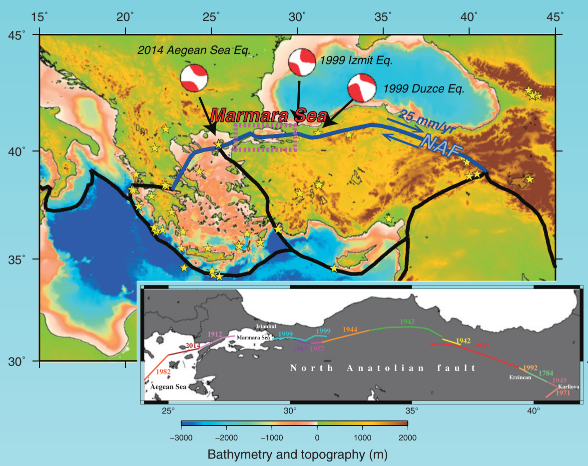
Earth, Planets and Space

The Next Marmara Earthquake: Disaster Mitigation, Recovery and Early Warning



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PREFACE

Open Access

Special issue "The next Marmara earthquake: disaster mitigation, recovery, and early warning"

Takane Hori[1*], Ali Pinar[2], Ocal Necmioglu[2], Muneo Hori[3] and Azusa Nishizawa[4]

The Marmara Sea, accommodating the fault segments of a major transform fault, is well known as a seismic gap along the North Anatolian Fault (NAF), running through the northern part of Turkey and connecting the East Anatolian convergent area with the Hellenic subduction zone (e.g., Pınar 1943; Toksöz et al. 1979; Pondard et al. 2007; Şengör et al. 2014). It is obvious from historical records spanning more than 2000 years that the region is subject to frequent strong shaking that is likely associated with tsunami waves, threatening heavily populated and industrialized locations (Ambraseys 2002; Erdik et al. 2004; Hébert et al. 2005). In the twentieth century, magnitude (M) 7-class earthquakes sequentially occurred from east to west along the NAF zone, as shown in Fig. 1 (Stein et al. 1997). The last two successive events hit the eastern Marmara region in August 17 and November 12, 1999, known as Izmit (Mw = 7.5) and Düzce (Mw = 7.2) earthquakes, respectively, killing about 20,000 people and devastating the region. On the other hand, at the western edge of Marmara Sea, an $M \sim 7$ earthquake occurred in 1912, rupturing onshore and offshore fault segments where 4–5 m lateral displacements were measured (Armijo et al. 2005; Aksoy et al. 2010). Furthermore, in the Marmara Sea, it has been considered that the last M7 class earthquake occurred in 1766. With an average slip rate of 2 cm/year, several meters have accumulated over the past 250 years (Straub 1996; Meade et al. 2002). Based on a time-dependent model that includes the coseismic and post-seismic effects of the 1999 Kocaeli earthquake with moment magnitude Mw = 7.4, Parsons (2004) concluded that the probability of an earthquake with Mw > 7 in the Sea of Marmara near Istanbul is 35–70% in the next 30 years. According to a 2011 study, an earthquake with Mw = 7.25 on the Main Marmara Fault is expected to heavily damage or destroy 2–4% of the near 1,000,000 buildings in Istanbul, which has a population of around 13 million, with 9–15% of the buildings receiving medium damage and 20–34% of the buildings lightly damaged (Erdik 2013).

The aim of this special issue is to gather information about the risk of another Marmara earthquake from the latest geophysical, geological, geotechnical, computational, and building science research results to discuss ways of mitigating disaster in advance. The collection of 12 papers constituting this special issue is based on recent research on imaging the crustal structure, the geometry of the fault segments and their microseismicity features, source characteristics of large earthquakes inferred from historical seismograms, tsunami hazard assessment and mitigation studies, site response evaluations, and development of an integrated earthquake simulation system.

Polat et al. (2016) portrayed a tomographic image of the crust beneath the Sea of Marmara and its close surrounding area, derived from a dataset of more than ninety thousand P- and S-wave arrival times from local earthquakes recorded at land-based stations and ocean bottom seismographs. Their seismic velocity images illustrate positive anomalies nearby the fault segments of NAF, correlating with regions of higher seismicity. The study of Yamamoto et al. (2015) closely inspects the NAF segments beneath the Sea of Marmara, especially the fault geometry and their seismic activity carried out by the deployment of 15 OBS stations at locations close to the Main Marmara Fault (MMF). A deeper than previously known seismogenic zone, extending to the lower crust, is one of the most striking features derived from the OBS observations. The offshore seismic stations nearby MMF constrained the depth, dip, and lateral extent of the seismicity much better and, consequently, the geometry of the fault

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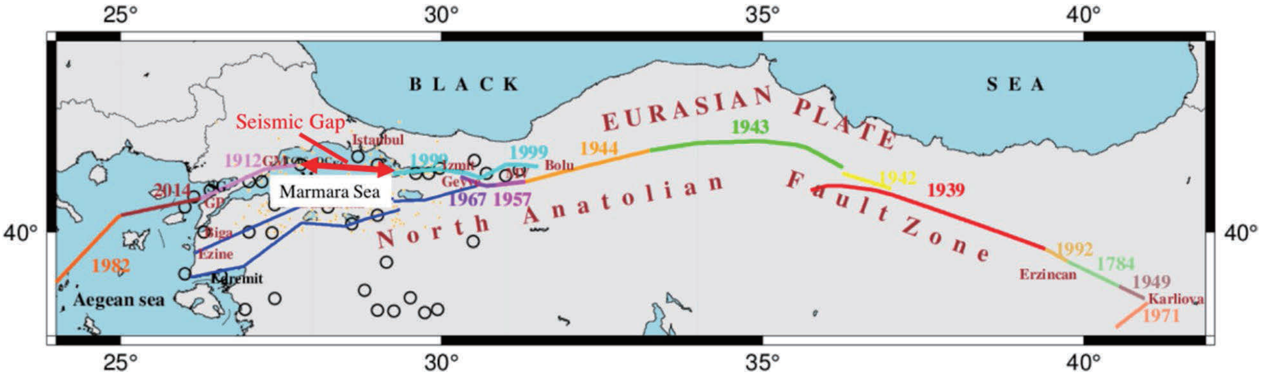

Fig. 1 Surface rupture extent associated with major earthquakes along NAF

segments. The geometry between the fault segments and the orientation of the maximum horizontal compressive stress axis is correlated through the frictional strength of faults in the study presented by Pinar et al. (2016). They use the frequency distribution of P- and T-axes of the focal mechanisms of events taking place around three fault segments in the eastern Marmara. A low frictional coefficient for the Princes' Islands segment and high frictional coefficients for the Yalova-Çınarcık and Yalova-Hersek segments are derived by the authors.

Further information on the fault segmentation of NAF in the Marmara Sea and north Aegean Sea regions is determined by modeling the waveforms at broadband land stations to retrieve the source properties of moderate to large events, estimating the CMT parameters and source time functions (Nakano et al. 2016). The source time function of the 2014 North Aegean earthquake (Mw = 6.9) provides evidence on ruptures of different fault segments associated with the mainshock. Moreover, the CMT solutions derived for the events taking place along the MMF fault indicate fault parallel T-axis orientations, suggesting segmentation and development of local extension features. Baştürk et al. (2016) relocated two ancient moderate-sized earthquakes, using historical seismograms of events occurring in 1935 in the proximity of Marmara Island. Applying modern techniques to the old seismograms, CMT parameters for the two events are retrieved that indicate predominantly normal faulting mechanisms taking place at the upper crust. Similar source parameters are obtained for the 1963 Çınarcık earthquake, whose location was long a subject of debate. The location of the fault segment ruptured by the 1963 earthquake and its source mechanism is of great importance in seismic hazard assessment studies. Mert et al. (2016) tried to predict the strong ground motions to be generated by a rupture on the Princes' Islands segment, which lies beneath the Çınarcık basin, using physically based probabilistic seismic hazard analysis (PSHA) methodology where broadband strong ground motion simulations are conducted. To generate the high-frequency (0.5–20 Hz) part of the broadband earthquake simulation, real, small-magnitude earthquakes recorded by a local seismic array were used as empirical Green's functions. As for frequencies below 0.5 Hz, the synthetic Green's functions are calculated by an explicit 2D/3D elastic finite difference wave propagation routine.

Aytore et al. (2016) used NAMI-DANCE code to carry out high-resolution tsunami simulations in the Marmara Sea, focusing on Haydarpaşa Port in the megacity of Istanbul, and computed the tsunami parameters in and around the port. They observed that the stability of the breakwaters is one of the major factors that influence whether agitation and inundation can be diminished in the event of a tsunami in Haydarpaşa Port, as harbor protection structures have not been designed to withstand tsunamis. The flow depth, momentum fluxes, and current pattern were identified as the other factors that cause unexpected circulation and uncontrolled movements of objects on land and vessels in the sea. Cankaya et al. (2016) applied a new methodology in Yenikapı region as a case study for tsunami vulnerability assessment, based on high-resolution coastal inundation modeling. Using NAMI-DANCE code, they constructed vulnerability at location and evacuation resilience maps, using the analytical hierarchical process (AHP) method of multi-criteria decision analysis (MCDA) to define the tsunami human vulnerability of the region. The vulnerability at location map is composed of metropolitan use, geology, elevation, and distance from shoreline layers, whereas the evacuation resilience map considers slope, distance within flat areas, distance to buildings, and distance to road networks layers. Following this, they computed the tsunami risk map from the proposed new relationship, which uses flow depth maps, vulnerability at location maps, and evacuation resilience maps. Necmioglu (2016) indicated that in the absence of adequate post-earthquake assembly areas, especially in heavily urbanized Istanbul, citizens would be rushing to landfill assembly and recreational areas in the coastal parts of the city after a major earthquake. To address this, he proposed a model for a tsunami warning system specific for the Marmara region that is strongly coupled with the earthquake early warning system and stakeholders of tsunami mitigation activities, such as the local and regional components of disaster and emergency management and civil protection units. This would ensure that the citizens would stay away from the coastline in case of a large earthquake. Necmioglu also discussed associated challenges, such as decoupled earthquake and tsunami mitigation activities in the Marmara region.

Istanbul is the largest metropolitan city expected to be hit by the impending Marmara Sea earthquake. Rapid response systems are effective in mitigating the loss of life and property. Zülfikar et al. (2017) describe how real-time ground motion shaking maps are constructed from the strong motion stations distributed throughout the densely populated areas of the city. Building damage estimation is then computed by using grid-based building inventory, and the related loss is estimated. Zülfikar et al. (2017) further inform how rapidly estimated data enable public and private emergency management authorities to take action to allocate and prioritize resources, minimizing casualties in urban areas during immediate post-earthquake periods. Site response plays an important role in generating shake maps. Karagoz et al. (2015) explore the S-wave velocity structure of shallow soils using microtremors to estimate site responses in Tekirdag and the surrounding area. They collected data at 44 sites in Tekirdag, Marmara Ereglisi, Corlu, and Muratlı, and estimated phase velocities of Rayleigh waves from the microtremor data using a spatial autocorrelation method. A hybrid genetic simulated annealing algorithm was applied by the authors to obtain a 1D S-wave velocity structure at each site. All the studies constituting this special issue contribute to some extent to an integrated earthquake simulation (IES) system that was developed for Istanbul by Sahin et al. (2016). The IES for Istanbul is built in MATLAB and includes site response analysis as well as structural seismic response analysis of existing buildings; building models are made by using GIS databases. An initial application is performed in the Zeytinburnu District of Istanbul, and the results are expressed in the form of spatial distribution of ground motion and building responses. The IES analysis illustrates a non-uniform distribution of seismic responses, indicating the possibility that there are more severely damaged areas in the district compared with others.

The Marmara region, long ago identified as a seismic gap, is waiting for the impending major earthquake to rupture the MMF segments. Meanwhile, several studies have been carried out to determine the seismic hazard level, the fault geometry and segmentation, mitigation of seismic risk, rapid response, and early warning. All these subjects are tackled in this special issue, making a valuable contribution on the existing information that is constrained by high-quality data acquired in the frame of the MarDIM project, a joint effort of Turkish and Japanese scientists financially supported by JICA, JST and the Ministry of Development in Turkey.

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FRONTIER LETTER **Open Access**

Assessment of tsunami resilience of Haydarpaşa Port in the Sea of Marmara by high-resolution numerical modeling

Betul Aytore, Ahmet Cevdet Yalciner*, Andrey Zaytsev, Zeynep Ceren Cankaya and Mehmet Lütfi Suzen

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Abstract

Turkey is highly prone to earthquakes because of active fault zones in the region. The Marmara region located at the western extension of the North Anatolian Fault Zone (NAFZ) is one of the most tectonically active zones in Turkey. Numerous catastrophic events such as earthquakes or earthquake/landslide-induced tsunamis have occurred in the Marmara Sea basin. According to studies on the past tsunami records, the Marmara coasts have been hit by 35 different tsunami events in the last 2000 years. The recent occurrences of catastrophic tsunamis in the world's oceans have also raised awareness about tsunamis that might take place around the Marmara coasts. Similarly, comprehensive studies on tsunamis, such as preparation of tsunami databases, tsunami hazard analysis and assessments, risk evaluations for the potential tsunami-prone regions, and establishing warning systems have accelerated. However, a complete tsunami inundation analysis in high resolution will provide a better understanding of the effects of tsunamis on a specific critical structure located in the Marmara Sea. Ports are one of those critical structures that are susceptible to marine disasters. Resilience of ports and harbors against tsunamis are essential for proper, efficient, and successful rescue operations to reduce loss of life and property. Considering this, high-resolution simulations have been carried out in the Marmara Sea by focusing on Haydarpaşa Port of the megacity Istanbul. In the first stage of simulations, the most critical tsunami sources possibly effective for Haydarpaşa Port were inputted, and the computed tsunami parameters at the port were compared to determine the most critical tsunami scenario. In the second stage of simulations, the nested domains from 90 m gird size to 10 m grid size (in the port region) were used, and the most critical tsunami scenario was modeled. In the third stage of simulations, the topography of the port and its regions were used in the two nested domains in 3-m and 1-m resolutions and the water elevations computed from the previous simulations were inputted from the border of the large domain. A tsunami numerical code, NAMI DANCE, was used in the simulations. The tsunami parameters in the highest resolution were computed in and around the port. The effect of the data resolution on the computed results has been presented. The performance of the port structures and possible effects of tsunami on port operations have been discussed. Since the harbor protection structures have not been designed to withstand tsunamis, the breakwaters' stability becomes one of the major concerns for less agitation and inundation under tsunami in Haydarpaşa Port for resilience. The flow depth, momentum fluxes, and current pattern are the other concerns that cause unexpected circulations and uncontrolled movements of objects on land and vessels in the sea.

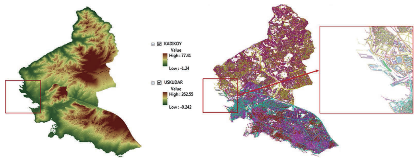

Figure 2

Keywords: Tsunami, Resilience, Port, Marmara Sea, Simulation, Modeling

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FULL PAPER **Open Access**

Offshore seismicity in the western Marmara Sea, Turkey, revealed by ocean bottom observation

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Abstract

The faults' geometry and their seismic activity beneath the Marmara Sea have been under debate for a couple of decades. We used data recorded by three ocean bottom seismographs (OBSs) over a period of 3 months in 2014 to investigate the relationship of fault geometry to microseismicity under the western Marmara Sea in Turkey. We detected a seismic swarm at 13 to 20 km depth beneath the main Marmara fault (MMF), and the maximum depth of seismogenic zone was 25 km within the OBS observation area. These results provided evidence that the dip of the MMF is almost vertical and that the seismogenic zone in this region extends into the lower crust. Our analysis of past seismicity indicated that the seismic swarm we recorded is the most recent of an episodic series of seismic activity with an average recurrence interval of 2–3 years. The repetitive seismicity indicates that the MMF beneath the western Marmara Sea is coupled and that some of the accumulated strain is released every 2 to 3 years. Our study shows that OBS data can provide useful information about seismicity along the MMF, but more extensive studies using more OBSs deployed over a wider area are needed to fully understand the fault geometry and stick–slip behavior of faults under the Marmara Sea.

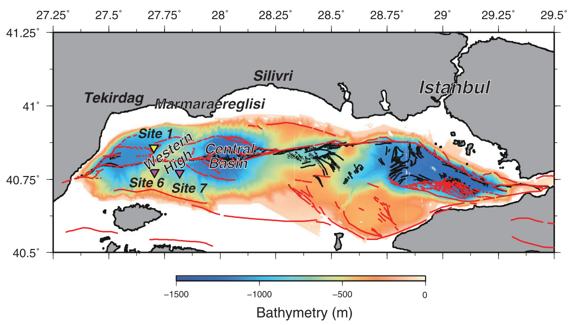

Figure 2

Keywords: North Anatolian fault, Marmara Sea, Ocean bottom seismograph, Seismic activity

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FULL PAPER **Open Access**

Focal mechanism determinations of earthquakes along the North Anatolian fault, beneath the Sea of Marmara and the Aegean Sea

Masaru Nakano*, Seckin Citak and Doğan Kalafat

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Abstract

We determined the centroid moment tensor (CMT) solutions of earthquakes that occurred along the North Anatolian fault (NAF) beneath the Sea of Marmara and the Aegean Sea, using data obtained from Turkey's broad-band seismograph network. The CMT solution of the 2014 Aegean Sea earthquake (*Mw* 6.9) represents a strike-slip fault, consistent with the geometry of the NAF, and the source-time function indicates that this event comprised several distinct subevents. Each subevent is considered to have ruptured a different fault segment. This observation indicates the existence of a mechanical barrier, namely a NAF segment boundary, at the hypocenter. CMT solutions of background seismicity beneath the Aegean Sea represent strike-slip or normal faulting along the NAF or its branch faults. The tensional axes of these events are oriented northeast–southwest, indicating a transtensional tectonic regime. Beneath the Sea of Marmara, the CMT solutions represent mostly strike-slip faulting, consistent with the motion of the NAF, but we identified a normal fault event with a tensional axis parallel to the strike of the NAF. This mechanism indicates that a pull-apart basin, marking a segment boundary of the NAF, is developing there. Because ruptures of a fault system and large earthquake magnitudes are strongly controlled by the fault system geometry and fault length, mapping fault segments along NAF can help to improve the accuracy of scenarios developed for future disastrous earthquakes in the Marmara region.

Keywords: Centroid moment tensor, Strike-slip fault system, Fault segment boundary, SWIFT system

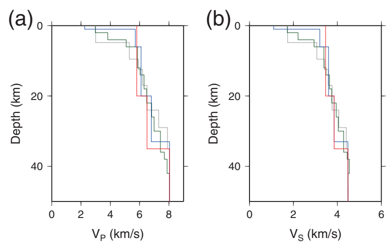

Figure 2

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FULL PAPER **Open Access**

Estimation of shallow S-wave velocity structure and site response characteristics by microtremor array measurements in Tekirdag region, NW Turkey

Ozlem Karagoz*, Kosuke Chimoto, Seckin Citak, Oguz Ozel, Hiroaki Yamanaka and Ken Hatayama

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Abstract

In this study, we aimed to explore the S-wave velocity structure of shallow soils using microtremors in order to estimate site responses in Tekirdag and surrounding areas (NW Turkey). We collected microtremor array data at 44 sites in Tekirdag, Marmara Ereglisi, Corlu, and Muratlı. The phase velocities of Rayleigh waves were estimated from the microtremor data using a Spatial Autocorrelation method. Then, we applied a hybrid genetic simulated annealing algorithm to obtain a 1D S-wave velocity structure at each site. Comparison between the horizontal-to-vertical ratio of microtremors and computed ellipticities of the fundamental mode Rayleigh waves showed good agreement with validation models. The depth of the engineering bedrock changed from 20 to 50 m in the Tekirdag city center and along the coastline with a velocity range of 700–930 m/s, and it ranged between 10 and 65 m in Marmara Ereglisi. The average S-wave velocity of the engineering bedrock was 780 m/s in the region. We obtained average S-wave velocities in the upper 30 m to compare site amplifications. Empirical relationships between the AVs30, the site amplifications, and also average topographic slopes were established for use in future site effects microzonation studies in the region.

Keywords: AVs30, Microtremor array observation, Phase velocity, Shear-wave velocity, Site amplification, Slope, Tekirdag

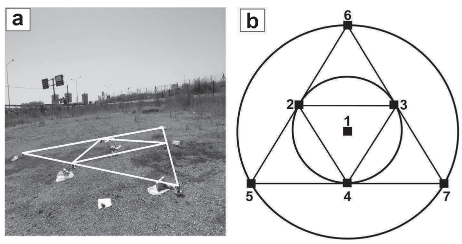

Figure 2

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FULL PAPER Open Access

Frictional strength of North Anatolian fault in eastern Marmara region

Ali Pinar*, Zeynep Coşkun, Aydin Mert and Doğan Kalafat

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Abstract

Frequency distribution of azimuth and plunges of *P*- and *T*-axes of focal mechanisms is compared with the orientation of maximum compressive stress axis for investigating the frictional strength of three fault segments of North Anatolian fault (NAF) in eastern Marmara Sea, namely Princes' Islands, Yalova–Çınarcık and Yalova–Hersek fault segments. In this frame, we retrieved 25 CMT solutions of events in Çınarcık basin and derived a local stress tensor incorporating 30 focal mechanisms determined by other researches. As for the Yalova–Çınarcık and Yalova–Hersek fault segments, we constructed the frequency distribution of *P*- and *T*-axes utilizing 111 and 68 events, respectively, to correlate the geometry of the principle stress axes and fault orientations. The analysis yields low frictional strength for the Princes' Island fault segments and high frictional strength for Yalova–Çınarcık, Yalova–Hersek segments. The local stress tensor derived from the inversion of *P*- and *T*-axes of the fault plane solutions of Çınarcık basin events portrays nearly horizontal maximum compressive stress axis oriented N154E which is almost parallel to the peak of the frequency distribution of the azimuth of the *P*-axes. The fitting of the observed and calculated frequency distributions is attained for a low frictional coefficient which is about $\mu \approx 0.1$. Evidences on the weakness of NAF segments in eastern Marmara Sea region are revealed by other geophysical observations. Our results also show that the local stress field in Çınarcık basin is rotated ≈30° clockwise compared to the regional stress tensor in Marmara region derived from the large earthquakes, whereas the local stress tensor in Yalova–Çınarcık area is found to be rotated ≈30° counterclockwise. The rotation of the two local stress fields is derived in the area where NAF bifurcates into two branches overlaying large electrical conductor.

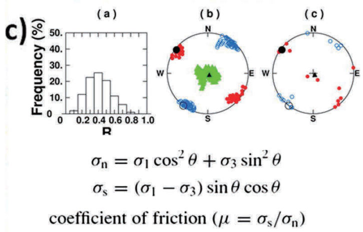

Figure 1

Keywords: Local stress field, Frictional coefficient, Marmara Sea, Çınarcık basin, Stress field rotation

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FULL PAPER Open Access

Development of integrated earthquake simulation system for Istanbul

Abdurrahman Sahin*, Rafet Sisman, Aysegul Askan and Muneo Hori

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Abstract

Recent advances in computing have brought a new and challenging way to tackle the earthquake hazard and disaster problems: integration of the seismic actions in the form of numerical models. For this purpose, integrated earthquake simulation (IES) has been developed in Japan, and now a new version is being developed in Turkey which targets Istanbul. This version of IES is being built in MATLAB and includes site response analysis and structural analysis of existing buildings with data obtained via GIS databases. In this study, we present an initial application in Zeytinburnu district of Istanbul where the results are expressed in the form of spatial distributions of ground motion and building responses. At the end of the analysis, it is seen that most of the buildings make small displacements and the displacement values are directly proportional to the total height of the structures. Since the obtained ground motion distribution and peak values are not very high, structural damage has not been observed under the current simulation. The effect of bedrock depth and soil parameters on strong ground motion distribution has been observed. The most effective ground motion locations in the selected area have been determined, and the critical buildings that have maximum displacement during the earthquake motion are detected. Currently, the IES on MATLAB does not include the source to bedrock wave propagation mechanism and the resulting ground motions at each grid point. In future studies, alternative models for this purpose along with input model parameters for Istanbul will be applied. Once the source-to-structure integrated model is complete, past earthquakes as well as potential scenario events in Istanbul will be modeled in the final form of IES on MATLAB. Results will be valuable for a variety of purposes ranging from disaster mitigation to emergency management. In future part of this study, site vibration tests will also be made for buildings that do not comply with seismic design codes and constitute the largest portion of the seismic risk. New models will be developed for these buildings and adopted into the IES system.

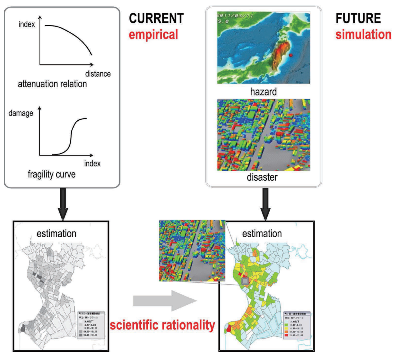

Figure 1

Keywords: Integrated earthquake simulation, Full-scale models, Earthquake disaster simulation, Earthquake hazard simulation, Virtual city, SoVeLAB, CitySeis

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FULL PAPER **Open Access**

Investigating P- and S-wave velocity structure beneath the Marmara region (Turkey) and the surrounding area from local earthquake tomography

Gulten Polat*, Nurcan Meral Özel and Ivan Koulakov

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Received: 19 October 2015, Accepted: 5 July 2016, Published: 22 July 2016

Abstract

We investigated the crustal structure beneath the Marmara region and the surrounding area in the western part of the North Anatolian fault zone. These areas have high seismicity and are of critical significance to earthquake hazards. The study was based on travel-time tomography using local moderate and micro-earthquakes occurring in the study area recorded by the Multi-Disciplinary Earthquake Research in High Risk Regions of Turkey project and Kandilli Observatory and Earthquake Research Institute. We selected 2131 earthquakes and a total of 92,858 arrival times, consisting of 50,044 P-wave and 42,814 S-wave arrival times. We present detailed crustal structure down to 50 km depth beneath the Marmara region for P- and S-wave velocities using the LOTOS code based on iterative inversion. We used the distributions of the resulting seismic parameters (*Vp*, *Vs*) to pick out significant geodynamical features. The high-velocity anomalies correlate well with fracturing segments of the North Anatolian fault. High seismicity is mostly concentrated in these segments. In particular, low velocities were observed beneath the central Marmara Sea at 5 km depth.

Keywords: Marmara Sea, North Anatolian fault zone, Seismic tomography, Seismic velocity structure, Seismicity

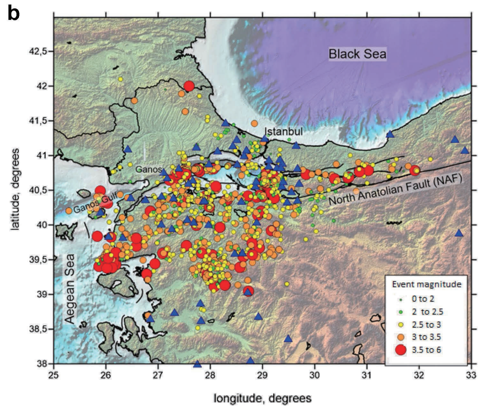

Figure 2

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FULL PAPER **Open Access**

A new GIS-based tsunami risk evaluation: MeTHuVA (METU tsunami human vulnerability assessment) at Yenikapı, Istanbul

Zeynep Ceren Cankaya, Mehmet Lutfi Suzen, Ahmet Cevdet Yalciner*, Cagil Kolat, Andrey Zaytsev and Betul Aytore

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Abstract

Istanbul is a mega city with various coastal utilities located on the northern coast of the Sea of Marmara. At Yenikapı, there are critical vulnerable coastal utilities, structures, and active metropolitan life. Fishery ports, commercial ports, small craft harbors, passenger terminals of intercity maritime transportation, waterfront commercial and/or recreational structures with residential/commercial areas and public utility areas are some examples of coastal utilization that are vulnerable to marine disasters. Therefore, the tsunami risk in the Yenikapı region is an important issue for Istanbul. In this study, a new methodology for tsunami vulnerability assessment for areas susceptible to tsunami is proposed, in which the Yenikapı region is chosen as a case study. Available datasets from the Istanbul Metropolitan Municipality and Turkish Navy are used as inputs for high-resolution GIS-based multi-criteria decision analysis (MCDA) evaluation of tsunami risk in Yenikapı. Bathymetry and topography database is used for high-resolution tsunami numerical modeling where the tsunami hazard, in terms of coastal inundation, is deterministically computed using the NAMI DANCE numerical code, considering earthquake worst case scenarios. In order to define the tsunami human vulnerability of the region, two different aspects, vulnerability at location and evacuation resilience maps were created using the analytical hierarchical process (AHP) method of MCDA. A vulnerability at location map is composed of metropolitan use, geology, elevation, and distance from shoreline layers, whereas an evacuation resilience map is formed by slope, distance within flat areas, distance to buildings, and distance to road networks layers. The tsunami risk map is then computed by the proposed new relationship which uses flow depth maps, vulnerability at location maps, and evacuation resilience maps.

Keywords: METU tsunami human vulnerability assessment (MeTHuVA), Tsunami risk analysis, Geographic information systems (GIS), Multi-criteria decision analysis (MCDA), Analytical hierarchical process (AHP), Tsunami, Istanbul, Yenikapı

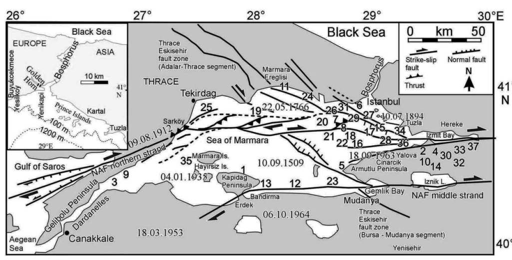

Figure 1

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FULL PAPER Open Access

Physically based probabilistic seismic hazard analysis using broadband ground motion simulation: a case study for the Prince Islands Fault, Marmara Sea

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Abstract

The main motivation for this study was the impending occurrence of a catastrophic earthquake along the Prince Island Fault (PIF) in the Marmara Sea and the disaster risk around the Marmara region, especially in Istanbul. This study provides the results of a physically based probabilistic seismic hazard analysis (PSHA) methodology, using broadband strong ground motion simulations, for sites within the Marmara region, Turkey, that may be vulnerable to possible large earthquakes throughout the PIF segments in the Marmara Sea. The methodology is called physically based because it depends on the physical processes of earthquake rupture and wave propagation to simulate earthquake ground motion time histories. We included the effects of all considerable-magnitude earthquakes. To generate the high-frequency (0.5–20 Hz) part of the broadband earthquake simulation, real, small-magnitude earthquakes recorded by a local seismic array were used as empirical Green's functions. For the frequencies below 0.5 Hz, the simulations were obtained by using synthetic Green's functions, which are synthetic seismograms calculated by an explicit 2D/3D elastic finite difference wave propagation routine. By using a range of rupture scenarios for all considerable-magnitude earthquakes throughout the PIF segments, we produced a hazard calculation for frequencies of 0.1–20 Hz. The physically based PSHA used here followed the same procedure as conventional PSHA, except that conventional PSHA utilizes point sources or a series of point sources to represent earthquakes, and this approach utilizes the full rupture of earthquakes along faults. Furthermore, conventional PSHA predicts ground motion parameters by using empirical attenuation relationships, whereas this approach calculates synthetic seismograms for all magnitudes of earthquakes to obtain ground motion parameters. PSHA results were produced for 2, 10, and 50 % hazards for all sites studied in the Marmara region.

Keywords: Simulation of strong ground motion, Probabilistic seismic hazard assessment, Empirical Green's function, Synthetic Green's function, Prince Island Fault

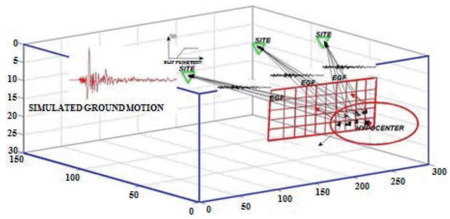

Figure 2

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FULL PAPER Open Access

Seismic parameters re-determined from historical seismograms of 1935-Erdek–Marmara Island and 1963-Çınarcık Earthquakes

Nilay Başarır Baştürk*, Nurcan Meral Özel and Marco Caciagli

Earth, Planets and Space 2016, **68**:158 DOI: 10.1186/s40623-016-0528-8
Received: 31 August 2015, Accepted: 24 August 2016, Published: 20 September 2016

Abstract

In this study, the original seismograms of the 1935-Erdek–Marmara Island and 1963-Çınarcık Earthquakes, recorded at local and regional distances, were vectorized. The epicentral locations have been calculated using available readings from original records and also ISS and seismic station bulletins for 04.01.1935-14:41 and 16:20 Marmara Island–Erdek Earthquakes and 18.09.1963-16:58 Çınarcık Earthquake. The epicenter determinations show that the first event in 04.01.1935 was located at 40.72N–27.72E, while the second one occurred at 40.61N–27.43E, indicating that both were located near the Marmara Island. Another finding is that the 1963 event was located at 40.80N–29.18E, near the Princes' Island fault. Furthermore, moment tensor inversion method was applied on these earthquakes by using original seismograms, which provided an opportunity to illuminate the seismotectonic features of Marmara Region based on the retrieved fault mechanism solutions. For the first time, the fault mechanisms for 04.01.1935-14:41 and 16:20 Earthquakes were determined using moment tensor inversion from the original seismic waveforms. Likewise, the result obtained for the fault mechanism of 1963 Çınarcık Earthquake showed normal fault mechanism with much shallower depth than estimated before. Our preferred solutions showed that the fault mechanisms for the three events are normal faults and coincide with the seismotectonic structure of the Marmara Region.

Keywords: Historical seismograms, Seismic parameters, Çınarcık Earthquake, Erdek–Marmara Island Earthquake

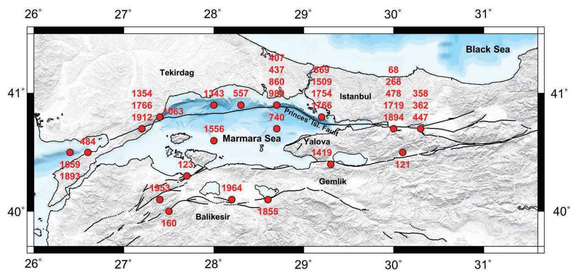

Figure 1

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FULL PAPER **Open Access**

Real-time earthquake shake, damage, and loss mapping for Istanbul metropolitan area

A. Can Zülfikar*, N. Özge Zülfikar Fercan, Süleyman Tunç and Mustafa Erdik

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Received: 6 September 2015, Accepted: 29 November 2016, Published: 3 January 2017

Abstract

The past devastating earthquakes in densely populated urban centers, such as the 1994 Northridge; 1995 Kobe; 1999 series of Kocaeli, Düzce, and Athens; and 2011 Van-Erciş events, showed that substantial social and economic losses can be expected. Previous studies indicate that inadequate emergency response can increase the number of casualties by a maximum factor of 10, which suggests the need for research on rapid earthquake shaking damage and loss estimation. The reduction in casualties in urban areas immediately following an earthquake can be improved if the location and severity of damages can be rapidly assessed by information from rapid response systems. In this context, a research project (TUBITAK-109M734) titled "Real-time Information of Earthquake Shaking, Damage, and Losses for Target Cities of Thessaloniki and Istanbul" was conducted during 2011–2014 to establish the rapid estimation of ground motion shaking and related earthquake damages and casualties for the target cities. In the present study, application to Istanbul metropolitan area is presented. In order to fulfill this objective, earthquake hazard and risk assessment methodology known as Earthquake Loss Estimation Routine, which was developed for the Euro-Mediterranean region within the Network of Research Infrastructures for European Seismology EC-FP6 project, was used. The current application to the Istanbul metropolitan area provides real-time ground motion information obtained by strong motion stations distributed throughout the densely populated areas of the city. According to this ground motion information, building damage estimation is computed by using grid-based building inventory, and the related loss is then estimated. Through this application, the rapidly estimated information enables public and private emergency management authorities to take action and allocate and prioritize resources to minimize the casualties in urban areas during immediate post-earthquake periods. Moreover, it is expected that during an earthquake, rapid information of ground shaking, damage, and loss estimations will provide vital information to allow appropriate emergency agencies to take immediate action, which will help to save lives. In general terms, this study can be considered as an example for application to metropolitan areas under seismic risk.

Keywords: Rapid response, Loss estimation and mapping, Shakemaps, Damage estimation, Real-time information, Istanbul city

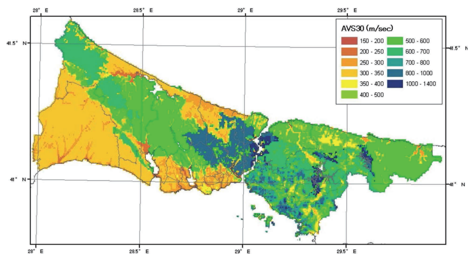

Figure 3

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TECHNICAL REPORT **Open Access**

Design and challenges for a tsunami early warning system in the Marmara Sea

Öcal Necmioğlu

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Abstract

Since 1900, around 90,000 people have lost their lives in 76 earthquakes in Turkey, with a total affected population of around 7 million and direct losses of around 25 billion USD. Based on a time-dependent model that includes coseismic and post-seismic effects of the 1999 Kocaeli earthquake with moment magnitude Mw = 7.4, Parsons (J Geophys Res. 109, 2004) concluded that the probability of an earthquake with Mw > 7 in the Sea of Marmara near Istanbul is 35 to 70 % in the next 30 years. According to a 2011 study, an earthquake with Mw = 7.25 on the Main Marmara Fault is expected to heavily damage or destroy 2 to 4 % of around 1,000,000 buildings in Istanbul with a population around 13 million, with 9 to 15 % of the buildings receiving medium damage and 20 to 34 % of the buildings damaged lightly (Erdik, Science 341:72, 2013). In the absence of adequate post-earthquake assembly areas especially in the heavily urbanized Istanbul, it is evident that after a major earthquake, especially in the coastal parts of the city, citizens would be storming to landfill assembly and recreational areas. Besides earthquakes, around 30 tsunamis have been reported by Altınok et al. (Natural Hazards Earth System Science 11:273–293, 2011) in the Marmara Sea. Among those, catastrophic earthquakes such as 1509, 1766, and 1894 resulted in considerable tsunamis and some damage. The latest tsunami observed in Marmara was due to a triggered submarine landslide of the 1999 Mw = 7.4 Kocaeli earthquake which led to reported run-up heights of 1–3 m in most places (Tinti et al., Marine Geology 225:311–330, 2006). In this study, I propose a design for a tsunami warning system specific for the Marmara region that is strongly coupled with the earthquake early warning system (due to the short arrival times of tsunami) and stakeholders of the tsunami mitigation activities, such as local and regional components of disaster and emergency management and civil protection units, to ensure that the citizens would remain away from the coastline in case of a large earthquake, while discussing associated challenges such as decoupled earthquake and tsunami mitigation activities in the Marmara region.

Keywords: Marmara, Tsunami early warning

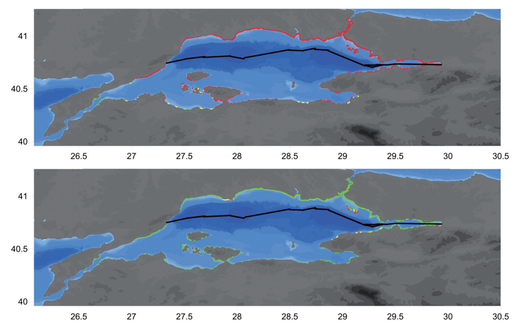

Figure 2

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Correspondence

If you have any questions, please contact editorial@earth-planets-space.com.

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