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A Big Earthquake Awaits Istanbul: Mini Review

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Abstract
Istanbul earthquakes occur due to tectonic movements in the northern branch of the North Anatolian Fault, which is called the Main Marmara Fault and lies under the Sea of Marmara. In the past, Istanbul witnessed many devastating earthquakes. It is possible to reach archive information about the Istanbul earthquakes recorded since the Roman-Byzantine periods. Records show that there were approximately 26 earthquakes that caused destruction in the city during the Byzantine period. The earthquakes of 1509, 1719, 1766, 1894 and 1912 during the Ottoman Empire and the recent earthquake of 1999 caused serious destruction and many casualties in the city. The conducted studies reveal that intense seismic energy has accumulated in the unbroken segments of the Main Marmara Fault in the recent past and a severe earthquake awaits Istanbul. Considering the importance of Istanbul for both our country and the whole world, it is important to prepare the city for before and after the earthquake.

Keywords: Disaster, Earthquake, Istanbul, Marmara Sea, North Anatolian Fault

İstanbul'u Büyük Bir Deprem Bekliyor: Mini Derleme

Özet
İstanbul depremleri, Kuzey Anadolu Fayı'nın Ana Marmara Fayı olarak adlandırılan ve Marmara Denizi altında uzanan kuzey kolundaki tektonik hareketler nedeniyle meydana gelmektedir. İstanbul geçmiş dönemlerde çok sayıda yıkıcı depremlere sahne olmuştur. Roma-Bizans dönemlerinden beri kayıt altına alınan İstanbul depremleri konusunda arşiv bilgilerine ulaşmak mümkündür. Kayıtlarda Bizans döneminde şehirde yıkıma neden olan yaklaşık 26 depremin yaşandığı görülmektedir. Osmanlı döneminde meydana gelen 1509, 1719, 1766, 1894 ve 1912 depremleri ve yakın zamanda yaşanan 1999 depremi şehirde ciddi harabiyete ve çok sayıda can kaybına yol açmıştır. Yapılan çalışmalar Ana Marmara Fayı'nın yakın geçmişte kırılmamış segmentlerinde yoğun bir sismik enerji biriktiğini ve İstanbul'u şiddetli bir depremin beklediğini ortaya koymaktadır. İstanbul'un gerek ülkemiz gerek tüm dünya için taşıdığı önem göz önüne alınarak şehrin deprem öncesi ve sonrasına hazırlanması önem arzetmektedir.

Anahtar Kelimeler: Afet, Deprem, İstanbul, Marmara Denizi, Kuzey Anadolu Fayı

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1. Introduction

Earthquakes are defined as the shaking of the earth as a result of the spreading of tremors in waves, which are caused by the sudden discharge of the energy accumulated on the fault planes in the earth (Stanfor Earth, 2020). Earthquakes can cause buildings to collapse, secondary hazards such as fires, landslides and tsunamis, resulting in deaths of many people and heavy economic losses (Michigan Technological University, 2007)

Around 500 000 detectable earthquakes occur every year around the world. Approximately 100,000 of these earthquakes are strong enough to be felt, and approximately 100 are reported to be large enough to cause damage to buildings (USGSa, 2020). According to the report of the United States Geological Research Institute, 3071 earthquakes with magnitudes more than 6 occurred worldwide between 2000-2019 (USGSb, 2020). In Turkey, between the same years, nine earthquakes of magnitude 6 or above have been recorded and 887 people have lost their lives in these earthquakes (World Data, 2020).

Earthquakes occurring in Turkey develop as a result of the breaking of Local faults in the Aegean region, Eastern Anatolian fault line, and North Anatolian fault line, which are active fault lines (Yalçın, Gülen, & Utkucu, 2013). It is not possible to detect earthquakes in advance with today's technology. However, satellite tracking of fault lines, examination of historical earthquakes and developing various statistical models can be able to provide important data on possible earthquakes. Researches on this subject show that the probability of rupture is high in the segments of the North Anatolian fault line extending under the Marmara Sea and that a major earthquake, which can affect Istanbul, can ocur (Lange et al., 2019; Parsons, 2004).

2. Istanbul Earthquakes in History

Many earthquakes have occurred in Istanbul, which is very close to the branch of the North Anatolian Fault Line extending from Izmit Bay to the Marmara Sea (Table 1) (Ambraseys, 2002; Parsons, 2004; B.Ü. KRDAE, 2020). According to the earthquake catalog prepared by Ambrasays, it can be seen that approximately 72 earthquakes occurred in Istanbul during the Byzantine period and roughly 26 of these earthquakes were large enough to cause destruction in the city (NN Ambraseys, 2001). During the Ottoman period, there were also severe earthquakes in Istanbul that caused many people to die. Among these earthquakes, those that caused serious destruction occurred in 1509, 1719, 1766, 1894 and 1912 (Lostris & Yıldız, 2017).

Table 1. Severe Earthquakes in Istanbul From History to The Present[7,9,10]

Date	M_s	Intensity	Latitude	Longitude	Broken fault segment	Death toll
14.09.1509	7,2	IX	40.75	29	East Marmara fault	10000-13000
25.05.1719	7,4	IX	40.7	29.5	Gulf fault	6000
02.09.1754	6,8	IX	40.8	29.4	East ridge west fault	2000
22.05.1766	7,2	IX	40.9	28.6	Central Ridge Northern fault	>5000
10.07.1894	7,3	X	40.6	28.7	Prince Islands fault	1300
09.08.1912	7,3	X	40.7	27.2	Ganos fault	>2000
17.08.1999	7,4	IX	40.81	29.98	Gulf fault	>17.000

2.1. September 14, 1509 Earthquake

The earthquake of September 14, 1509, known as the small apocalypse, caused a great destruction in Istanbul. About 1070 houses destroyed in the aftershocks caused by this earthquake (Lostris & Yıldız, 2017). According to the report of Ambraseys, different figures can be shown in different sources regarding the number of deaths in this earthquake and the figures vary between 10000-13000 (Ambraseys, 2001). It was stated in historical records that this earthquake caused a tsunami and a large but the unknown number of people fell into the crevices on the ground and disappeared (Ambraseys, 2001; Lostris & Yıldız, 2017).

2.2. May 25, 1719 Earthquake

Many buildings in Istanbul had been heavily damaged in the earthquake. Almost all houses sustained great harm, domes cracked, towers and most of the walls collapsed. The detectable number of deaths reached nearly 4000 (Parsons, 2004).

2.3. May 22, 1766 Earthquake

The aftershocks of the 1766 earthquake, one of the biggest earthquakes affecting Istanbul, were felt for a year. The epicenter of the earthquake was in the eastern part of the Marmara Sea. With an estimated magnitude of 7.2 according to the surface wave magnitude scale, this earthquake caused destruction in a wide area extending from Izmit to Tekirdağ and more than 5 thousand people died. In the same year, on August 5, Istanbul was hit by a second earthquake. As for the magnitude of the second earthquake was calculated as 7.4 (N. N. Ambraseys & Jackson, 2000; Parsons, 2004).

2.4. July 10, 1894 Earthquake

The center of the earthquake was detected to be in the southeast Marmara Sea, 8 kilometers from Yeşilköy. The Grand Bazaar collapsed, a 40-meter crevice opened in the Sirkeci dock, and 1087 houses sustained severe damage in the earthquake that occurred in three consecutive tremors. In the earthquake 474 people lost their lives and 482 people injured within the provincial borders of Istanbul (Sezer, 1997).

2.5. August 9, 1912 Earthquake

The earthquake that took place in Şarköy-Mürefte in 1912 was felt in Istanbul in the form of tremors that lasted for days. Affecting a very wide area, the earthquake caused the death of more than 2000 people (Parsons, 2004). Many buildings damaged badly in the earthquake, chimneys of some houses collapsed, some towers and telegraph posts fell into ruin (Ürekli, 2010).

2.6. August 17, 1999 Earthquake

In the Kocaeli/Gölcük earthquake (1999), which was 7.4 in magnitude and Mercalli intensity was IX, nine provinces (Bolu, Bursa, Düzce, Eskişehir, İstanbul, Kocaeli, Sakarya, Yalova, Zonguldak) where 14.5 million people lived were affected. According to the Parliament Research Report (2010), 18.373 people died, 48.901 people were injured, 505 people were disabled, and 96.796 houses became unusable in this earthquake. According to official figures, approximately 4000 buildings damaged severely and 981 people died in this earthquake, which epicenter was approximately 120 km from Istanbul (Grand National Assembly of Turkey Report, 2010).

3. Expected Istanbul Earthquake and Possible Predictions

Throughout history, it is seen that many earthquakes caused the deaths of thousands of people, damaged the city structuring, and caused the destruction of cultural and historical monuments. This is a result of Istanbul being located very close to the North Anatolian Fault (NAF), which is

located between the two main tectonic plates where devastating earthquakes frequently occur (Houseman, 2018). Studies carried out after the 17 August 1999 earthquake, the last major earthquake that shook Istanbul, show that due to tectonic plates movements, a significant seismic tension has been accumulated under the Marmara Sea near Istanbul and that a major earthquake is waiting for Istanbul (Bohnhoff et al., 2013; Lange et al., 2019; Yamamoto et al., 2019).

There are remarkable studies on the magnitude and time of the expected earthquake in Istanbul based on different calculation methods (Ergintav et al., 2014; Bulut et al., 2019). Two of these studies that have attracted the most attention are the work of Tom Parsons and his friends from the United States Geological Survey. In the studies of Tom Parsons et al. published in Science Journal in 2000; The probability of an earthquake of 7.0 or higher magnitude between 2000 and 2030 in the Marmara Sea was 62 ± 15%, while the probability of occurring between 2000 and 2010 was measured as 32 ± 12% (Parsons et al., 2000). Parsons updated these probabilities in 2004 by making a new analysis. According to the results of the research published by Parsons in 2004, the probability of an earthquake that would directly affect Istanbul in the Marmara Sea region between 2004-2034 was calculated as 44 ± 18% (Parsons, 2004).

According to the study of Yaltırak et al. (2003) on this subject, the fault segments with the highest risk of break are the West Marmara, Central Ridge Northern fault, and East Marmara fault segments. According to the model created by Yaltırak et al. based on the amount of strain accumulated in the period between historical earthquakes, the probability of breaking in these three faults in 2022 is 75%, 75%, and 82%, respectively. The same rate is 83%, 82%, 85% for 2027 and for the year 2032, it is 88%, 87% , 87% respectively. Yaltırak et al. stated in their study (2003) that within 60 years all fault segments at the bottom of the Marmara Sea will reach the breaking threshold and the possibility of four destructive earthquakes is almost certain (Yaltırak, Erturaç, Tüysüz & Saki-Yaltırak, 2003).

The earthquakes that affected Istanbul the most were caused by the breaking of the segments forming the northern branch of the North Anatolian Fault under the Sea of Marmara (Figure 1) (Bulut, Aktuğ, Yaltırak, Doğru, & Özener, 2019; B.Ü. KRDAE, 2020). Kocaeli (7.4 Mw) and Düzce (7.2 Mw) earthquakes (1999) caused a large strain decline in the Izmit segment of the NAF line (Kalkan, Gülkan, Öztürk, & Çelebı, 2008). However, the fact that seismic activity has not been detected for a long time in the Prince Islands fault (Çınarcık basin) and the Central Ridge fault south of Küçükçekmece-Marmara Ereğlisi, increased the accumulated tectonic strain in these fault segments and the possibility of earthquakes (Bohnhoff et al., 2013; Kalkan et al., 2008; Lange et al., 2019; Le Pichon, Chamot-Rooke, Rangin, & Sengör, 2003).

Using the micro earthquake records of the Prince Islands off Istanbul, Bohnhoff et al. determined that there is a 30 km long and 10 km deep totally asismic fault segment at the western end of the Izmit fault, which was broken in 1999. The results of the research published in the Nature journal show that the seismic silence in this 30x10 km area, which is less than 20 km south of the city center of Istanbul, causes “slip deficit accumulation” and creates a potential earthquake hazard of at least 7 magnitude (Bohnhoff et al., 2013).

Lange et al. determined that a part of the North Anatolian Fault in the Central Marmara Sea is locked, and therefore strain has accumulated. The last known break in this segment caused the 1766 earthquake. Lack of tectonic activity after this date has caused a slip deficit of at least 4m in the segment. This situation creates an earthquake hazard for Istanbul with a magnitude ranging from 7.1 to 7.4 (Lange et al., 2019).

Earthquakes with high magnitude occurred on the North Anatolian Fault Line in certain time periods after the 1939 Erzincan Earthquake (Figure 2) (Kalafat, 2011; B.Ü. KRDAE, 2020) These

earthquakes indicate a semi-systematic stress transfer migrating westward in the NAF line (DeVries, Krastev, & Meade, 2016). Stress transfer migrating to the west and the lack of tectonic activity in the segments of the Marmara Sea branch of the NAF line close to Istanbul for a long time strengthen the possibility of a severe earthquake that will affect Istanbul (Barka 1996; Stein et al. 1997; Wikipedia, 2020).

Figure 1.The Northern Branch of the North Anatolian Fault Below the Marmara Sea (Bulut et al., 2019; B.Ü. KRDAE, 2020)

According to the research of Bulut et al., the slip deficit below the Western segment (Tekirdağ Basin) reaches 1.7 meters, while the slip deficit below the Central (Central High and Kumburgaz Basin) and Eastern segments (Çınarcık Basin) reach 4.0m and 5.4 meters, respectively. These segments, which were last broken in August 1766, May 1766 and October 1509, have the potential to create earthquake with magnitude of 7.2 Mw, 7.4 Mw and 7.5 Mw respectively, today. When the historical process is examined, it can be seen that there is no simultaneous break in three segments. However, a simultaneous break that may occur in the two segments in the west is expected to cause an earthquake with magnitude of 7.5 Mw, a simultaneous break that can be seen in the two segments in the east, 7.6 Mw, and a simultaneous fragmentation that can be seen in all three segments will cause an earthquake with magnitude of 7.7 Mw (Bulut et al., 2019).

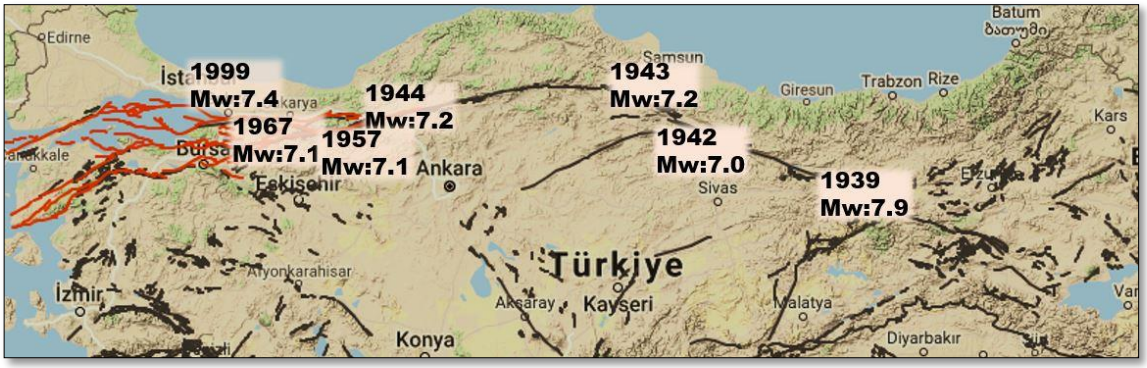

Figure 2. Earthquakes on the North Anatolian Fault Line (DeVries et al., 2016; B.Ü. KRDAE, 2020)

Estimating the damage and loss of life caused by the earthquake is very important in terms of organization of rescue teams, emergency response and rapid information communication. According to the estimates made by the Kandilli Observatory and Earthquake Research Institute, if an earthquake of 7.5 magnitude occurs at night, it is expected that the average loss of life in Istanbul will be around 14.150 and the number of seriously injured will be around 8.100. If the earthquake occurs during daylight hours, it is estimated that 12.400 people could die and 7.450 people could be seriously injured (Çaktı, Şafak, Hancılar, & Şeşetyan, 2020). In an earthquake with a magnitude of 7.5, it is predicted that 26% of the buildings in Istanbul may be damaged lightly, 13% moderately, 3% heavy and 1% very heavy and may cause 26.04 billion dollars economic loss. (Çaktı, Şafak, Hancılar, & Şeşetyan, 2020; Kundak, 2004). In addition, according to article of Erdik et al. published in Science, scientific research (2011) shows that an earthquake with a magnitude of 7.25 can cause severe damage to 2-4% of buildings in Istanbul, moderate damage to 9-15%, and slight damage to 20-34% (Erdik, 2013).

4. Conclusion and Recommendations

Risk analysis studies using various methods show that a major earthquake is being awaited for Istanbul. Scientific data and studies do not leave any hesitation about the earthquake. On the other hand, there is no certainty about the magnitude and possible date of the earthquake. Istanbul is an ancient city with its place in world history, geographical location, contribution to trade, art, culture, religious and historical buildings. The effects of this city being heavily damaged by a major earthquake may be greater than predicted not only for our country but also for the whole world. It should be seen as a historical responsibility for us to take this effect into consideration in preparation efforts for the expected earthquake and to carry it out in cooperation with the international community.

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