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ISTANBUL EARTHQUAKE RAPID RESPONSE AND THE EARLY WARNING SYSTEM

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SUMMARY

One hundred strong motion accelerometers have been placed in populated areas of Istanbul, within an area of approximately 50x30km, to constitute a network that will enable rapid shake map and damage assessment after a damaging earthquake. After triggered by an earthquake, each station will process the streaming strong motion to yield the spectral accelerations at specific periods and will send these parameters in the form of SMS messages to the main data center through available GSM network services.

A shake map and damage distribution will be automatically generated. The shake and damage maps will be available on the Internet and will also be pushed to several end users. For earthquake early warning information ten strong motion stations were located as close as possible to the Marmara Fault. The continuous on-line data from these stations will be used to provide near-real time warning for emerging potentially disastrous earthquakes.

BACKGROUND AND INTRODUCTION

Potential impact of large earthquakes on urban societies can be reduced by timely and correct action after a disastrous earthquake. The rapid response systems implemented in California (USGS, Caltech and CDMG TriNet ShakeMaps - http://www.trinet.org/shake/, Caltech-USGS Broadcast of Earthquakes (CUBE) System http://www.gps.caltech.edu/~bryant/cube.html, UC Berkeley Seismological Laboratory and USGS Menlo Park (REDI) www.seismo.berkeley.edu/seismo/redi), Taiwan (Earthquake Rapid Reporting System of CWB http://www.earth.sinica.edu.tw/cdr/IASPEI/data/cwb/rapid.html) and Japan (Real-time Earthquake Assessment Disaster System in Yokohama -READY - http://www.city.yokohama.jp/me/bousai/dppc/handout-e.html) are current examples. Earthquake Early

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Warning in urban and industrial areas allows for clean emergency shutdown of systems susceptible to damage such as power stations, transportation, computer centers and telephone systems. Currently such systems are either implemented on in construction or planning stage in Mexico, Romania, California, Japan, Taiwan, Turkey and Greece. Earthquake early warning systems, currently in operation in Bucharest (http://www.infp.ro/publications/ews.htm) and Mexico (http://www.gfz-potsdam.de/ewc98/abstract/espinosa.html), have the capability of issuing an earthquake early warning in advance, by relying on significant distances between the source and the populated urban regions. A general treatment of the earthquake early warning and rapid response systems exist in Kanamori [1]. Espinosa-Aranda and Rodriquez-Cayeros [2], Gee et al [3] and Hauksson et al [4] provides respectively descriptions of the Seismic Alert System in Mexico City, REDI and TriNet Projects.

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Istanbul faces a significant earthquake hazard and risk as illustrated by the recently developed earthquake risk scenario for Istanbul (http://www.koeri.boun.edu.tr/ depremmuh/EXEC_ENG.pdf), also Erdik et al [5]. The tectonic setting showing the location of the Main Marmara Fault and EMS98 intensity distribution that would result from a moment magnitude Mw=7.5 scenario earthquake is provided in Fig. 1. To assist in the reduction of losses in a disastrous earthquake in Istanbul a dense strong motion network is established, Erdik et al [6]. One hundred (100) of the strong motion recorders are stationed in dense settlements in the Metropolitan area of Istanbul in dial-up mode for Rapid Response information generation (Fig. 2). Ten (10) of the strong motion stations are sited at locations as close as possible to the Great Marmara Fault in on-line data transmission mode to enable Earthquake Early Warning (Fig. 3). The remaining 40 strong motion recorder units will be placed on critical engineering structures in addition to the already instrumented structures in Istanbul http://www.koeri.boun.edu.tr/ depremmuh/stronmotion.htm). All together this network and its functions is called Istanbul Earthquake Rapid Response and Early Warning System (IERREWS). The system is designed and operated by Bogazici University with the logistical support of the Governorate of Istanbul, First Army Headquarters and Istanbul Metropolitan Municipality. The construction of the system is realized by the GeoSig Inc. (http://www.geosig.com) and Electrowatt-Ekono (www.ewe.ch) consortium. Communications are provided by ARIA GSM (http://www.aria.com.tr) service provider.

IERREWS consists of the following components:

- Monitoring system composed of various sensors,
- Communication link (off-line for the Rapid Response and on-line for the Early Warning) that transmits data from the sensors to computers,
- Data processing facilities that converts data to information, and
- System that issues and communicates the rapid response information and early warning.

RAPID RESPONSE SYSTEM

The Rapid Response part of the IERREWS has the objective of providing:

- Reliable information for accurate, effective characterization of the shaking and damage by other rapid post-earthquake maps (Shake, Damage and Casualty maps) for rapid response;
- Recorded motion for post-earthquake performance analysis of structures;
- Empirical basis for long-term improvements in seismic microzonation, seismic provisions of building codes and construction guidelines; and
- Seismological data to improve the understanding of earthquake generation at the source and seismic wave propagation.

The Rapid Response System satisfies the COSMOS (The Consortium of Organizations for Strong-Motion Observation Systems) Urban Strong-Motion Reference Station Guidelines (www.cosmos-eq.org) for the location of instruments, instrument specifications and housing specifications. The relative instrument spacing is about 2-3km which corresponds to about 3 wavelengths in firm ground conditions and more than 10 wavelengths for soft soils for horizontally propagating 1s shear waves. Strong-motion instruments are generally located at grade level in small and medium-sized buildings, such that the motion recorded corresponds to that on the ground in the surrounding area. Site geology at stations has been characterized in general terms. Certain stations have bore-hole data. New bore-hole surveys for other stations are being planned. For communication of data from the rapid response stations to the data processing center and for instrument monitoring a reliable and redundant GSM communication system (backed up by dedicated landlines and a microwave system) is used, on the basis of a protocol agreement with the ARIA GSM Service provider. In normal times the rapid response stations are be interrogated (for health monitoring and instrument monitoring) on regular basis. After triggered by an earthquake, each station will process the streaming three-channel strong motion data to yield the spectral accelerations at specific periods, 12Hz filtered peak ground acceleration and peak ground velocity and will send these parameters in the form of SMS messages at every 20s directly to the main data center through the GSM communication system. A picture of the strong ground motion monitoring/recording/transmitting instrument is given in Fig. 4. A picture of the main data processing center, located at the Department of Earthquake Engineering - Kandilli Observatory and Earthquake Research Institute of Bogazici University (KOERI-BU) is provided in Fig. 5. A secondary center located at the Seismological Laboratory of the same Institute serves as a redundant secondary center that can function in case of failure in the main center. Shake, damage and casualty distribution maps will be automatically generated at the data centers after the earthquake and communicated to the end users within 5 minutes. Full-recorded waveforms at each station can be retrieved using GSM and GPRS modems subsequent to an earthquake.

For the generation of Rapid Response information two methodologies based on spectral displacements and instrumental intensities are used. These methodologies are coded into specific computer programs similar to HAZUS (http://www.fema.gov/hazus/). Both of the methodologies essentially rely on the building inventory database, fragility curves and the methodology developments in the Istanbul Earthquake Risk Assessment Study conducted by the Department of Earthquake Engineering of Bogazici University (http://www.koeri.boun.edu.tr/depremmuh/EXEC_ENG.pdf). For the computation of input ground motion parameters, spectral displacements obtained from the SMS messages sent from stations will are interpolated to determine the spectral displacement values at the center of each geo-cell using two-dimensional splines. The earthquake demand at the center of each geo-cell is computed using these spectral displacements. The instrumental intensity at each the center of each geo-cell is computed as a function of short-period spectral acceleration. Using the response spectra and the instrumental intensities the building damage and the casualties are computed separately by using the spectral-displacement based and intensity based fragility curves. The computations are conducted at the centers of a 0.01 x 0.01 grid system comprised of geo-cells (1120 m x 830 m) size. The building inventories (in 24 groups) for each geocell together with their spectral displacement and intensity based fragility curves are incorporated in the software. The casualties are estimated on the basis of the number of collapsed buildings and degree of damage. Example of building damage map that results from a randomly simulated strong motion data is provided in Fig. 6. For transmission of the Rapid Response information to the concerned agencies (Istanbul Governorate, Istanbul Municipality and First Army Headquarters) digital radio modem and GPRS communication systems are used. The strong motion data, shake maps and the building damage maps will be made available on the Internet immediately after an earthquake (http://www.koeri.boun.edu.tr/depremmuh/EWRR/EWRRMain.htm). The waveforms will also be catalogued for a "Green's Function" database to be used in earthquake simulations. So far (July, 2003) the system has been exposed to only small magnitude earthquakes. An example data set from a small magnitude earthquake is illustrated in Fig. 7.

EARLY WARNING SYSTEM

In the Early Warning component of the IERREWS, ten strong motion stations were located as close as possible to the Great Marmara Fault in "on-line" mode. Continuous telemetry of data between these stations and the main data center is realized with digital spread spectrum radio modem system involving repeater stations selected in the region (Fig. 3). Considering the complexity of fault rupture and the short fault distances involved, a simple and robust Early Warning algorithm, based on the exceedance of specified threshold time domain amplitude levels is implemented. The band-pass filtered accelerations and the cumulative absolute velocity (CAV-time integral of the absolute acceleration) are compared with specified threshold levels. When any acceleration or CAV (on any channel) in a given station exceeds specific selectable threshold values it is considered a vote. Whenever we have 2 or 3 (selectable) station votes within selectable time interval, after the first vote, the first alarm is declared. The early warning information (consisting three alarm levels) will be communicated to the appropriate servo shut-down systems of the recipient facilities, which will automatically decide proper action based on the alarm level. Depending on the location of the earthquake (initiation of fault rupture) and the recipient facility the alarm time can be as high as about 8s.

To enhance the Early Warning algorithm, Böse [7] have proposed an approach that considers the problem of earthquake early-warning as a seismic pattern recognition task. The patterns are defined by the shape and frequency content of the parts of seismograms that are available at each time step. From these, parameters that are relevant to seismic damage, such as peak ground acceleration (PGA), peak ground velocity (PGV), response spectral amplitudes at certain periods and macroseismic intensity, are estimated using Artificial Neural Networks (ANN). We plan to combine pattern recognition with an additional rule-based system in order to detect inconsistencies between ground motion estimations and measurements. This combination is believed to provide a reliable and accurate system for early-warning.

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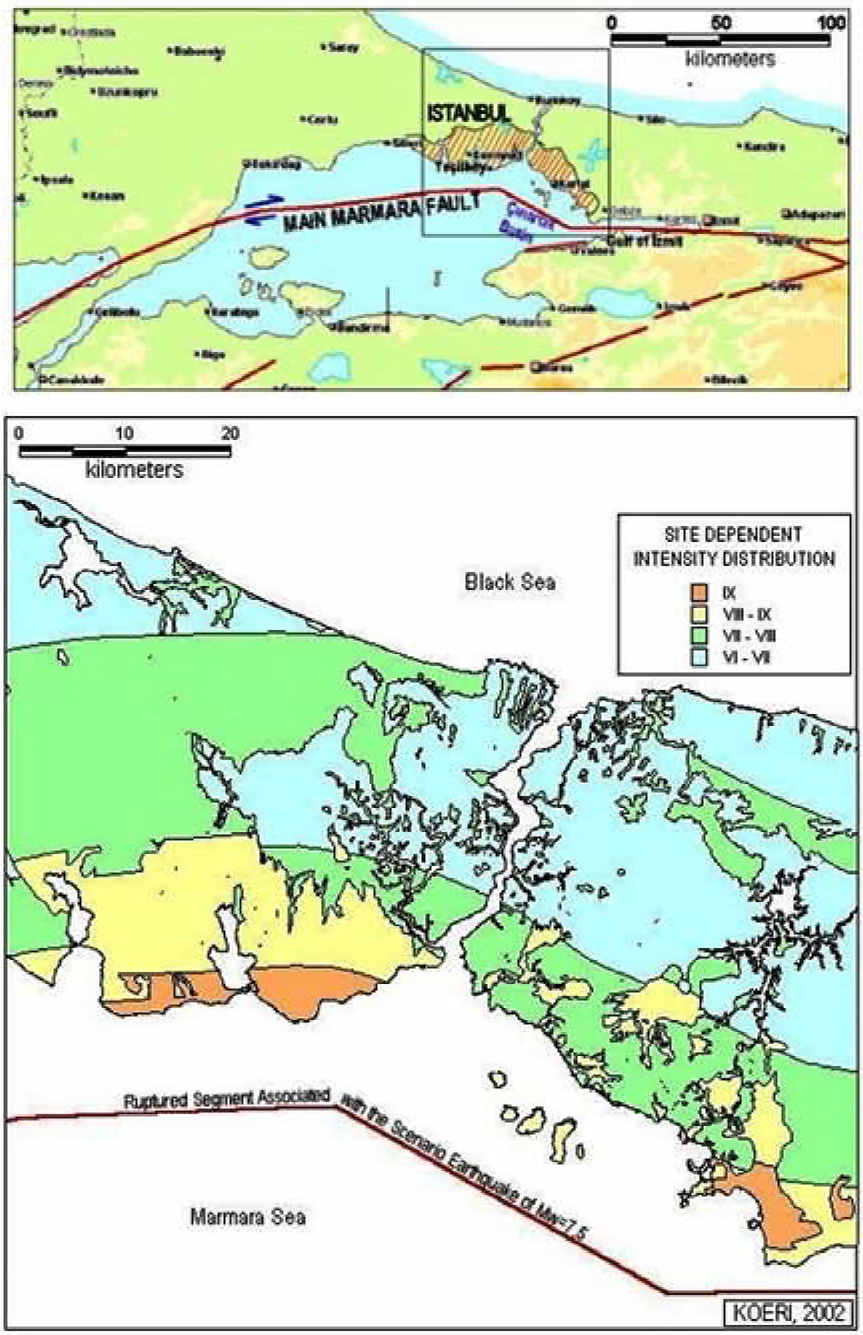

Fig. 1: Location of the IRREW System in Marmara Region and Scenario Earthquake-Based Hazard in Istanbul.

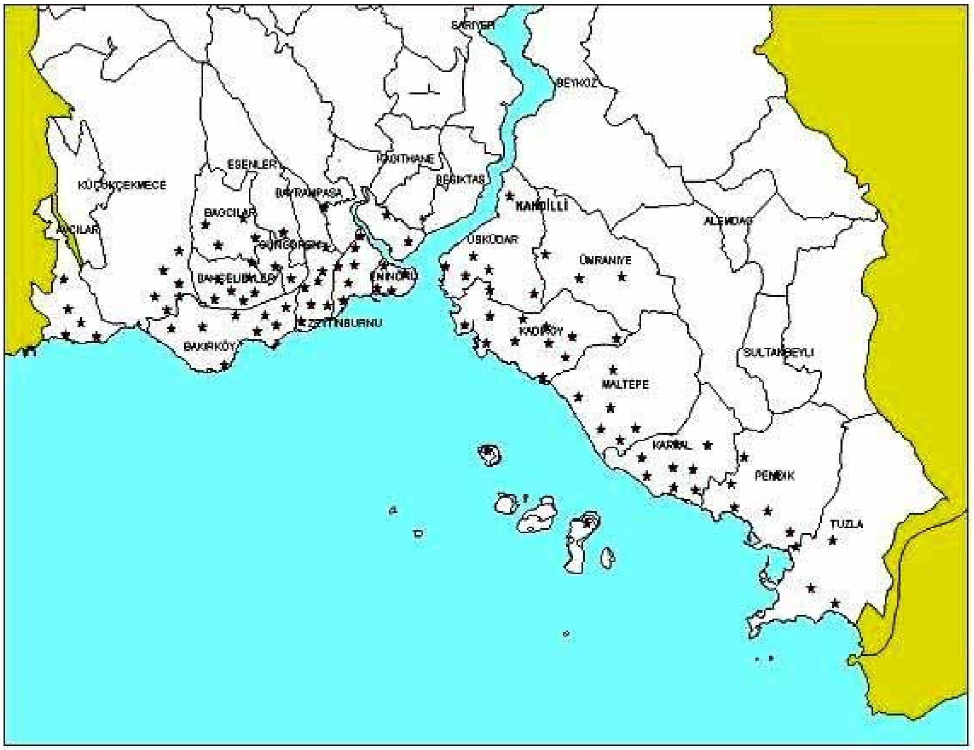

Fig. 2: Rapid Response Stations.

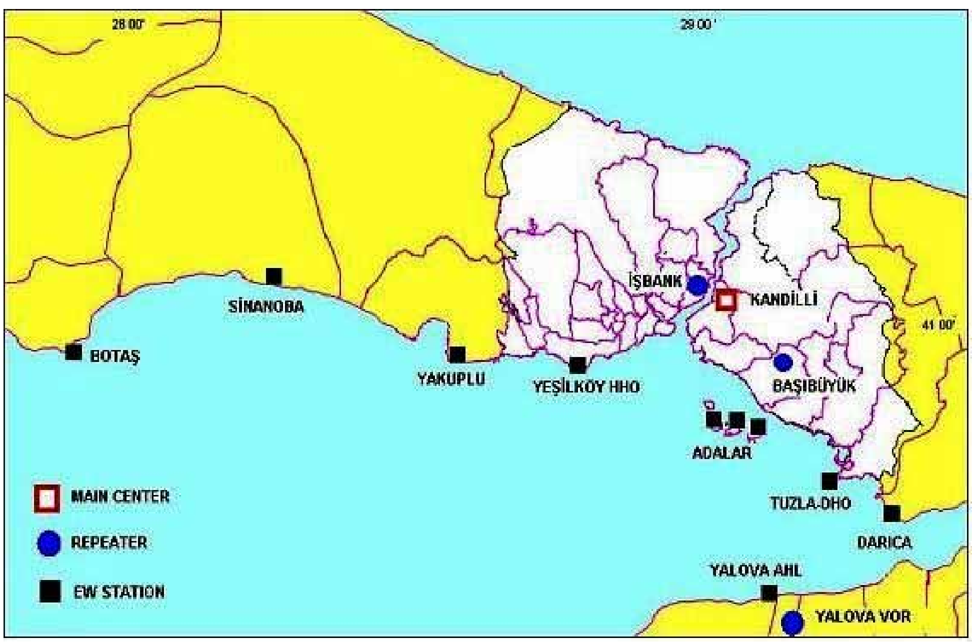

Fig. 3: Early Warning Stations.

Fig. 4: Strong motion accelerometer.

Fig. 5: Main data Center.

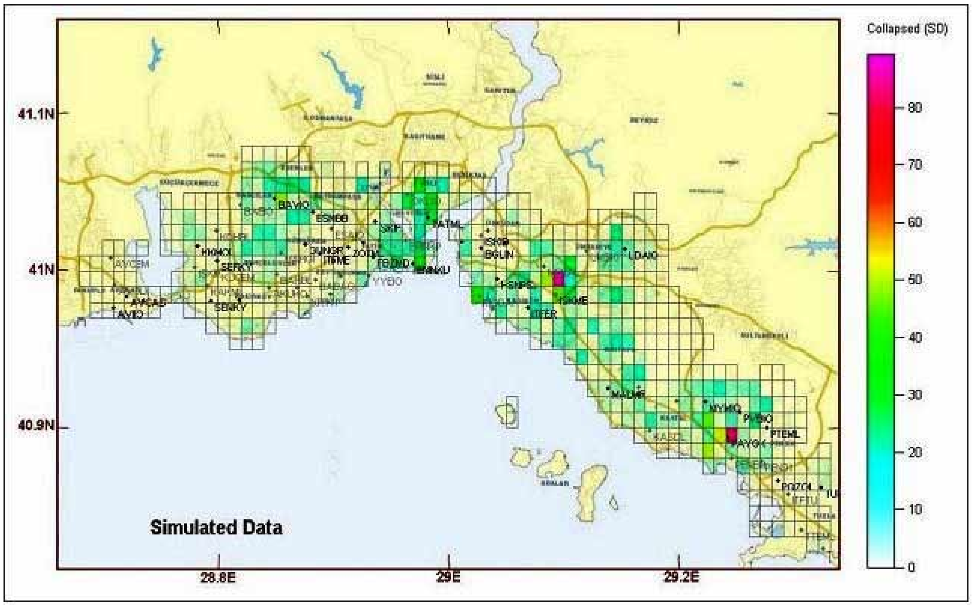

Fig. 6: Example of building damage map that results from a randomly simulated strong motion data.

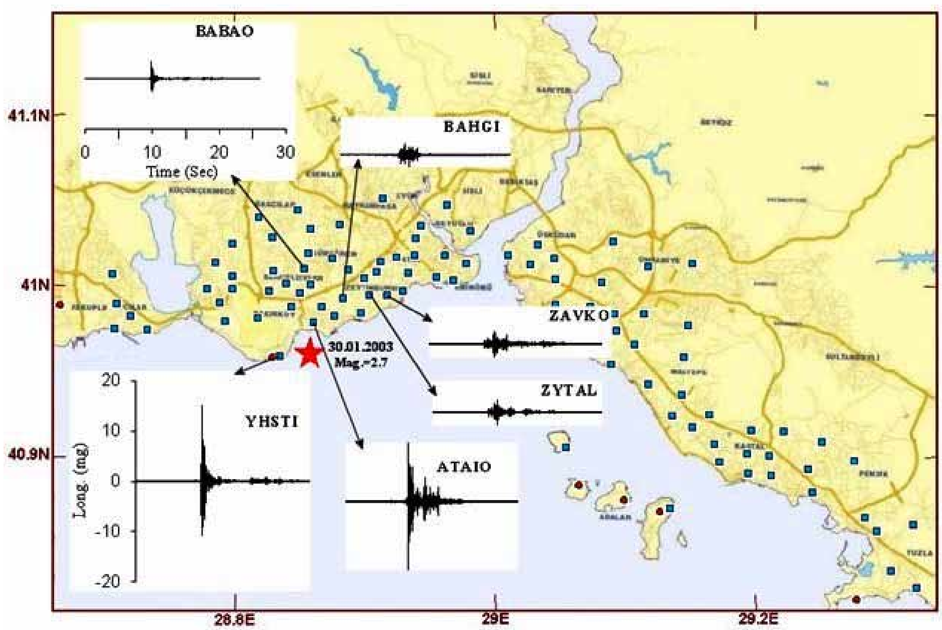

Fig. 7: Recorded strong motion data by rapid response stations for small event at Marmara Sea.