PROBABILISTIC EARTHQUAKE RISK ANALYSES IN THE REGION OF SINDIRGI – SİNANPAŞA FAULT ZONE, TURKIYE

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ABSTRACT

The Sındırgı-Sinanpaşa Fault Zone is one of the most significant active fault zones in western Anatolia, Turkiye. Numerous historical (1728 – M ?, 1875 - M:6.1) and instrumental period earthquakes (1944 – Ms 6.0, 1970 – Ms 5.9, 27 June 2011 – M 5.0) have occurred along the fault zone. Therefore, Understanding the seismic behavior of the zone is critical for determining suitable settlement areas in the region. The earthquake recurrence interval was determined as the best-case and the worst-case scenario data for the region. According to the best-case scenario, the average recurrence period of earthquakes with magnitude of 5.5, 6 and 6.5 is 4 - 19 years, 13 - 68 years, and 34 - 258 years, respectively. In addition, the probability of an earthquake with a magnitude of 7.0 occurring within 50 years is 5.0% - 44.5%. In the worst-case scenario, the average recurrence period of earthquakes with magnitudes of 5.5, 6 and 6.5 is 4 – 9, 13 – 34, and 49 – 131 years, respectively. Additionally, the probability of an earthquake with a magnitude of 7.0 occurring within 50 years is 9.4% - 24.3%. Lastly, the average ground acceleration is 0.23 - 0.56 g, with a probability of exceeding 99% - 45% in 50 years for earthquakes with a radius of 100 km in the region. Our findings suggest that the region is seismically active, where risk-based approaches should be employed in establishing settlement areas.

KEY WORDS: Earthquake, Probabilistic analysis, Risk analyses, Active fault zone, Western Turkiye

1-INTRODUCTION

95% of earthquakes occur at active plate boundaries (Işık and Cağlayan 2018). Turkiye is located in a region where the relative movements of the Eurasian, African, and Arabian plates (Şengör and Yılmaz

1981, Çağlayan et al. 2019). The west and southwest movements of the Anatolian plate are provided by the North Anatolian Fault Zone (NAFZ) and the East Anatolian Fault Zone (EAFZ). These fault zones are the most important fault zones in Turkiye (Figure 1A).

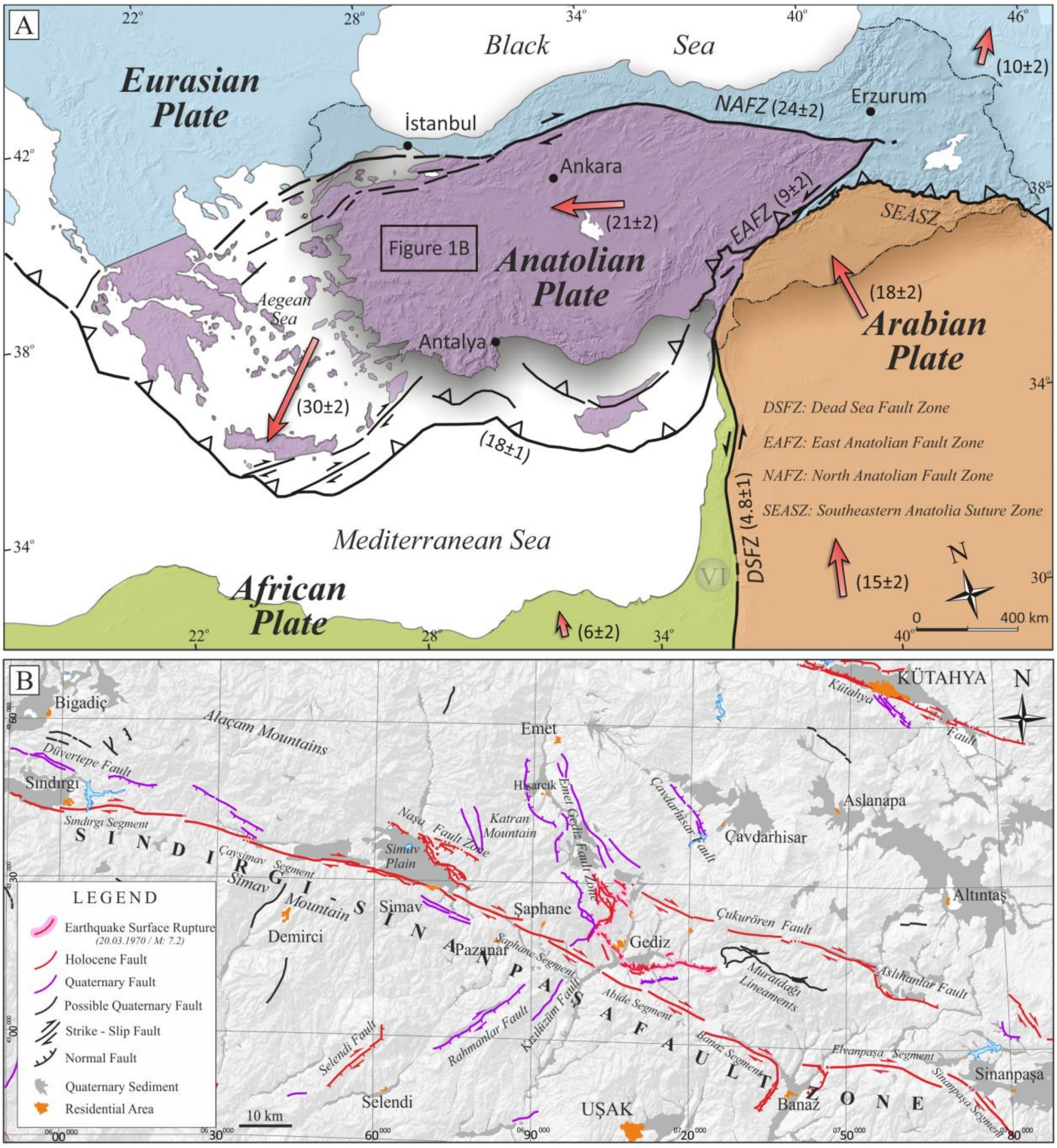

Figure 1 (A) The map shows the plate geometries of Turkiye and its surroundings (taken from Caglayan et al. 2019). (B) The map shows the Sındırgı-Sinapaşa Fault Zone and active- possible active faults in the region (Faults and quaternary areas were simplified and redrawn from Emre et al. 2013)

Another important fault zone is the Sındırgı – Sinanpaşa Fault Zone (Figure 1B). Although there are different opinions about the characteristics of the fault zone, it is drawn as a strike-slip fault on the Active Faults Map of Turkiye. In the literature, the features of this zone have also been presented as a normal fault, or that the faulting began as a strike-slip fault and later progressed to a normal fault. Moreover, it is an active fault zone in western Turkiye that has been classified into seven segments (Emre et al. 2013). These segments are named Sındırgı, Çaysimav, Şaphane, Abide, Banaz, Elvanpaşa, and Sinanpaşa. In addition, it is a N60°W fault zone with a length of approximately 200 km between the residential areas of Sındırgı (Balıkesir) in the northwest and Sinanpaşa (Afyon) in the southeast. The activity of the Sındırgı-Sinanpaşa Fault Zone and its surroundings is recorded in historical (e.g., 1728-M:?, 1875-M: 6.1, 1896-M:?) and instrumental period earthquake data (e.g., 1928-Ms: 6.1, 1944-Ms: 6.0, 28 Mart 1970-Mw: 7.2, 1970-Ms: 5.9, 17 Şubat 2009-Mw: 5.3, 19 Mayıs 2011-Mw: 5.9, 27 Haziran 2011-M: 5.0, 3 Mayıs 2012-Mw: 5.8) (Figure 2).

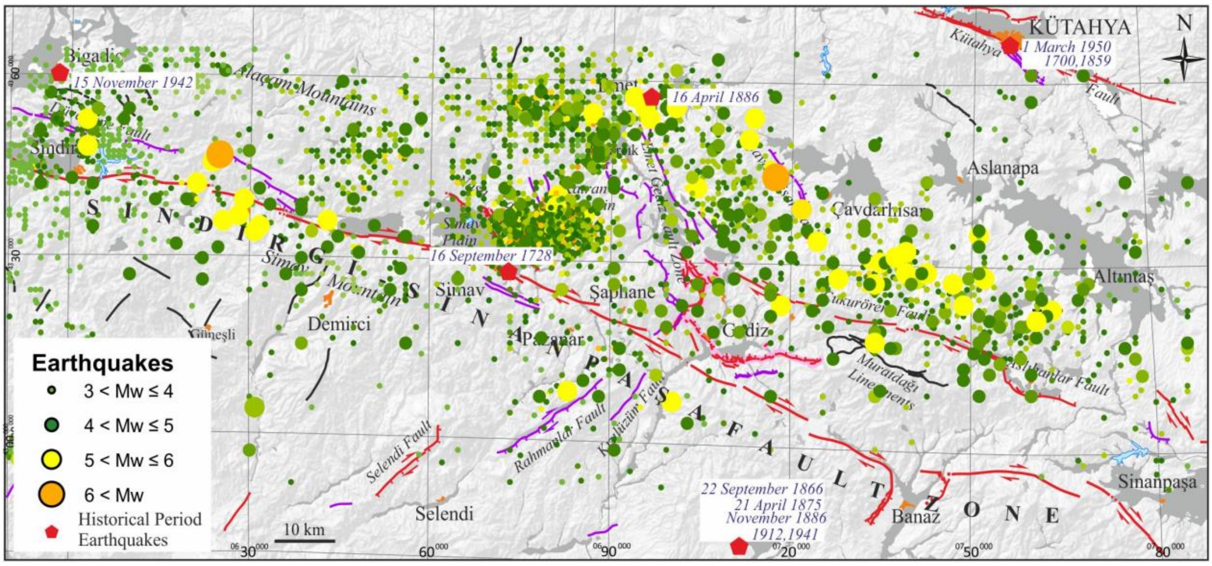

Figure 2 The map shows historical and instrumental period earthquake data

The fault zone affects many settlements with medium or high population such as Alacaatlı, Sındırgı, Pürsünler, Osmanlar, İzzettin, Söğütcük, Yeniköy, Hisarbey, Ahmetli, Demirci, Simav, Yeşilköy, Kuşdemir, Hatipler, Kaplangı, Paşacık, Çayhisar. As a result, it is critical to study the tectonic activity of the Sındırgı- Sinanpaşa Fault Zone, determine the earthquakes that have occurred in the past and understand the potential risks in the future.

2-METHOD and APPLICATION

Earthquakes of magnitude 4.5 or more that occurred along the Sındırgı-Sinanpaşa Fault Zone throughout the instrumental period were determined, and a probabilistic earthquake risk analysis was performed along the zone. Earthquake data were obtained from the Boğaziçi University Kandilli Observatory and the Earthquake Research Institute Regional Earthquake-Tsunami Monitoring and Evaluation Center website. In addition, the data were taken both within a radius of 100 km from the center of the zone and regionally throughout the fault zone, and these data were compared. Moreover, four different types of earthquake magnitude data were obtained. These are body-wave magnitude (Mb), local magnitude (Ml), duration-dependent magnitude (Md), and the largest magnitude value among the magnitude values given in the earthquake catalog (xM). Furthermore, Ms magnitude data were converted from Ml, Md, and Mb magnitudes with formulas, and xM size was directly evaluated and interpreted. Additionally, the results obtained were interpreted both regionally and along the fault zone. Finally, the Zemin Jeofizik Analiz software prepared by Özçep (2005) was used for the study. The earthquake recurrence interval and Poisson probability distribution were determined as the best-case and the worst-case scenario data for the region.

3-RESULTS

Firstly, instrumental period earthquakes with a magnitude of 4.5 and above occurring in the fault zone within a circular area with a radius of 100 km were used for the probability analysis. In the table, the Poisson probability distribution and recurrence periods were calculated according to xM and the data obtained by converting three different earthquake magnitudes into Ms magnitude (Table 1).

Table 1. Poisson probability distribution and recurrence periods of the fault zone within a circular area with a radius of 100 km

	Probability for D (Year)(%)				**Probability for D (Year)(%)**				**Probability for D (Year)(%)**				**Recurrence interval**			
	50				**75**				**100**				**(Year)**			
Magnitude (M)	**xM**	**Ml**	**Md**	**Mb**	**xM**	**Ml**	**Md**	**Mb**	**xM**	**Ml**	**Md**	**Mb**	**xM**	**Ml**	**Md**	**Mb**
4.5	100	100	100	100	100	100	100	100	100	100	100	100	0	1	0	1
5	100	100	100	100	100	100	100	100	100	100	100	100	1	2	1	2
5.5	100	99.8	100	100	100	100	100	100	100	100	100	100	4	8	5	5
6	97.7	83.9	95.0	97.5	99.6	93.5	98.9	99.6	99.9	97.4	99.8	99.9	13	27	17	14
6.5	64.1	41.5	58.7	77.1	78.5	55.2	73.4	89.0	87.1	65.8	82.9	94.7	49	93	57	34
7	24.3	14.5	22.9	44.5	34.2	21	32.4	58.7	42.7	27.0	40.6	69.2	179	318	192	85

Secondly, instrumental period earthquakes with a magnitude of 4.5 and above occurring in the region with coordinates of 39.252992°N-28.048134°E / 38.661007°N – 30.248331°E were used for probability analysis. In the table, the Poisson probability distribution and recurrence periods were calculated according to xM and the data was obtained by converting three different earthquake magnitudes into Ms magnitude (Table 2).

Table 2. Poisson probability distribution and recurrence periods of the region with coordinates of 39.252992°N-28.048134°E / 38.661007°N – 30.248331°E

	Probability for D (Year)(%)				**Probability for D (Year)(%)**				**Probability for D (Year)(%)**				**Recurrence interval**			
	50				**75**				**100**				**(Year)**			
Magnitude (M)	**xM**	**Ml**	**Md**	**Mb**	**xM**	**Ml**	**Md**	**Mb**	**xM**	**Ml**	**Md**	**Mb**	**xM**	**Ml**	**Md**	**Mb**
4.5	100	100	100	100	100	100	100	100	100	100	100	100	1	1	1	2
5	100	100	100	100	100	100	100	100	100	100	100	100	2	5	4	6
5.5	99.6	93.7	97.7	93.2	100	98.4	99.6	98.2	100	99.6	99.9	99.5	9	18	13	19
6	76.9	51.9	67.5	56.9	88.9	66.7	81.5	71.7	94.7	76.9	89.4	81.4	34	68	44	59
6.5	31.6	17.6	28.6	23.2	43.5	25.3	39.6	32.6	53.3	32.2	49.0	40.9	131	258	149	190
7	9.4	5.0	9.6	7.9	13.8	7.4	14.0	11.6	17.9	9.8	18.2	15.2	507	973	497	606

Thirdly, instrumental period earthquakes that occurred both within a circular area with a radius of 100 km and at the coordinates of 39.252992°N-28.048134°E / 38.661007°N – 30.248331°E, according to the magnitude specified as xM in the catalog, were used. In the table, the Poisson probability distribution and recurrence periods were calculated according to xM (Table 3).

Table 3. According to xM, Poisson probability distribution and recurrence periods of the fault zone within a circular area with a radius of 100 km, and at the coordinates of 39.252992°N-28.048134°E / 38.661007°N – 30.248331°E

	Probability for D (Year)(%)		Probability for D (Year)(%)		Probability for D (Year)(%)		Recurrence interval	
	50		75		100		(Year)	
Magnitude (M)	xM-100km radius	xM-coordinates	xM-100km radius	xM-coordinates	xM-100km radius	xM-coordinates	xM-100km radius	xM-coordinates
4,5	100	100	100	100	100	100	0	1
5	100	100	100	100	100	100	1	2
5,5	100	99.6	100	100	100	100	4	9
6	97.7	76.9	99.6	88.9	99.9	94.7	13	34
6,5	64.1	31.6	78.5	43.5	87.1	53.3	49	131
7	24.3	9.4	34.2	13.8	42.7	17.9	179	507

Lastly, in the study area, the danger level for 5.9 - 7.0 magnitude earthquakes has been calculated for a 50-year building life. The average ground acceleration was determined to vary between 0.23 and 0.56 g, and the probability of exceeding 99% - 45% was calculated. It was determined that such earthquakes pose a high danger for earthquakes with a radius of 100 km in the region.

4-CONCLUSIONS

The earthquake recurrence interval was determined as the best-case and the worst-case scenario data for the region. The best-case scenario was determined from the region limited by the coordinates and within a circular area with a radius of 100 km in the region. The worst-case scenario was determined from the region with both limited coordinates and the regional with xM values. Thus, the following results were obtained:

i) According to the best-case scenario, the average recurrence period of earthquakes with a magnitude of 5.5 is 4 - 19 years, while the average recurrence period of earthquakes with a magnitude of 6.0 is 13 - 68 years. Moreover, the average recurrence period of earthquakes with a magnitude of 6.5 is 34 - 258 years. In addition, the probability of an earthquake with a magnitude of 7.0 occurring within 50 years is 5.0% - 44.5%, and the probability of an earthquake with a magnitude of 7.0 occurring within 100 years is 9.8% - 69.2%.

ii) In the worst-case scenario, the average recurrence period of earthquakes with magnitudes of 5.5, 6 and 6.5 is 4 – 9, 13 – 34, and 49 – 131 years, respectively. Additionally, the probability of an earthquake with a magnitude of 7.0 occurring within 50 years is 9.4% - 24.3%, and the probability of an earthquake with a magnitude of 7.0 occurring within 100 years is 17.9% - 42.7%.

The average ground acceleration is 0.23 - 0.56 g, with a probability of exceeding 99% - 45% in 50 years for earthquakes within a circular area with a radius of 100 km in the region. Our findings suggest that the region is seismically active and that risk-based approaches should be employed in establishing settlement areas.

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