A Case Study for Seismic Zonation in Municipal Areas

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Summary

We determined the seismic model of the soil column on a district basis within the Municipality of Izmit, Turkey. Specifically, we conducted refraction seismic survey at 16 locations and estimated the P- and S-wave velocity-depth profiles down to a depth of 30 m. We then combined the seismic velocities with the geotechnical borehole information about the pedology and lithology of the soil column and determined the geotechnical earnthquake engineering parameters for each district. Specifically, we computed the soil amplification and its effective depth range, design spectrum periods *TA-TB,* and liquefaction probability and depth range. We diagnosed that the cause of the severe damage by the August 1999 earthquake with 7.4 magnitude within the municipal area of Izmit is soil amplification and localized liquefaction.

In addition to geotechnical characterization of the soil column at each district, we also conducted shallow reflection seismic surveys at 10 locations within the municipal area along line traverses with an average length of 450 m primarily in the EW direction and derived seismic images down to a depth of 100 m. From the interpretation of the seismic sections, we delineated several faults most of which reach the surface and cause significant lateral velocity variations within the near-surface as verified by the first-arrival tomography solution for P-wave velocity-depth models along the line traverses. These are most likely the active auxiliary faults associated with and oblique to the North Anatolian right-lateral strike-slip fault which traverses the muncipal area in the EW direction. We conclude that the neotectonic model of the area is represented by pull-apart tectonism rather than pure strike-slip fault mechanism.

Introduction

The August 1999 earthquake with 7.4 magnitude caused a severe damage within the municipality of Izmit, 170 km east of Istanbul. A survey of the damaged buildings was made by the municipal authorities shortly after the earthquake. The Municipal Government decided to conduct a pilot seismic zonation project to determine whether the cause of the damage was poor construction materials and methods or weak soil conditions. In this project, we investigated the soil conditions with two objectives in mind: (1) to estimate the seismic model of the soil column at each district so as to determine the geotechnical earthquake engineering parameters, and (2) to map active faults within the municipal area.

Figure 1 shows the location map for the refraction and reflection profiles. The size of the municipal area is approximately 10 km in the EW direction and 6 km in the NS direction.

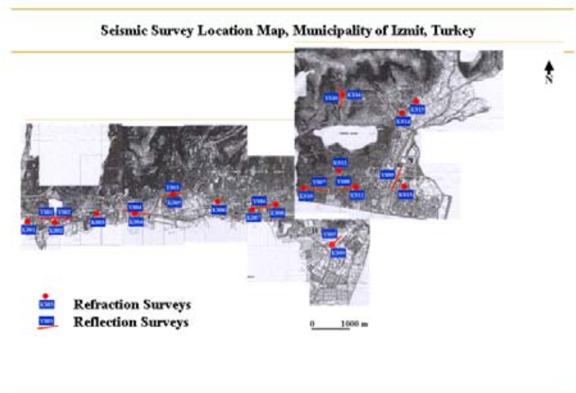

Figure 1. Location map for the seismic survey conducted within the Izmit municipal area. The survey cocnsists of refraction profiling at 16 locations and reflection profiling at 10 locations.

Data Acquisition

Refraction Seismic Survey. At 16 locations within the municipal area (Figure 1), we recorded seismic data on asphalt paved roads. We deployed a receiver spread with 48 4.5-Hz vertical geophones at 2-m interval. We used an accelerated impact source and acquired three shot records with source locations at each end of the spread and at the center of the spread (Figure 2).

Reflection Seismic Survey. Along the 10 line traverses with a total linear length of about 4,500 m (Figure 1), we recorded seismic data on asphalt paved roads. We deployed a receiver cable in the form of a land streeamer with 48 14-Hz vertical geophones at 2-m interval and 10-m near-offset. We used an accelerated impact source and acquired shot records at 4-m interval along each of the 450-m line traverses, thus achieving 12 fold of coverage.

Data Analysis

Analysis of Refraction Survey Data. By applying a nonlinear traveltime tomography (Zhang and Toksoz, 1998) to the first-arrival times picked from the three shot records, we estimated a near-surface P-wave velocity-depth model along the receiver spread at each of the 16 locations.

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By applying smoothing during the inversion and lateral averaging after the inversion, we then obtained a P-wave velocity-depth profile representative of each location (Figure 3).

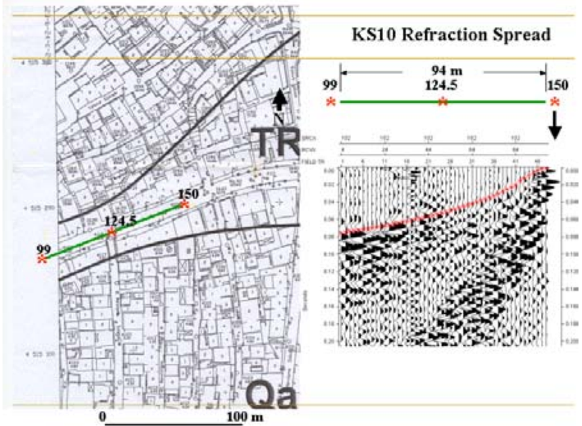

Figure 2. Refraction survey at location KS10 shown on the street map (left) with a sample shot record (right). The line above the record represents the receiver spread, the numbered asterisks represent the shot locations, and the curve on the record represents the picked first-arrival times.

Next, we identified the off-end shot record with the most pronounced dispersive surface-wave pattern and performed plane-wave decomposition to transform the data from offset-time to phase-velocity versus frequency domain. A dispersion curve associated with the fundamental mode of Rayleigh-type surface waves was picked in the transform domain based on the maximum-energy criterion and inverted to estimate the S-wave velocity as a function of depth as shown in Figure 3 (Park et al., 1999; Xia et al., 1999). The velocity estimation from surface seismic data represents a lateral average over the receiver spread length in contrast with the velocity estimation from borehole seismic measurements which are influenced by localized lithologic anomalies and borehole conditions.

Estimation of Geotechnical Earthquake Engineering Parameters. The seismic model of the soil column, combined with the pedology and lithology of the soil column from the nearest geotechnical borehole, is used to perform microzonation analysis, liquefaction analysis, and aseismic design of structures (Kaneko et al., 1990). To determine the geotechnical earthquake engineering parameters, we begin with an SH accelerogram associated with the August 1999 earthquake recorded at a rock site within the municipal area (Figure 4a). Given the seismogram at the rock site, we extrapolated it through the soil column knowing the S-wave velocity-depth profile and the geotechnical borehole information to model the seismogram at the soil site (each of the 16 KS locations) (Figure 4a). At each of the KS locations, we computed the maximum acceleration as a function of depth (Schnabel et al., 1972; Kramer, 1996) (Figure 4b), and determined the soil amplification factor at the ground level and the depth range for which amplification is significant.

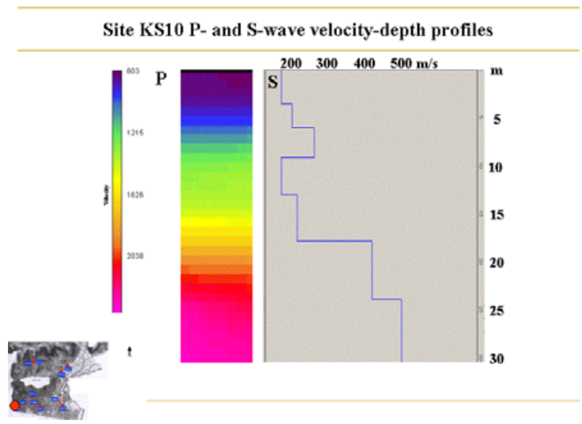

Figure 3. The P-wave velocity-depth (left) and the S-wave velocity-depth (right) profiles down to 30-m depth.

Next, we computed the design spectra (Figure 4c) --- response of buildings with a range of natural periods to the modeled ground motion at the soil site and the actual ground motion at the rock site (Kramer, 1996). The building structure is defined as a spring system with a single-degree of freedom. From the design spectra, we determined the design spectrum periods *TA* and *TB*.

A region in the plane of the S-wave velocity versus maximum ground acceleration corresponds to the likely occurrence of liquefaction (Stokoe, 1988). We extended this relationship between the S-wave velocity and maxium acceleration to account for water saturation in the soil column. Provided certain soil conditions are also met, the liquefaction process occurs when the medium becomes fully saturated, in which case the P-wave velocity increases while the S-wave velocity is unchaged (Yilmaz, 2001). By correlating the *Vp/Vs* ratio with the maximum ground acceleration and the S-wave velocity (Figures 4b,d,e), all as a function of depth, we determined the liquefaction probability or earthquake-induced settlement and its depth range of occurrence at each of the 16 sites. In this analysis, we also took into account the fines content information from the geotechnical borehole data.

The geotechncial earthquake engineering parameters listed in Table 1 indicate that the cause of the severe damage in Izmit by the August 1999 earthquake is primarily soil amplification in addition to liquefaction at certain localities. In most districts of the municipality, the soil conditions are such that soil remediation would be very costly. Therefore, use of timber and steel, rather than heavy concrete, for construction material would reduce the structural mass of the buildings and provide safer habitation for the municipal residents.

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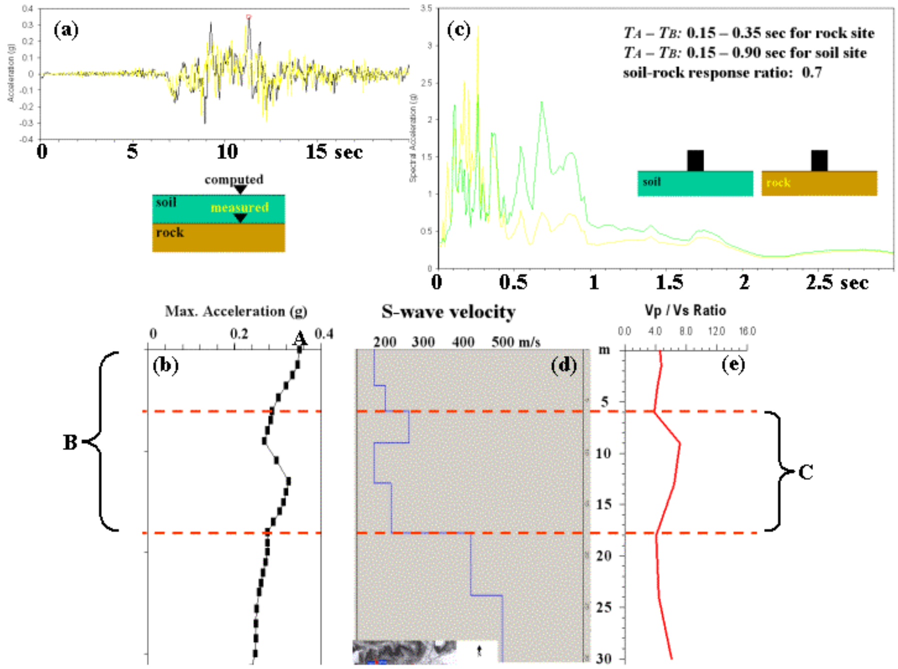

Figure 4. Analysis for geotechnical earthquake engineering parameters at site KS10: (a) An SH accelerogram associated with the August 1999 Izmit earthquake measured at a rock site and a modeled seismogram at the soil site KS10; (b) maximum acceleration as a function of depth --- A denotes the maximum acceleration at the ground level and B denotes the depth range for which maximum acceleration is significant; (c) design spectra for the rock site and the soil site; (d) S-wave velocity as a function of depth; and (e) *Vp/Vs* ratio as a function of depth --- C denotes the depth range for likely occurrence of liquefaction.

Table 1. Geotechnical earthquake engineering parameters determined from the seismic model of the soil column and geotechnical borehole data at 16 sites.

Site	*Soil amplification at ground level*	*Depth interval (m) for significant amplification*	*Maximum soil-rock response ratio*	*TA – TB (sec)*	*Liquefaction probability and depth interval (m)*
KS01	3.6	0 - 10	2.7	0.15 - 0.35	Nill
KS02	2.4	0 - 20	1.5	0.15 - 0.90	High 7 - 17
KS03	2.6	0 - 22	1.6	0.15 - 0.55	Nill
KS04	2.6	0 - 5	1.6	0.15 - 0.35	Nill
KS05	2.6	0 - 20	2.0	0.15 - 0.40	Nill
KS06	4.1	0 - 7	2.3	0.15 - 0.35	Nill
KS07	2.3	0 - 25	1.0	0.15 - 0.70	Medium 7 - 17
KS08	2.4	0 - 14	1.5	0.15 - 0.70	Medium-High 5 - 10
KS09	3.3	0 - 8	2.5	0.15 - 0.35	Medium 4 - 9
KS10	2.3	0 - 18	0.7	0.15 - 0.90	High 6 - 18
KS11	2.5	0 - 10	1.5	0.15 - 0.70	Low-Medium 4 - 11
KS12	2.5	0 - 22	1.7	0.15 - 0.70	Medium-High 4 - 9
KS13	2.3	0 - 22	1.1	0.15 - 0.75	Nill
KS14	2.6	0 - 10	1.5	0.15 - 0.55	Nill
KS15	3.5	0 - 7	2.3	0.15 - 0.35	Low 7 - 9
KS16	2.5	0 - 4	1.1	0.15 - 0.35	Nill

Analysis of Reflection Survey Data. In contrast with a comprehensive processing sequence applied to reflection seismic data used in exploration for oil and gas fields (Yilmaz, 2001), shallow reflection seismic data usually require a simple processing sequence (Steeples and Miller, 1990) that includes application of a bandpass filter and AGC. Aside from deriving a seismic section that represents the subsurface image down a depth of 100 m, we also estimated the near-surface P-wave velocity-depth model, again using the nonlinear traveltime tomography, for each of the 10 line traverses (Figure 5). The nonlinear tomography solution is based on not just the first-arrival times but also changes in traveltime gradient. As such, within the near-surface, we were able to resolve strong lateral velocity variations associated with the fault system observed on the seismic sections.

In most sections, many of the faults reach the surface --- typical of active faults. The fault patterns observed on the seismic sections are oblique to the North Anatolian right-lateral strike-slip fault system with EW orientation in the area. Such fault patterns, combined with the strike-slip fault system, are often associated with pull-apart tectonism. Therefore, the Izmit area, which is the eastern tip of the Marmara Basin, is a transition zone from the dominant strike-slip regime along the North Anatolian Fault System to the pull-apart tectonic regime of the Marmara Basin.

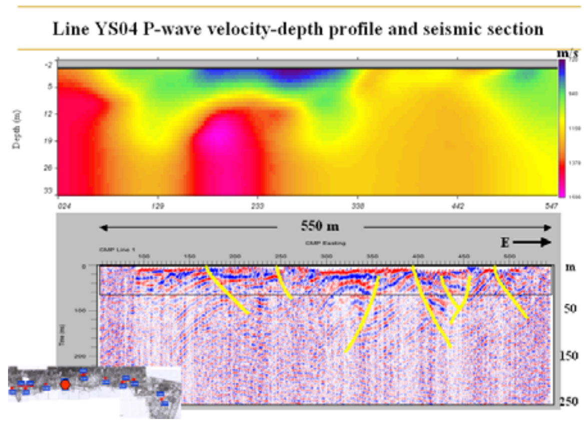

Figure 5. Top: the P-wave velocity-depth model down to 30-m depth derived from the application of nonlinear traveltime tomography to first-arrival times on shot records; bottom: the seismic section derived from the analysis of reflected waves. The model on top corresponds to the rectangular region in the seismic section below.

Acknowledgements

We thank the Izmit Municipality for giving us the opportunity to conduct this integrated seismic project and granting the permission for publishing the results. We sincerely thank Rick Miller for sharing his wisdom and experience on shallow seismic data acquisition.

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