IzmirNet: A Strong-motion Network in Metropolitan Izmir, Western Anatolia, Turkey

by

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INTRODUCTION

A 16-station strong-motion seismic monitoring network covering metropolitan Izmir and the surrounding region was established in July 2008. The seismic network was installed as a cooperative effort involving the Earthquake Research and Implementation Center (ERIC-DAUM) of Dokuz Eylul University (DEU, Izmir), the Earthquake Research Department (ERD) of the General Directorate of Disaster Affairs (GDDA, Ankara), the Izmir Metropolitan Municipality, and the Ministry of Public Works and Settlement. The project was funded by the Scientific and Technological Research Council of Turkey (TUBITAK) to collect strong-motion data for earthquake hazard assessment studies and to develop a real-time monitoring system in Turkey (Inan et al. 2007) to address public safety issues.

The network is critically important to addressing earthquake hazard issues in western Turkey, an area known to have historically damaging earthquakes. Izmir is the third largest city in Turkey in terms of population, industrial density, economic capacity, and contribution to the national economy, and the economic and human consequences of a damaging earthquake in the Izmir area would be significant.

A primary goal of this project is to acquire strong-motion ground data in order to understand propagation and site response characteristics of the Quaternary and Neogene sediments that underlie the Izmir metropolitan area and are thought to produce large site amplification and seismic hazard (Aydinoglu 2000; Masure et al. 2000). These data will complement laboratory data to characterize the properties of the soft soils underlying the Izmir metropolitan residential area so that engineers and architects can design appropriate earthquake-resistant structures for the region. This project is also a first step toward developing a “Rapid Response and Damage Prediction System” for metropolitan Izmir where near real-time strong ground-motion records can be used to compute ground-shaking maps showing the areas most strongly affected by earthquakes.

SEISMOTECTONIC SETTING

The tectonic framework of western Anatolia is dominated by crustal extension. The Aegean region to the south of 39.50N extends in a N-S direction with an upper bound rate of 20 mm/y, while the north Anatolian fault zone (NAFZ) and east Anatolian fault (EAF) are characterized by strike-slip deformation (Figure 1; see also Jackson and McKenzie 1984; Saroglu et al. 1992). Within this extensional framework, the study area is located at the western termination of the Gediz graben system (GGS), close to the city of Manisa in the north and Doganbey cap (DC) in the south (Pamukcu and Yurdakul 2008; Polat et al. 2008).

The 16 stations comprising the IzmirNet are shown in Figure 2. Dominant tectonic features in the study area are the Izmir fault (IF); the Orhanli fault zone (OFZ); and the Seferihisar, Urla, Gulbahce, and Karaburun faults (SF, UF, GF and KF, respectively; Ocakoglu et al. 2005; Uzel and Sozbilir 2008). The IF, trending in an E-W direction, is a normal fault bounding the southern Gulf of Izmir. Its activity has been well documented, with the occurrence of strong events including the 688 and 1668 events (both with \( I_0 = 1X \), Ergin et al. 1967) and the earthquake of 10 July 1688 (\( I_0 = X \); Ambraseys and Finkel 1995). The OFZ and SF run between Doganbey Cap and the Izmir Gulf. Here the dominant character of these faults is right-lateral strike-slip (Uzel and Sozbilir 2008). A strong earthquake on 6 November 1992 (\( M_w = 6.0 \)) occurred along this zone, revealing a right-lateral fault plane solution (Tan et al. 2008). The most devastating earthquake along the UF from the historical period is reported on 15 October 1883 (\( I_0 = 1X \), Ergin et al. 1967). Toward the west, the 17–21 October 2005 (\( M_s = 5.9 \)) earthquake series occurred along the GF and near the KF, at the north of Sigacik Bay. Fault movement of most of
the events reveals pure strike-slip faults as evidenced from focal mechanism solutions (Aktar et al. 2007; Benetatos et al. 2006).

The region is situated in the first-degree hazard zone in the Official Earthquake Hazard Regionalization Map of Turkey. By using historical (since 5th century B.C.) and instrumental (from 1911 on) data, Papazachos et al. (2004) postulated the possibility of a severe earthquake with magnitude larger than 6.4 in the study area. Koravos et al. (2003) proposed a maximum earthquake magnitude 7.2 ± 0.1 near KF by using a combination of instrumental, historical, and geodetic data. Since devastating earthquakes occur relatively infrequently in the region, this should be treated with caution. A missed opportunity for proper recording of the ground motions these events produce represents the loss of important and irreplaceable scientific data in metropolitan Izmir and the surrounding area. High-density strong-motion networks are justified because if effects of these rare occurrences are recorded, they could provide valuable insight to engineers and seismologists about what to expect in a future damaging earthquake.

**DESCRIPTION OF IZMIRNET**

The main conceptual aims of the new network are: 1) adequate coverage of the various sedimentary environments in Izmir and surroundings, 2) station locations close to potential fault planes, 3) free-field station installations wherever logistically possible, 4) remote accessibility to the data, and 5) continuous recording (as opposed to triggered recording) so that relatively small events are recorded at all stations. The IzmirNet covers an area of approximately 50 km × 20 km around the Gulf of Izmir and is deployed over the active fault system. A list of the basic parameters for all stations is given in Table 1.

**Station Hardware**

All stations are free-field and equipped with three-component CMG-5TD accelerographs (Guralp Systems, Reading, UK) with CMG-5T force balance accelerometer and built-in 24-bit AD converter for data acquisition. The system contains two supply boxes for communication and uninterruptible power...
▲ Figure 2. Main tectonic elements near metropolitan Izmir, Aegean region of Turkey. Tectonic features are mainly compiled from Ocakoglu et al. (2005) and Uzel and Sozbilir (2008). KF—Karaburun fault, GF—Gulbahce fault, IF—Izmir fault, SF—Seferihisar fault, OFZ—Orhanlı fault zone, UF—Urla fault.

TABLE 1
Station Parameters of the IzmirNet Strong-Motion Network

<table>
<thead>
<tr>
<th>Code</th>
<th>Lon. deg E</th>
<th>Lat. deg N</th>
<th>Elev. (m)</th>
<th>Location</th>
<th>Environment</th>
<th>Installation Date *</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLC</td>
<td>27.04300</td>
<td>38.40900</td>
<td>3</td>
<td>Balçova</td>
<td>Institute of Marine Sciences and Technology of DEU</td>
<td>6/22/2008</td>
</tr>
<tr>
<td>BRN</td>
<td>27.25630</td>
<td>38.42130</td>
<td>76</td>
<td>Bornova</td>
<td>FIGSAN Spicery Factory</td>
<td>7/16/2008</td>
</tr>
<tr>
<td>BUC</td>
<td>27.15160</td>
<td>38.40090</td>
<td>79</td>
<td>Buca</td>
<td>Züeyde Hanım Nursing Home</td>
<td>6/22/2008</td>
</tr>
<tr>
<td>BYN</td>
<td>27.16710</td>
<td>38.45840</td>
<td>2</td>
<td>Bayındırlik</td>
<td>Province Directorate of Development and Settlement</td>
<td>6/21/2008</td>
</tr>
<tr>
<td>BYR</td>
<td>27.15810</td>
<td>38.47620</td>
<td>197</td>
<td>Bayraklı</td>
<td>Local Health Home of Karşıyaka Municipality</td>
<td>7/16/2008</td>
</tr>
<tr>
<td>BOS</td>
<td>27.09404</td>
<td>38.46498</td>
<td>17</td>
<td>Bostanlı</td>
<td>Mehmet-Seniye Öz bey Primary School</td>
<td>7/17/2008</td>
</tr>
<tr>
<td>KYN</td>
<td>27.19364</td>
<td>38.37560</td>
<td>136</td>
<td>Kaynaklar</td>
<td>Main University Campus of DEU</td>
<td>7/16/2008</td>
</tr>
<tr>
<td>KON</td>
<td>27.14350</td>
<td>38.43120</td>
<td>7</td>
<td>Konak</td>
<td>İzmir Fair</td>
<td>7/17/2008</td>
</tr>
<tr>
<td>KSK</td>
<td>27.11124</td>
<td>38.45250</td>
<td>10</td>
<td>Karşıyaka</td>
<td>Province Directorate of Forest Affairs</td>
<td>6/21/2008</td>
</tr>
<tr>
<td>MNV</td>
<td>27.21110</td>
<td>38.47800</td>
<td>184</td>
<td>Manavkuyu</td>
<td>Atatürk Public Library</td>
<td>6/21/2008</td>
</tr>
<tr>
<td>MVS</td>
<td>27.07720</td>
<td>38.46780</td>
<td>1</td>
<td>Mavişehir</td>
<td>Deniz-Kent Municipality Restaurant</td>
<td>7/17/2008</td>
</tr>
<tr>
<td>CMD</td>
<td>27.19870</td>
<td>38.43570</td>
<td>68</td>
<td>Çam dibi</td>
<td>21st Family Health Center</td>
<td>7/17/2008</td>
</tr>
<tr>
<td>URL</td>
<td>26.77063</td>
<td>38.32823</td>
<td>76</td>
<td>Urla</td>
<td>Municipality Sports Hall</td>
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<tr>
<td>YMN</td>
<td>27.10730</td>
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<td>64</td>
<td>Yamanlar</td>
<td>Mümessyer Turfan Nursing Home</td>
<td>6/21/2008</td>
</tr>
<tr>
<td>YSL</td>
<td>27.10840</td>
<td>38.37230</td>
<td>106</td>
<td>Yeşilyurt</td>
<td>Naci Şensoy high school</td>
<td>6/21/2008</td>
</tr>
</tbody>
</table>

* = Connection is DSL (Digital Subscriber Line), DEU = Dokuz Eylül University of İzmir
and also a serial modem (Figure 3). A complete health status is available that assists in the diagnosis of system component failure or malfunction.

An asymmetric digital subscriber line (ADSL) system controls the stations and downloads real-time continuous data. It runs SCREAM! data acquisition software developed by Guralp Systems for the Windows and Linux platforms. Continuous waveform data, sampled at 100 sps (samples per second), are stored in Guralp compressed format (GCF) file format containing time and station information as well. This format is compatible and convertible with several software packages including SAC (Goldstein and Snoke 2005) and SEISAN (Haskov and Ottemoeller 1999) seismic analysis software. The IzmirNet stations use the ADSL technology to download and store data in the central processing laboratories in Izmir and Ankara.

**Site Characterization**

Earthquake resistant but economical structures can be designed and constructed only if the nature of the ground motion is understood. This understanding can only come from direct measurement and subsequent analysis of the strong ground motion recorded during actual earthquakes. Many studies have demonstrated the ability of geologic conditions to alter observed seismic motions and to affect the amount of damage. Site amplification is considerably effective on the building response especially for the near field and/or large scale earthquakes.

Izmir city and metropolitan area is located very close to active faults and is sited on thick Quaternary–Neogene-age sediments. Since unconsolidated deposits in the Izmir basin may significantly change the propagation of ground motions to the surface, the assessment of seismic hazard for the Izmir region is an important issue. The IzmirNet strong-motion seismic array has been established to calculate the site response characteristics in the region, which are of interest in the engineering seismology and earthquake engineering disciplines. We performed borehole drilling, microtremor, electrical resistivity, and seismic refraction techniques, as well as multichannel analysis of surface waves (MASW) measurements in the IzmirNet stations in order to determine the geological, geophysical, and geotechnical site characterization as a function of depth (up to 30 m). A sample is shown in Figure 4. The data obtained by the application of these techniques will be input to make a reliable probabilistic seismic hazard analysis for metropolitan Izmir and its vicinity.

The acceleration recorders were installed mainly at sites where thick Quaternary and Neogene formations are exposed. Stations are mainly distributed on these units in the Izmir Bay area. They are in Bornova basin at the east, the Karşıyaka-Mavisehir area at the north, and between Balçova and Urla at the south. Quaternary sediments and cretaceous flysch are the main units near the Balçova area, with a sedimentary fill up to 180 m. Here, the Izmir fault plays an important role in the development of one of the most important geothermal areas in western Anatolia. Some stations are also near Buca settlement.
toward the south extremity of the city, where geological units generally exhibit limestone and marl.

**SAMPLE DATA**

Figure 5 shows an example from time and frequency domain analysis for the earthquake ($M_d = 3.0$) that occurred on 10 August 2008. A horizontal-component accelerogram (SH) was used to analyze the site and source characteristics of the selected event. We plan to compute source size, spectral level ($\omega_0$), seismic moment, stress drop, and validity of corner and cut-off frequency ($f_{\text{max}}$), with a discussion of the effect of various attenuation models on the source spectra. Two horizontal motions are combined in the Z-component to infer the particle motion characteristics. This study procedure allows a detailed analysis of frequencies at which the ground motion is the largest and most polarized. Particle motion in the horizontal plane represents an ellipse, and it is a very important measure of horizontal shaking that provides a complete description of the magnitude of motions. Here, we estimated mainly north and east directions for the KSK and KYN stations, respectively, for the selected event of 10 August 2008.

Figure 6 shows the data quality and selected earthquakes recorded by IzmirNet. The three-component event that occurred on 3 September 2008 ($M_D = 2.8$) has a 10-km hypocentral distance. The earthquake of 10 August 2008 ($M_D = 3.0$) was recorded by at least 13 stations. These data examples present local microearthquakes with a good $S/N$ ratio. Since all stations are remotely accessible, we plan to use the data to perform a rapid calculation of intensities.

**FUTURE PLANS**

Due to its high density, wide dynamic range (flat response from DC to 50 Hz), and advanced data-acquisition and data-transmission technologies, IzmirNet will become the core infrastructure of a prototype “Rapid Response and Damage Prediction System” in metropolitan Izmir. In the near future, it will be devoted to real-time estimation of magnitude and earthquake location to calculate rapid ground-shaking maps for the whole of the city.

The principal aim of the network is to address site-response issues in Izmir. But IzmirNet will also contribute to emergency response in the near future by increasing the number of stations in the region and connecting to a broader system for reporting earthquake locations and magnitudes and computing the shakemaps. The information provided by the network during the first few seconds of a potentially damaging seismic event will be used to activate several types of security measures, such as the shutdown of critical systems, such as gas or oil pipelines or water, sewer, and electricity lines, etc. Hence, the IzmirNet is closely concerned with the lifeline systems and public social life. The network will provide precise peak ground acceleration (PGA) distribution, which is one of the most important parameters when projecting loss estimates as the result of a potential strong earthquake. In the near future, ground-shaking maps
will also play an important role in reducing the negative impact of destructive earthquakes in urban areas. This local array will be used to fully exploit the PGA distribution during the earthquake and exhibit critical settlement areas of the city (Ulusay et al. 2004).

CONCLUSIONS

The IzmirNet strong-motion network has been fully operational since August 2008. It promises to be useful for research and implementation in engineering and strong-motion seismology. The array is already recording small-scale earthquakes in the Gulf of Izmir and the surrounding area (Figure 6). Location parameters are given in Table 2. Most of the events are low magnitude, but they lay the groundwork for studying a future large earthquake and predicting its ground motion.

To make accurate epicenter locations and to produce more reliable ground-shaking maps after a strong earthquake in or around Izmir, we plan to install additional recorders near the Gulf of Izmir in locations north of Karaburun Peninsula (to the west), the western half of the Cigli and Mavisehir districts (in the north), and near the Gaziemir district (to the south). These additional stations will be equipped with the same instruments and communication protocols to retrieve peak ground parameters.

IzmirNet is part of the national strong-motion network of the GDDA (Ankara) that is already operating and includes several local arrays in western Anatolia. The long-sought goal of the GDDA is to increase the total number of accelerographs in Turkey (Gulkan et al. 2007). Currently, the national network consists of about 220 strong-motion recorders; the local IzmirNet array, a joint operation between ERIC in Izmir and ERD in Ankara, will help reduce the chances of missing important seismological data if a moderate-to-large earthquake were to hit the Aegean region and western Anatolia.

▲ Figure 5. Sample analysis of the event of 10 August 2008 ($M_d = 3.0$). (A) Two horizontal components of the BLC station in time domain. (B) Displacement spectra of the event showing corner frequency ($f_c$), $f_{max}$ (Hanks 1982), and spectral level ($\Omega_o$) to compute source parameters for Brune’s (1970) model. (C) Examples of the particle motion analysis at KSK and KYN stations in the plane NS-Z and EW-Z.
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