large-scale microzonation project financed by Istanbul Metropolitan Municipality. Part of the data from this site investigation study is used to conduct a pilot earthquake damage scenario for Zeytinburnu, a district in Istanbul, Turkey. The damage distribution calculated based on site response analyses is compared with estimated damage distribution based on NEHRP site classification and corresponding site amplification factors. The comparison provided evidence that there are significant variations in the ground motion parameters within the investigated region which cannot be detected when the site conditions and their effects are evaluated using NEHRP site classification and related amplification factors. Therefore it appears essential to perform site response analyses to have more reliable ground shaking characteristics that will be used to estimate probable damage level.

Introduction

Seismic microzonation and earthquake loss estimation scenarios are needed for city planning, disaster preparedness, risk reduction, hazard mitigation decisions, and urban rehabilitation actions in earthquake prone areas. Loss estimation due to earthquakes in an urban environment is a very complex process that requires compilation of detailed building inventories, estimation of earthquake characteristics on the ground surface and assessment of vulnerabilities. Several methodologies have been developed over the past years that take into account various aspects of loss estimation process (Erdik et al., 2003; Zonno et al., 2003; Sousa et al., 2004;

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Molina-Palacios and Lindholm, 2006, Demircioglu et al., 2009). However, none of the loss estimation methodologies adopted in these software packages involves detailed analysis of local site conditions. The software package (KoeriLossV2) presented in the following pages provides an alternative loss estimation tool, where local site effects are taken into account by performing large numbers of 1D site response analyses using Shake91 code (Idriss and Sun 1992).

The developed software package computes seismic damage to buildings in an urban area for a given scenario earthquake. The adopted methodology is composed of two main phases. The first phase involves generation of microzonation maps with respect to earthquake ground shaking parameters due to the selected regional earthquake hazard scenario. In the second phase, vulnerability of buildings is analyzed based on the calculated earthquake ground shaking parameters and distribution of estimated damage is presented in tables and maps.

Methodology

A grid system is utilized to model site conditions and to estimate earthquake characteristics on the ground surface. The variations of earthquake characteristics on the bedrock outcrop for each cell are externally determined for a specified level of exceedance probability or by deterministic simulations. Site characterization is performed based on available geotechnical information by defining one representative soil profile for each cell with shear wave velocities extending down to the engineering bedrock ($Vs \geq 750$m/s).

Earthquake characteristics on the ground surface for each cell are calculated using an equivalent linear one dimensional site response analysis code Shake91 (Idriss and Sun, 1992). Previously recorded, as many as possible (i.e. 20-30), acceleration time histories compatible with the probable fault type, fault distance, and earthquake magnitude are used as input. Input acceleration time histories also may be calculated using simulation models for deterministic scenarios (Ansal et al., 2009). In case of using previously recorded acceleration time histories PGA scaling is adopted (Ansal et al., 2006b). The best fit NEHRP (2003) design spectra to the calculated average acceleration response spectra were determined using a standard optimization scheme (Ansal et al., 2006a). The structural seismic vulnerabilities are estimated based on the short period (T=0.2s) and long period (T=1s) spectral accelerations of the best fit NEHRP design spectra. The NEHRP design spectrum is preferred because of its flexibility in defining spectral accelerations for vulnerability assessment of buildings (Erdik and Fahjan, 2005).

The displacement-based approach of HAZUS (1999) is adopted in evaluation of the building damages. Vulnerability relationships that relate spectral displacements to building damage are employed to evaluate damage distribution in the building stock. Five descriptive damage states are defined to grade the damage in buildings: none, slight, moderate, extensive and complete.

The methodology is automated into a Visual Basic application where calculations are performed in Excel and Fortran codes and a GIS based software is used to display variation of ground shaking parameters and distribution of damage for the investigated area. The flow chart of the software procedure is schematically illustrated in Fig. 1. The procedure operates as a single executable file within Excel spreadsheet.

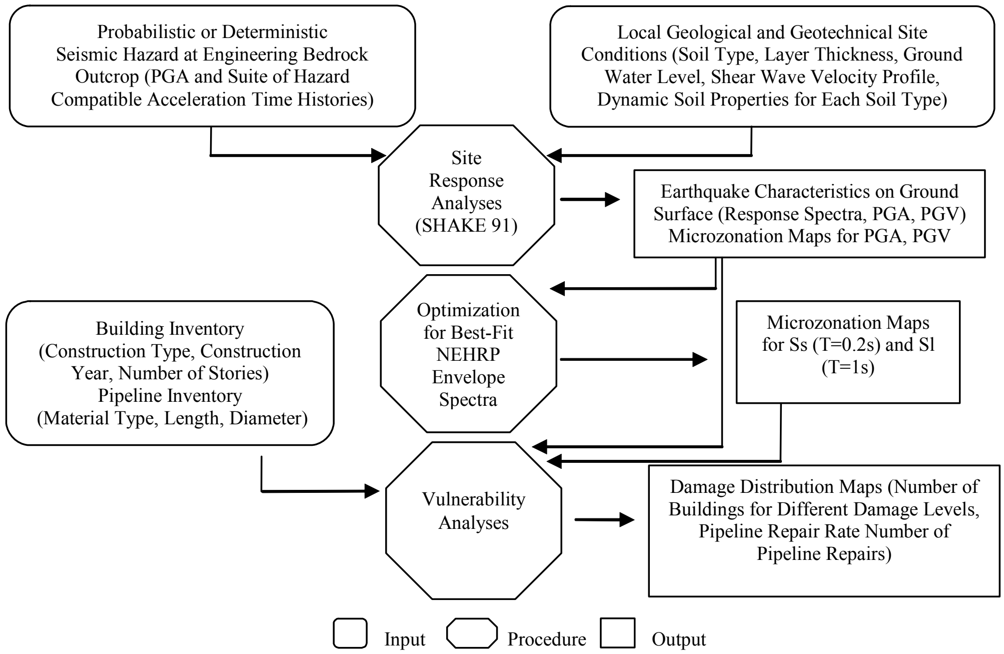

Figure 1. Schematic illustration of the software procedures for loss estimation in urban areas

The first worksheet in the excel software package contains information that defines input motions to be used in the analyses. The second worksheet contains information about dynamic shear modulus reduction and material damping ratio curves for different material types. The fourth and fifth worksheets contain pipeline and building inventory information, respectively.

In the present version of the software package, 22 building types are available. The building types are classified according to a so called 'Bijk building matrix'. The "i" in the Bijk matrix shows the construction type as: (1) Reinforced concrete frame building, (2) Masonry building, (3) Reinforced concrete shear wall building, (4) Precast building. The number of stories ("j" dimension of the matrix) is defined as: (1) Low rise (1-4 stories, including basement), (2) Mid rise (5-8 stories, including basement), (3) High-rise (more than 8 stories, including basement). The construction date ("k" dimension of the matrix) is defined as: (1) Construction year: Pre-1979 (included) and (2) Construction year: Post-1980. Each of the worksheets following the fifth worksheet contains information about geotechnical site conditions for one cell in the grid system. In each of these worksheets, the information that should be provided by the user includes soil type, soil layer thickness, ground water level and shear wave velocity profile down to the engineering bedrock ($V_s \geq 750$m/s).

The software package operates within Excel by running a VBA macro. Once executed, VBA macro performs all calculations without interference of the user. Graphical illustrations of average ground response spectrum and best-fit NEHRP design spectra, selected earthquake characteristics for microzonation, and the estimated building damage distribution for each cell are possible outputs. Building damage is given in terms of number of buildings at each damage state for each building type at each cell in the grid system.

Pilot Study

Recently, a comprehensive site investigation study was carried out on the European side of Istanbul as part of a large-scale microzonation project financed by Istanbul Metropolitan Municipality (OYO Inc., 2007). 2912 borings (mostly down to 30m depth with approximately 250m spacing) were conducted within an area of about 182 km^2 to investigate local soil conditions. The developed software package (KoeriLossV2) is used to carry out a pilot study to perform a damage scenario for Zeytinburnu, in Istanbul, Turkey using part of these recently complied soil data and based on probabilistic seismic hazard scenario by Erdik et al. (2005).

Seismic Hazard and Site Response Analyses

A grid system with cells of 250m×250m is defined for the study area. A probabilistic seismic hazard analysis is carried out to evaluate PGAs and spectral accelerations at T=0.2s and T=1s for each cell on the engineering bedrock outcrop (Erdik et al., 2005). A regional time dependent Poisson model for the return period of 475 years that corresponds approximately to 10% probability of exceedance in 50 years is used in the analysis (Erdik et al., 2004).

24 previously recorded earthquake acceleration time histories (PEER 2006) compatible with the seismic hazard (magnitude, distance, and fault type) and scaled with respect to estimated PGAs are used as outcrop input motion for site response analyses for each cell. Shear wave velocity profiles down to the engineering bedrock are estimated based on geological and geotechnical data and based seismic wave velocity measurements for all the cells.

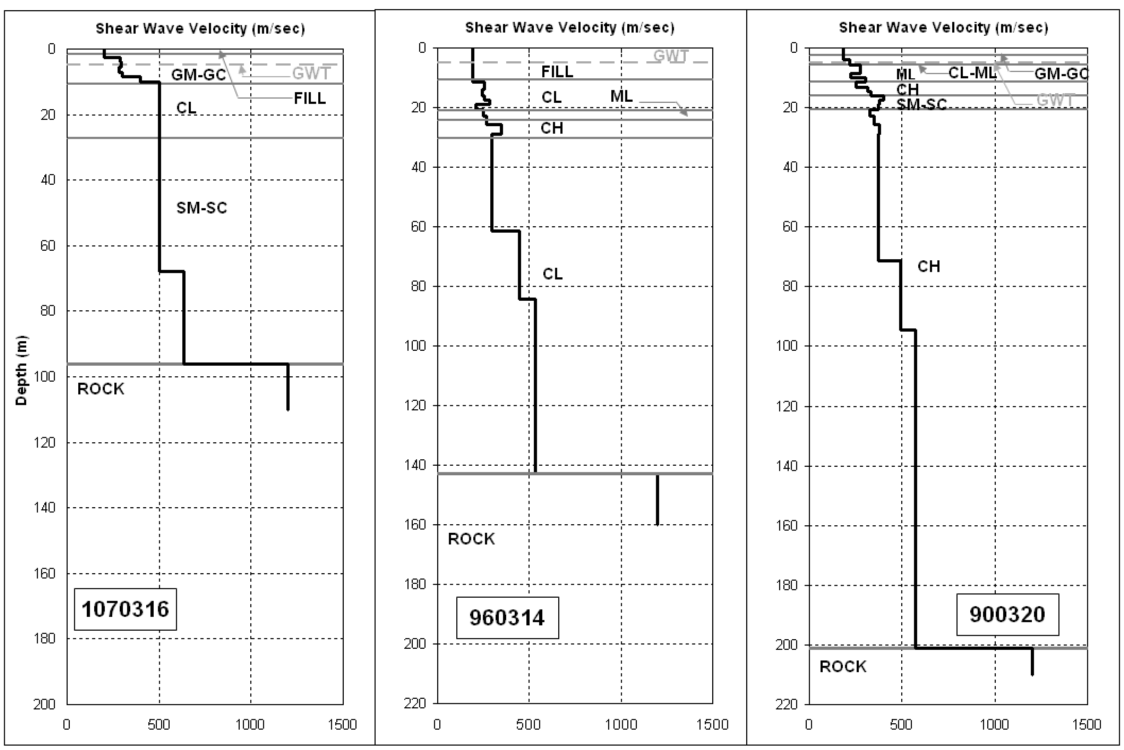

Figure 2. Typical shear wave velocity and soil profiles in Zeytinburnu

The averages of all calculated 24 PGA and ground response spectra are determined for each cell to define the variation of ground shaking parameters due to the probabilistic seismic hazard scenario. The short and long period spectral accelerations (Ss and Sl) are determined by an optimization algorithm for the calculated NEHRP design spectra. Microzonation maps generated with respect to Ss and Sl are shown in Fig. 3.

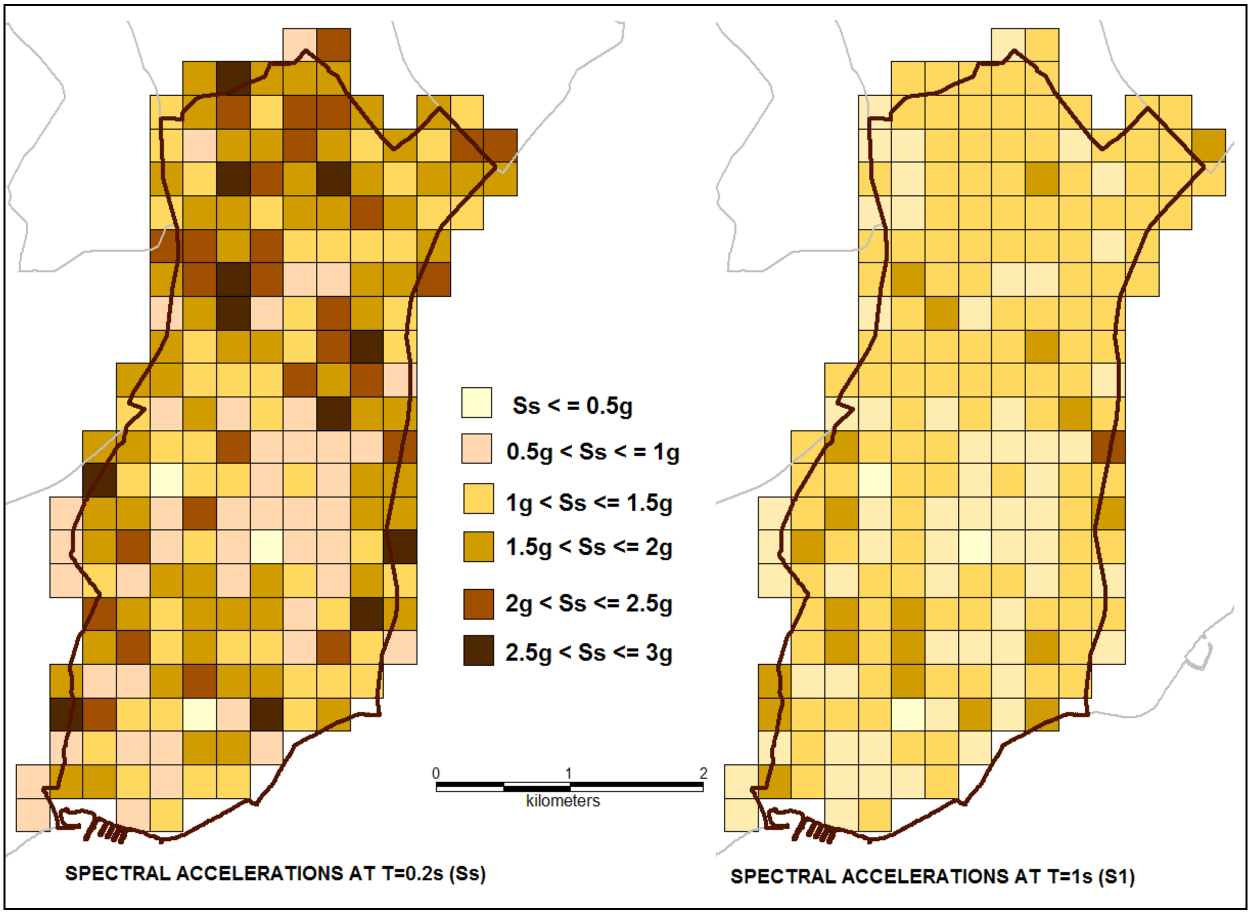

Figure 3. Variation of Ss and Sl determined from site-specific response analyses

Microzonation maps presented in Fig.3 are compared with the previously conducted earthquake scenario study for Zeytinburnu based on NEHRP amplification factors. The same regional probabilistic seismic hazard scenario was used to describe seismic hazard at the engineering bedrock level. The microzonation maps with respect to ground shaking parameters were generated based on NEHRP site classification and related amplification coefficients. Fig.4 shows microzonation maps with respect to Ss and Sl generated based on NEHRP site classification and related amplification factors. In contrast to what is shown in Fig. 3, almost no variation in the distribution of ground shaking parameters can be observed in Fig. 4. The spatial variation of earthquake characteristics presented in Fig. 3 can only be detected when site effects are evaluated by site-specific response analyses. In addition, the level of spectral acceleration calculated by the NEHRP amplification factors seems to be on the unconservative side in comparison to spectral acceleration calculated by site response analyses.

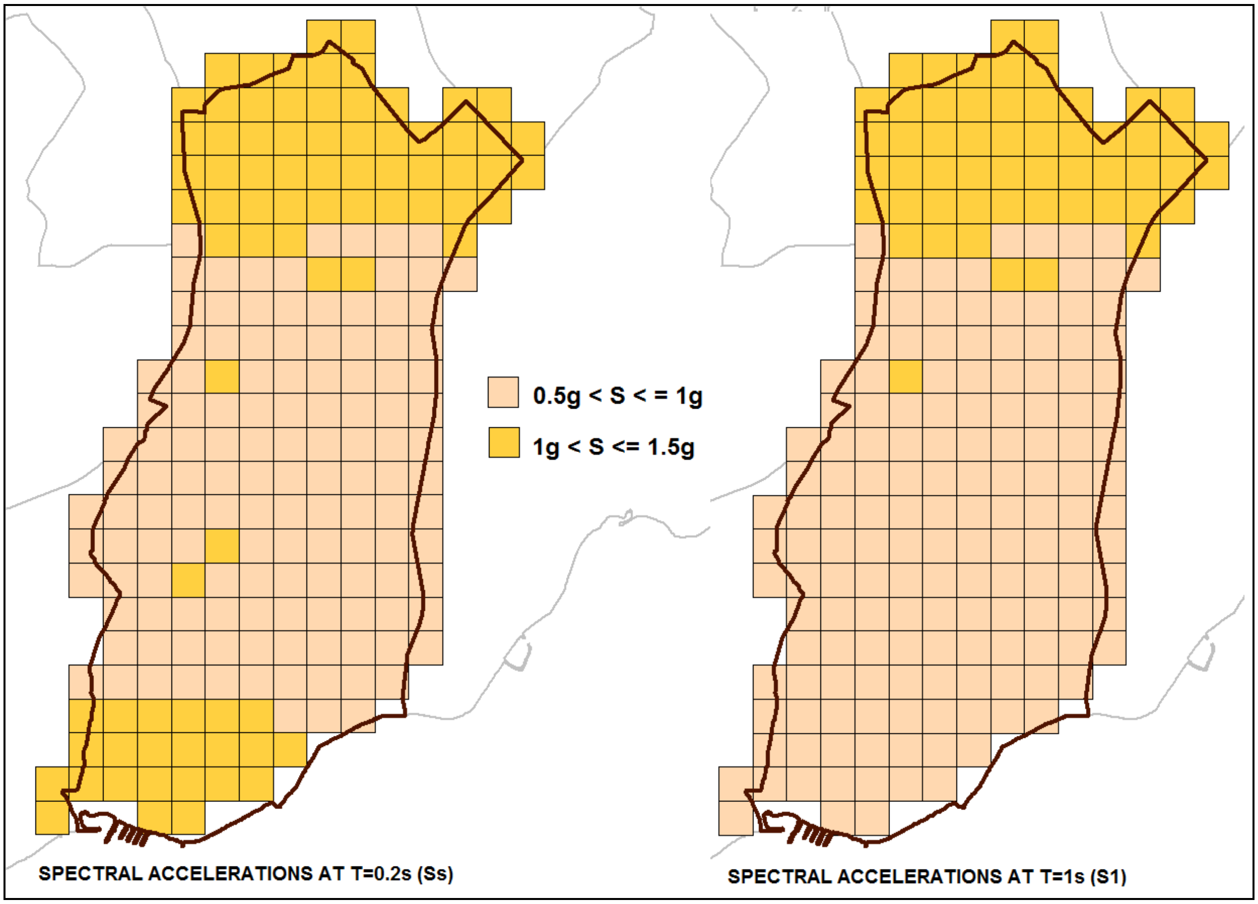

Figure 4. Variation of Ss and Sl determined using NEHRP amplification factors

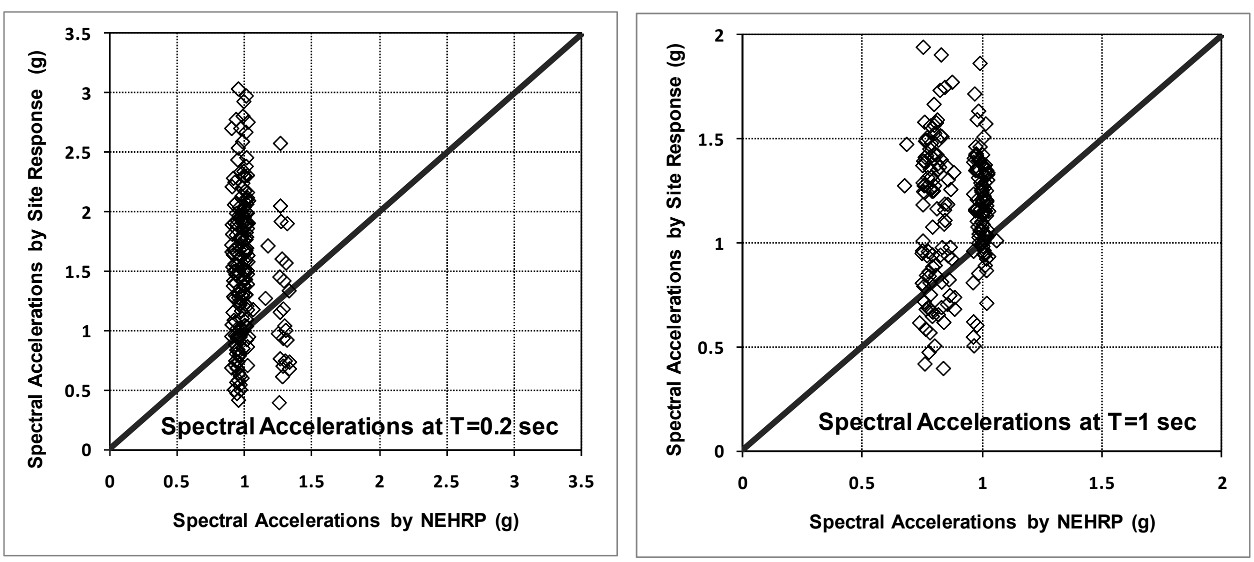

Figure 5. Comparison of Ss and S1 spectral accelerations calculated by site response analyses with those estimated using NEHRP amplification factors

The comparison between the spectral accelerations calculated from site response analyses using the best envelope fitting procedure and those values calculated by the NEHRP formulation indicates that the values obtained by site response analyses shows much larger variation as can be seen in Fig. 5. The difference in the data range is much more significant for short period spectral acceleration values.

Vulnerability Analyses for Buildings

A detailed inventory from street surveys of approximately 16000 buildings is used to estimate the vulnerability of Zeytinburnu (Erdik et al., 2003). Region-specific vulnerability relationships that relate spectral displacements to building damage for each building type are used to evaluate damage in Zeytinburnu (Aydinoglu and Polat, 2004). Distribution of number of buildings at each damage state for all building types in the area are calculated and displayed in maps showing total number of buildings at each cell for a given type of building and damage state.

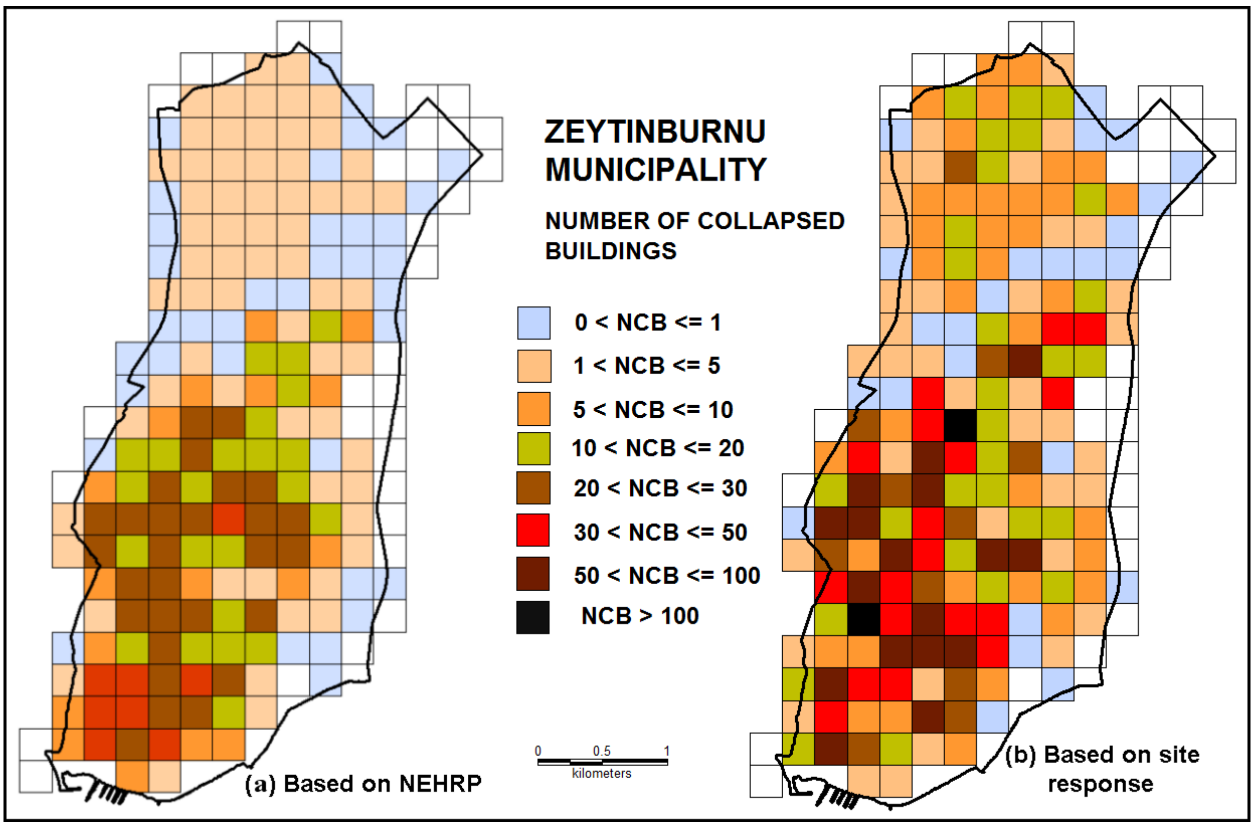

Figure 6. Distribution of collapsed buildings in Zeytinburnu estimated using a) results of site response analyses and b) NEHRP amplification factors

Distribution of total number of collapsed buildings in Zeytinburnu obtained using site-specific ground shaking parameters based on site response analyses and based on NEHRP amplification factors is shown in Fig. 6. As expected the difference between the two approach is significant and NEHRP approach yields lower damage results.

Larger scatter observed in the results obtained from site response analyses may be the indication of more accurate determination of site effects. NEHRP site classification based on equivalent shear wave velocity yields only two site classes in the case of Zeytinburnu. This is partly due to the fact that shear wave velocity ranges used in the NEHRP site classes are defined within relatively large ranges.

Conclusions

A software tool, KoeriLossV2, is developed to perform urban damage scenarios for structural loss estimation where local site effects are taken into account by conducting 1D site-specific ground response analyses. The procedure has two phases. The first phase involves calculation of site-specific ground motion characteristics using Shake91. In the second phase, vulnerability of the building inventory is estimated using empirical relationships. Application of KoeriLossV2 for a pilot study at a district in Istanbul, Turkey demonstrated that the software can efficiently incorporate detailed site response analyses in the loss estimation process and provides a practical tool for performing damage scenarios in urban areas. Comparison of results obtained from this study with previous seismic microzonation studies conducted for the same area indicated that detailed site characterisation is important and essential when performing site response analyses to have reliable and more accurate information on ground shaking characteristics that will be used for seismic loss estimation.

Acknowledgments

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