Challenge Journal of Structural Mechanics

Warning time analysis for emergency response in Sakarya city, Turkey against possible Marmara earthquake

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ABSTRACT

Sakarya, one of the biggest cities in the Marmara prefecture, with 835 thousand population has suffered severe damages due to the North Anatolian Fault System (NAFS) which is a major active right lateral-moving fault in northern Anatolia running along the tectonic boundary between the Eurasian Plate and the Anatolian Plate. One of the biggest disasters was on 17 August 1999 Izmit earthquake with M_w 7.4. The occurrence and the source information of huge events in the region indicate that an earthquake is expecting in near future from the underneath of the Marmara Sea. Therefore, this seismically vulnerable city needs urgent strong motion prediction and reliable Earthquake Early Warning System. The city is preparing now for further NAFS earthquakes and it is essential to inform society about the warning time of a possible imminent earthquake so that precautionary actions can be taken by the government officials, companies and individuals. This study highlights available warning time for the city. Warning time is calculated by considering the theoretic P- and S- wave velocities for Marmara region. Results indicate that Sakarya will have approximately 37.9 second in average with 7.4 second standard deviation before the arrival of strong shaking to the city.

ARTICLE INFO

Article history:
Received 28 May 2015
Accepted 12 July 2015

Keywords:
Warning time
Earthquake early warning
North Anatolian fault
Marmara earthquakes

1. Introduction

The Marmara region, north-east of Turkey, is bounded by approximately longitudes of 26° to 31° and latitudes of 40° to 41°30'. It has a number of structural highlands and basins such as the Kocaeli, Strandja, Rhodope, Ganos, Gelibolu, Kapıdağ, Uludağ and Armutlu blocks and the intervening fault-controlled basins to sea ways, such as the Izmit-Sapanca, Adapazarı, Geyve, İznik, Gemlik, İnegöl, Bursa, Saros and Ergene basins, the Sea of Marmara, and the Dardanelles to Bosphorus.

Seismicity of the Marmara region is comparatively high as pointed out by both the historical and recent devastative earthquakes. 18 historical earthquakes with intensities of IX to X in the period of 29 AD to 1894, and 13 recent earthquakes with magnitudes of 6.1 to 7.4 in the period of 1912 to 1999 occurred in the Marmara region. These statistics correspond to the occurrence of an approximately 1/100 years historical and 1/7 years recent destructive earthquakes in the Marmara region (Koçyiğit, 2000). Since, more or less one to fourth of Turkey's population and most of industry are built-in in this region, this high rate of seismicity has a critical importance for the earthquake hazard (Fig. 1). The high seismicity and earthquake hazard is due to two contemporaneous neotectonic regimes and related structures in the region. These are the strike-slip and extensional neotectonic regimes characterized by a right lateral strike-slip fault system (the western section of NAFS) and an oblique-slip normal fault zone (Le Pichon et al., 2001).

In both historical and instrumental periods, various fault segments mainly both the North Marmara sub-fault system to the South Marmara sub-fault system reactivated and resulted in large devastative earthquakes. All

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of these fault segments are capable to produce large and destructive earthquakes and they could be sources of near future earthquakes in the Marmara region (Koçyiğit, 2000).

One of the largest disasters was on 17 August 1999 Golcuk earthquake with M_w 7.4. The occurrence of huge events in the area indicate that a likely earthquake is forthcoming in near future from the underneath of the Marmara Sea. Adapazari, located between Duzce and Golcuk, affected the most from the last catastrophe. It is expected that the next earthquake also will cause enormous consequences. This seismically vulnerable city needs urgent reliable Earthquake Early Warning System. The city is preparing now for further NAFS earthquakes and it is essential to inform society about the warning time of a possible imminent earthquake so that precautionary actions can be taken by the government officials, companies and individuals.

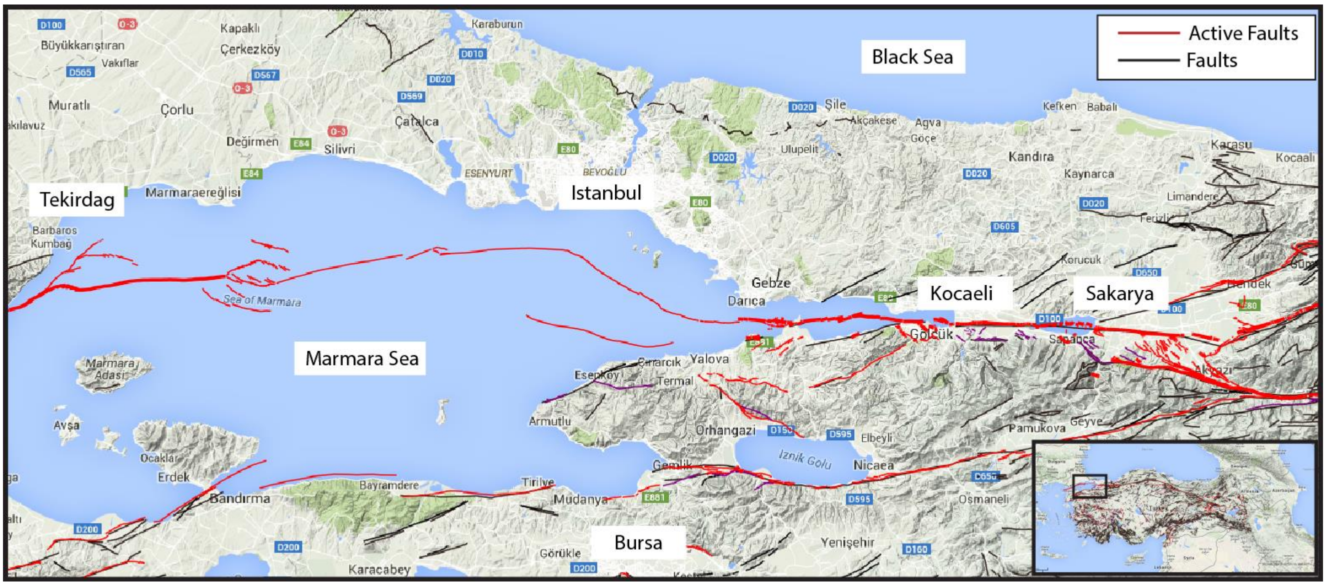

Fig. 1. Active faults segments at Marmara region with long-term seismic gaps (Emre et al., 2013).

Early warning systems give warnings of upcoming danger by rapid estimation of the earthquake source parameters such as magnitude and epicenter (Kuyuk and Allen, 2013a). To do so, systems use the capability of modern real-time systems to process and transmit information faster than seismic wave's propagation (up to 8 km/s). The possible warning time is usually in the range of up to 70 seconds (in Mexico), depending on the distances between seismic source, seismic sensor and user sites (Bose et al., 2014; Kuyuk et al., 2013b).

There have been several expressions used in the literature for this time interval, namely warning time. Various authors used "Alert time", "Warning time", "Available time" in different meanings but the same intentions (Cua and Heaton, 2007). Another difference is the considerations about occurrence of S wave or peak ground motion as a start of strong shaking. Generally "alert time" is defined as onset of P-wave in a nearest station to the fault. The warning time is then the difference between the alert time and the estimated time of S wave for a given location need to be alerted (Kuyuk and Allen, 2013b).

In this study, the available time analysis of likely upcoming offshore earthquake from Marmara Sea is investigated. Available time analysis is performed for Sakarya city by theoretical P- S- wave velocities using three locations Gebze, Kocaeli and Sakarya. P-P wave and S-S wave time difference between near and far sites also investigated. This study could contribute valuable information to public and seismic hazard studies.

2. Methodology

The available warning time of an earthquake Δt can be defined by the time interval between the detection of the P-wave by a sensor in near field and the arrival of energy carrying S-waves at the user site. The epicentral distance E_{user} of the first detection site, E_{user} of the user site and focal depth of earthquake z, the warning time Δt can be estimated by

$$\Delta t = \frac{\sqrt{(E_{user}^2 + z^2)}}{v_s} - \frac{\sqrt{(E_{sensor}^2 + z^2)}}{v_p} - t_{decision} - t_{transmission} \, , \quad (1)$$

where v_p and v_s are the P and S-wave average velocities and $t_{decision}$, $t_{transmission}$ are the time needed for decision of data processing and data transmission times. These two times are separated here to indicate that transmission is more related to technological problem where decision time is related how the decision maker wants to sure the level of earthquake destructivity.

The warning time depends mainly on two factors: the relative distance of stations to epicenter and velocity of the waves in the region and technical/decisional factors (Horiuchi et al., 2005). The alert of a P wave is generally available after 0.2 seconds of waveform reach the nearest station. Processing delay is assumed as 0.4 seconds (Kuyuk and Motosaka, 2009). This is stands for the transmission of waveform from nearest station to operation center of network.

Current seismic infrastructure with the development of communication technology develops a variable packet for the packetization of waveform data so that delay decreased to the insignificant level. The transmission of data to the processing center is generally less than 0.2 second (Motosaka et al., 2008). The processing time for the transmission can be negligible due to high performance computers.

P and S-wave average velocities (v_p and v_s) are depend on soil structure of earth. Travel time tables for different waves and paths (P, S, PS, PP etc.) through the earth were obtaining repeated observations. Various studies have been done to find out the velocities of P and S wave for the Marmara region due to the attractive and complex structure. The crustal structure and velocity variations in the crust have been examined by using the earthquake and controlled source data with different methods. The review of these studies has been done by Kalafat et al. (1987) and Küleli et al. (1996). It was assumed that average S-wave velocity is 3.69 km/sec and average P-wave velocity is 5.8 km/sec based on previous studies in the region.

Assurance and accuracy of the hazard prediction increases with time after an earthquake, while the time of available warning decreasing. Therefore it is important to calculate the probability of available time in a region where destructivity earthquakes are most likely happens. Here I assessed the distribution of warning times for many likely earthquakes in Marmara offshore earthquakes of Turkey (Fig. 2).

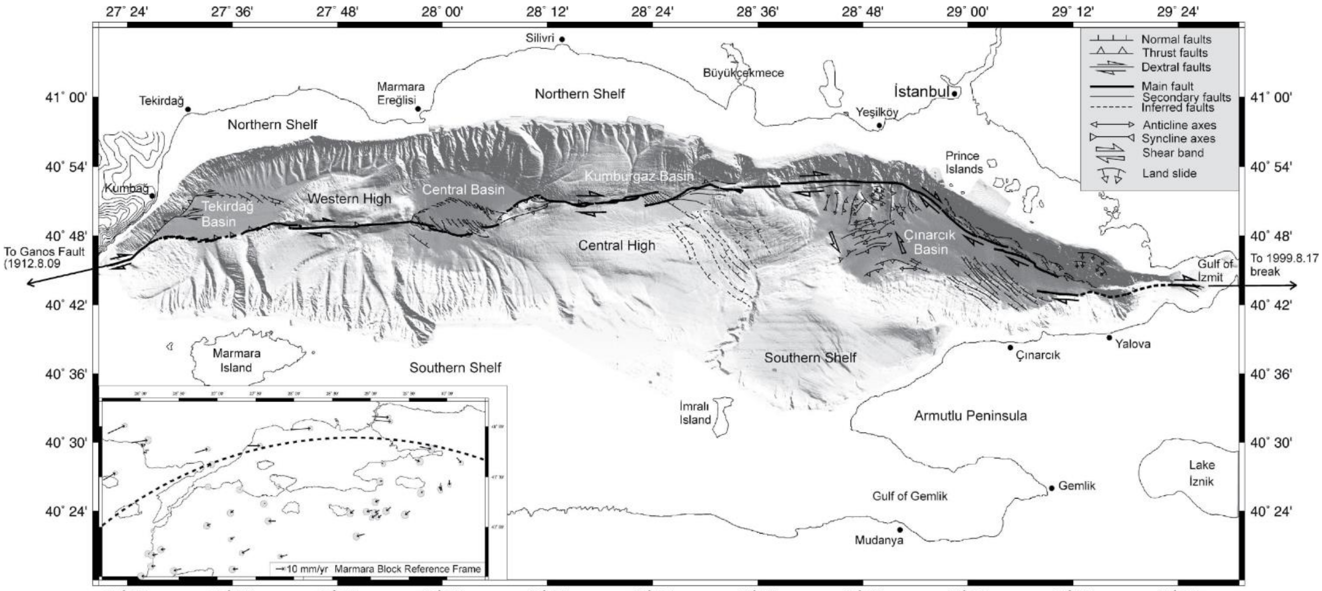

Fig. 2. Bathymetric map of the Marmara Trough with the main active structures (Le Pichon et al., 2001). (Main active faults are shown by thick black lines. The width of the lines refers to the relative importance of the faults.)

A window bounded by 40.6 - 40.9 latitude and 27. 5 - 29.5 degrees longitude was considered for the earthquake source. Sources were located with a time interval between 0.1 degree (about 11 km) in latitude and longitude and 10 to 30 km in depth with 10 km interval depths (three layers, Fig. 3 and Fig. 4) based on point source assumption. Therefore in the simulation there were totally 252 earthquake considered in the source area. Two stations GBZ, IZT, (the nearest inland points of strong ground motion network in the region) and SKR, located in Sakarya city were investigated for the available time analysis (Fig. 2, Table 1). These stations are operated by strong ground motion network, Disaster and Emergency Management Presidency (AFAD) Turkey. It was assumed that stations are providing online waveform as earthquake early warning system.

3. Results and Discussions

I investigated the onset time differences of P-wave between Gebze (GBZ) / Izmit (IZT) and Sakarya (SKR) (Fig. 5). This shows how many seconds it takes P-wave to arrive Sakarya after passing GBZ or IZT. GBZ station is closer to source area than IZT station. Therefore time difference for GBZ is much higher than the IZT station (Fig. 5(a-b)). Hypocenteral distances are the distance between GBZ station and the earthquake point source. After 100 km, the time difference of P-wave arrivals comes to a constant interval between 17 to 18 seconds. Time variance is large for the near source earthquake (varies between 12 to 17 seconds). The results in Fig. 5(b) show the same patterns with smaller time values due to smaller relative distance between IZT and SKR station. As a result there is minimum 7.8 seconds between onsets of P-waves.

Table 1. The coordinates of investigated stations.

Station Code	Longitude	Latitude
GBZ	29.45003	40.78627
IZT	29.91721	40.76650
SKT	30.38005	40.73707

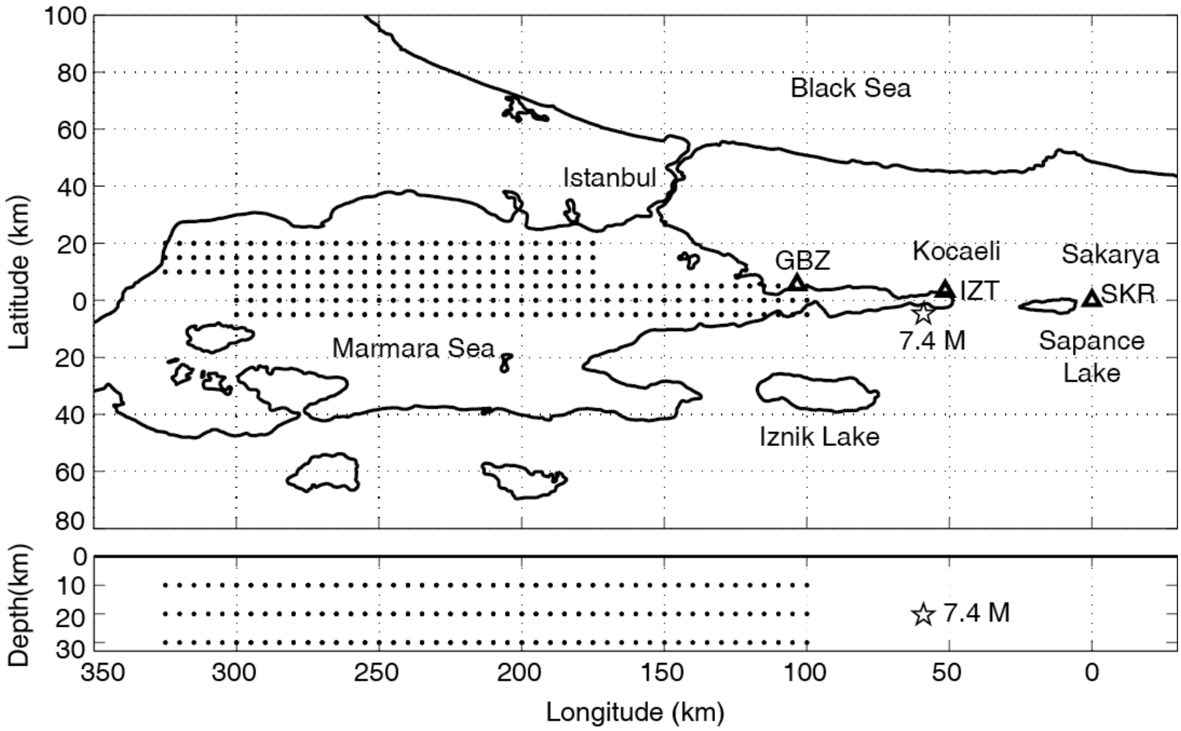

Fig. 3. The Marmara Sea and environment. Location of three stations; Sakarya (SKR), Izmit/Kocaeli (IZT), Gebze/Kocaeli (GBZ).
(Dots are the location of point source earthquakes. Star indicates the Golcuk/Izmit earthquake.)

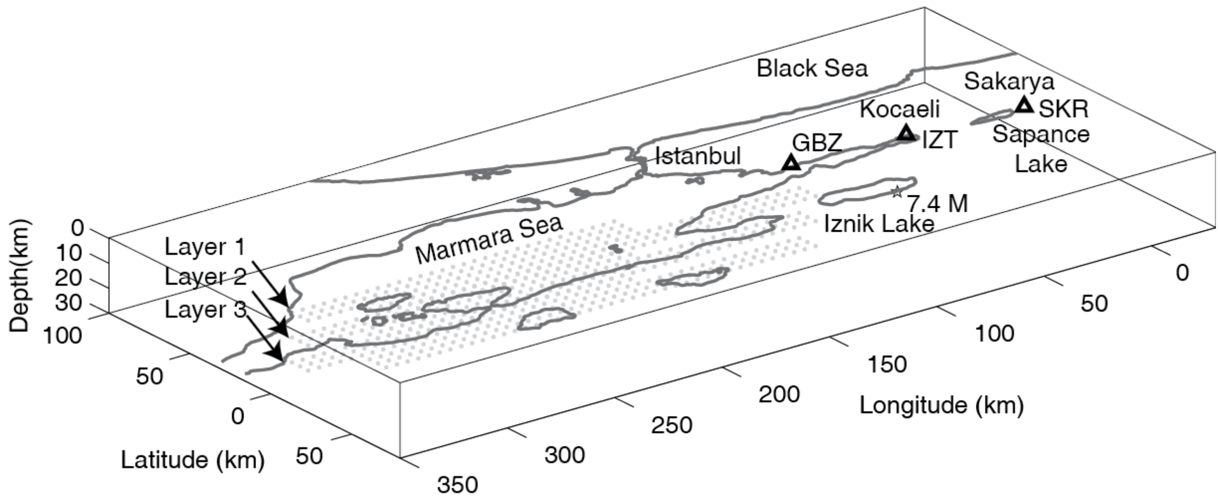

Fig. 4. The Marmara Sea and environment in 3D. Layers shows the interval of assumed point source earthquakes.

The arrivals of S-waves are calculated between GBZ/IZT and SKR stations (Fig. 6). Horizontal axis shows the hyponcentral distance from GBZ station. We observed same pattern as previous P-P wave analysis. There is minimum 18 seconds for Sakarya available after the S waves hit the GBZ station. In addition, there is minimum 12.4 seconds after detection of S-wave in Izmit to reach Sakarya city. Therefore there would be considerable warning time for Sakarya even after S wave detection in Izmit.

The available time for Sakarya according to Eq. (1) by assuming transmission and process time is zero, are shown in Fig. 7. Same as above, available times are as a function of hypocentral distance to GBZ station. The available time increase almost linearly with distance. The minimum available time is 21.9 seconds and maximum is 49.5 seconds where the average is the 37.9±7.4 seconds (Fig. 7(a)). By omitting GBZ station and assuming IZT station is the only one station, the minimum available time is 18 seconds and maximum is the 40.6 seconds with the average 29.5±6.7 seconds.

Although I dismissed the time needed to solve source parameters of an earthquake, there will be sufficient time to warn the Sakarya city. Because in existing network based earthquake early warning systems such as California ShakeAlert EEWS, 8 seconds in averages is needed in order to find the source parameters of an earthquake (Kuyuk et al., 2014). On the other hand the EEWS of Japan gives the earthquake source information less than 6 second in averages after detection of earthquake (Kuyuk et al., 2008). Therefore even the processing and transmission times are subtracted from available times, remaining seconds are promising for a threshold based early warning systems.

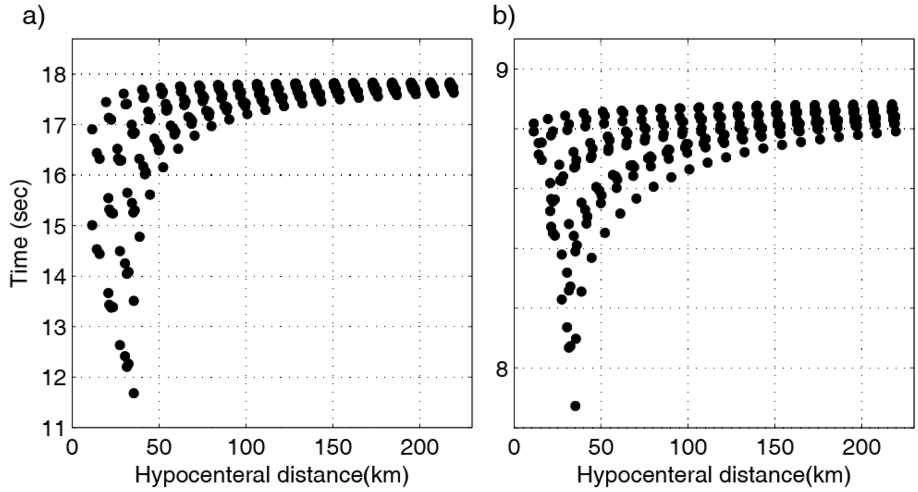

Fig. 5. The time difference of arrival of P-waves for two stations a) GBZ to SKR b) IZT to SKR.

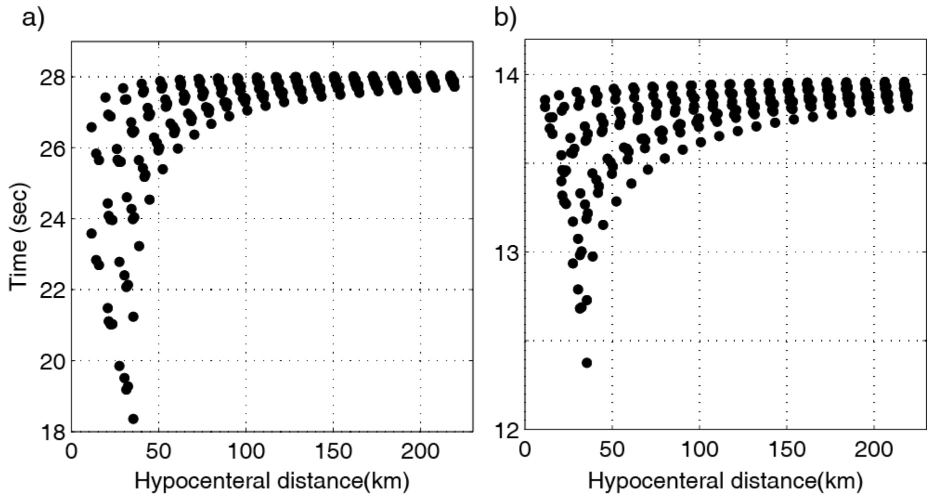

Fig. 6. The time difference of arrival of S-waves for two stations a) GBZ to SKR b) IZT to SKR.

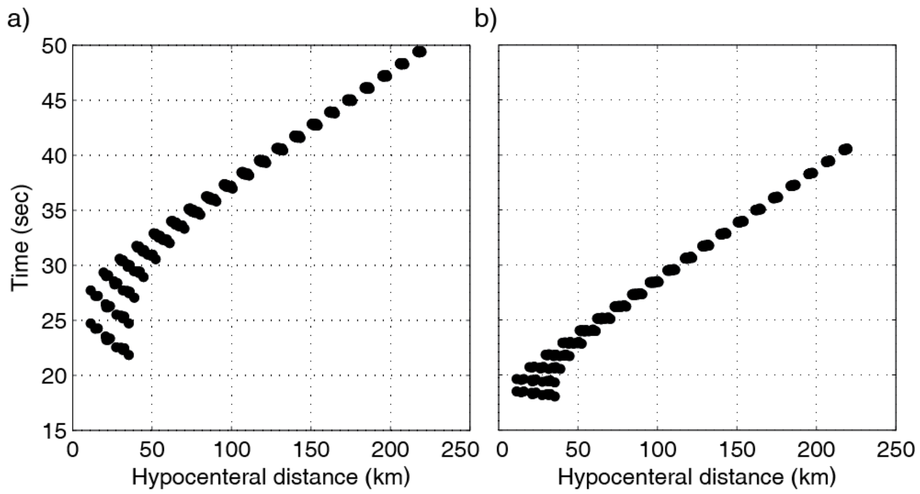

Fig. 7. The available time for Sakarya city. Time difference onset of P wave of a) GBZ b) IZT and S wave arrival to SKR stations. Hypocenteral distance are from GBZ stations.

One of the semiconductor companies in Miyagi Prefecture, Japan declared that they have a capability to stop their product line in their factory in three seconds (Kuyuk et al., 2008). Therefore for similar companies located in Sakarya city would be able to stop the production in any case of Marmara offshore earthquakes based on this study. About 30 seconds of available time would be sufficiently enough in order take some important countermeasures against expecting Marmara earthquake.

The conducted analysis in this study is fundamental research based on theoretic P and S wave velocities. The warning times might change by assuming different velocities. More detailed analysis is needed based on real recorded waveforms in order to validate theoretical results. However similar studies should be performed for other cities in earthquake prone region.

4. Conclusions

Over the earthquake history of Northwestern Turkey, Marmara region has been the site of several destructive earthquakes. It would be possible to inform individuals, government and the private companies about the warning time of next Marmara offshore earthquake if the city has an earthquake early warning system. Moreover, precautionary actions could be taken by the society and government for the next probable upcoming earthquake. Citizens living in their habitats could prepare themselves mentally and physically by real-time earthquake early warning system. Government could prepare real-time disaster prevention strategies for the city. For this purpose, the available time analysis performed for Sakarya City against approaching Marmara offshore earthquakes by using the existing seismic network geometry is presented in this study. Warning times are determined using the theoretic P- and S- wave velocities for Marmara region. Results indicate that Sakarya has about 37.9±7.4 second warning time in average before the strong shaking reach the city.

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