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A MULTIDISCIPLINARY STUDY FOR SEISMIC HAZARD IN MARMARA SEA REGION,TURKEY

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ABSTRACT

The Marmara Sea region of Turkey is one of the most active continents in nowadays tectonics. The crustal tectonic movement and deformation are of great scientific significance to the understanding of the continental dynamics. This document calculates the earthquakes recurrence interval of the major active faults in the Marmara Sea region based on the multidisciplinary multi-time scale data of geology and geodesy. The earthquake probability in the next 10 and 30 years is calculated using the time-dependent probability model.

1. INTRODUCTION

The seismic hazard assessment of active faults is not only the basis of seismic hazard zoning, earthquake prediction, mitigation of seismic and geological disasters, but also a core problem to ensure the safety of urban and engineering. At present, the mid- and long-term seismic hazard is based on the data of the active fault, the seismology and the geodesy, and so on. Firstly, the earthquake recurrence pattern of the single rupture zone and the earthquake recurrence probability model are determined according to the historical earthquake and the paleo earthquake. Secondly, the average recurrence interval is calculated by the fault slip rate method and seismic moment rate method. Lastly, time-dependent probability is determined [1-3].

Since seismic elastic rebound theory is proposed, the mid- and long-term seismic hazard assessment of active faults has been developed from the deterministic stage to the probabilistic stage, especially the time-dependent probability model is widely used at home and abroad [4]. The time-dependent probability model, also known as the real-time probability model, refers to the possibility that a rupture segment relapses a strong earthquake over a given period of time increases with the elapsed time since the last earthquake. Due to the presence of randomness, it is not possible to predict whether an earthquake in a given period of time will occur, and only probability is used to indicate the possibility of an earthquake. The model has been widely used because of the time-dependent assessment of the probability of earthquake risk assessment consistent with the general understanding of the mechanism of earthquake recurrence [1, 2, 5, 6]. For example, Wen used three probability models (Weibull distribution, Normal distribution and Lognormal distribution) to calculate the conditional probability of earthquake recurrence in the Xianshuihe fault in the next 30 years. The Working Group of California Earthquake Probability (WGCEP) calculated the probability of occurrence of the M ≥ 6.7 earthquakes in San Francisco Bay Region 2000-2030 and 2002-2031 using the Brownian Passage Time Model (BPT), which is applied to the region's earthquake zoning, earthquake insurance, structural reinforcement and standard development work [5, 7].

However, most of the previous studies have been based on the results of quantitative studies of active faults and historical earthquakes and paleo-seismic data, but few studies have applied GPS to seismic hazard analysis. With the abundance of GPS data and the maturation of GPS data processing technology, the application of GPS data to the seismic hazard analysis of active faults has been basically mature. Some research results show that GPS has potential application in the calculation of earthquake recurrence interval and seismic hazard analysis [8-11]. This document takes the northern Anatolia fault in the Marmara Sea region of Turkey as the research object. The recurrence intervals of the major active fault segment are calculated based on the GPS method and the seismic moment rate method. On this basis, the time-dependent probability model is used to calculate the earthquake probability.

1. GEOLOGICAL AND SEISMIC ACTIVITY IN THE STUDY REGION

The North Anatolia fault is a transition between the Eurasian plate and the African Arabian plate, east of Goykuz, through the Marmara Sea in the western part of Turkey, with a total length of 1200 km for the strike-slip fault [12]. It can be subdivided into several fault sections: Ganos fault section, length 15km; Central Marmara fault segment, length 105km; North boundary fault segment, length 45km, with simple geometry structure, which there is no bifurcation in the linearity and prone to stress transfer. Among the north boundary fault segment, the Izmit section occurred on August 17, 1999, the Ms7.4 earthquake. As a result of the Eurasian plate and the squeeze of the Arabian plate, the Anatolian block along the right-hand slippery north of the Anatolia fault and the left-wing strike of the East Anatolia fault westward escaped to reach the north-south extended Aegean Sea, which causes earthquakes along the western part of Turkey, is mostly extensional and strike-slip, while in the east there are squeezing and strike-slip earthquakes [12,13]. The Northern Anatolia fault is nucleated in the eastern part of Anatolia, late Miocene, and then westward, arriving in the Marmara Sea region in the Pliocene [14,15]. Figure 1 shows the seismic structure of the surrounding the Marmara Sea region.

According to the GPS data (Figure 2), the fault slip rate in Turkey is relatively high at 20 mm / a, which is comparable to that of the San Andreas Fault in California. The North Anatolia Fault has a similarity to the San Andreas Fault: the slip rate is quite high, and the length is quite the same, and the fracture activity is the same as the strike-slip fault. Due to the similarity between these two faults, seismic hazard assessment of the North Anatolia Fault can refer to ideas of the San Andreas Fault in the United States. Earthquake activity in Turkey is frequent, many of which have big magnitude. The earthquake catalog of M ≥ 4 in Turkish region in January 1901 - December 2015 is collected. These data show that, since 1901 there are 58 earthquakes with magnitude greater than or equal to 6, and there are 35 earthquakes with magnitude greater than or equal to 7.

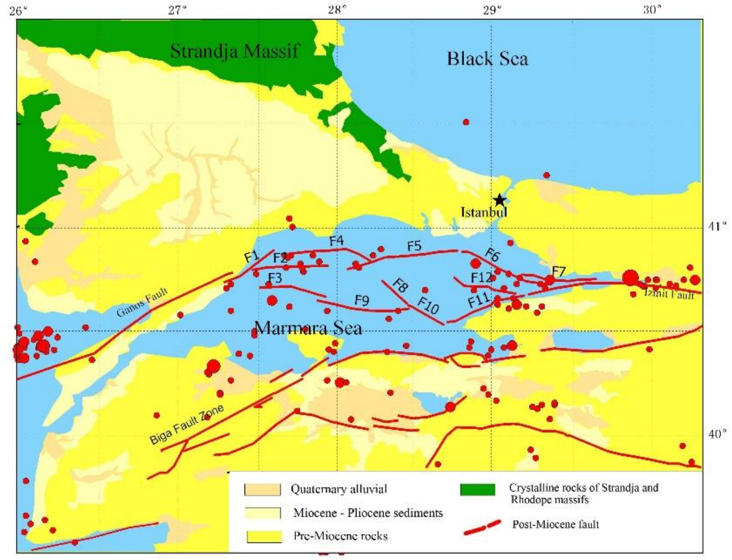

Figure 1: The seismotectonic map of Marmara Sea region

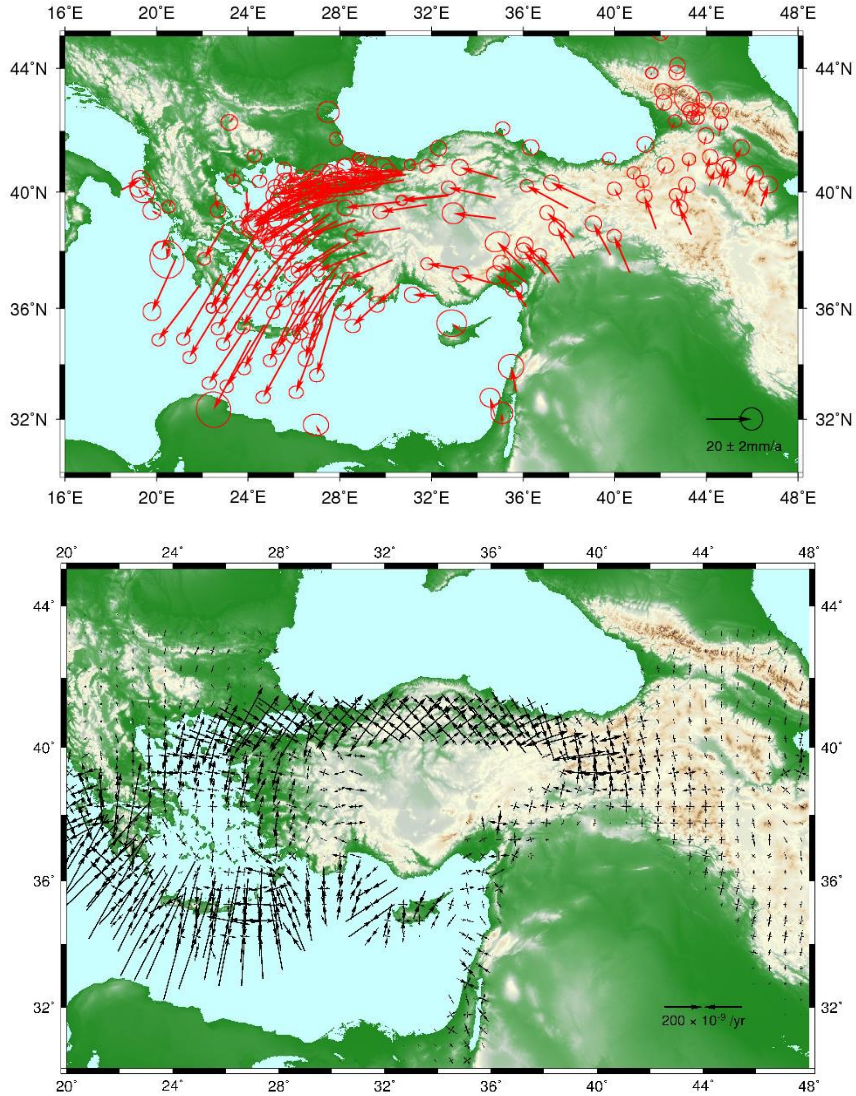

Figure 2: The Turkish GPS veloticy field (a) and the strain rate field

2. EARTHQUAKE AVERAGE RECURRENCE INTERVAL CALCULATION METHODS

The earthquake recurrence interval is one of the most important parameters of seismic hazard analysis. Estimation of the earthquake recurrence interval is mainly based on three methods: geologic method, seismic activity statistical method and geodetic method [16-18]. Due to the high degree of quantitative research on the active fault in the Marmara Sea region and the accumulation of abundant GPS observations, this document uses geologic method and geodetic method to calculate the recurrence interval of the major active fault segments in the study region. According to the reliability of the data used, the weight is given to get a comprehensive average recurrence interval.

3.1. Geological Method

Wesnousky proposed a method for calculating the earthquake recurrence interval using the seismic moment, calculated as:

$$T = \frac{M_0}{\dot{M}_0} \quad (1)$$

$$\dot{M}_0 = \mu A \nu \eta$$

Among them, M_0 means the characteristic seismic moment, which can be obtained by the quantitative study of the active fault. $\dot{M}_0$ means seismic moment rate, which is determined by the crustal elastic layer shear modulus (μ), the fault slip rate (ν), deformation unit area (*A*), and the seismic scale factor (η). The shear modulus(μ) generally takes 3.0 ~ 3.3 × 10^{10}N / m2. deformation unit area (*A*) is determinated by the legnth and width of the fault. The seismic scale factor (η) refers to the ratio of the slip of the earthquake to the total slip of the fault, which is 0.9 used in Working Group of California Earthquake Probability and the USA Probabilistic Seismic Hazard Map [19-21].The above parameters can be obtained by quantitative study of active fault, which is used to calculate the earthquake recurrence interval of the major activity fault in the Marmara Sea region (Table 1).

3.2. Geodetic Method

Ward derived the formula for calculating the earthquake recurrence interval using GPS data according to the Gutenberg-Richter's law and the seismic moment-magnitude relationship. This method is used to calculate the earthquake recurrence interval of Southern Sichuan-Yunan in China [22].

$$T(M) = \left[\frac{b}{c+b}\right] \frac{10^{(c+b)M_{\max}+d}}{\dot{M}_0\left[10^{bM_{\max}} - 10^{bM}\right]} \quad (2)$$

$T(M)$ is the earthquake recurrence interval with magnitude greater than or equal to *M*. And $M_{\max}$ is the maximum magnitude of the study region. The *b* is the parameter of the Gutenberg-Richter magnitude-frequency law (lg*N*=*a*-*bM*). The *c* and *d* are the parameters of the seismic-magnitude relationship ($\lg M_0 = c + dM$) of the study region. The seismic earthquake rate $\dot{M}_0$ is obtained by the seismic moment-strain rate relation [16]:

$$\dot{M}_0 = 2\mu A H_s \max(|\dot{\varepsilon}_1|, |\dot{\varepsilon}_2|, |\dot{\varepsilon}_1 + \dot{\varepsilon}_2|) \quad (3)$$

The *Hs* is the depth of deformation unit. It is believed that the elastic strain is accumulated at this depth and released in the form of earthquakes. $\dot{\varepsilon}_1$ and $\dot{\varepsilon}_2$ are geodetic principal strain rate, which can be calculated by the GPS velocity. Many researchers use the GPS data to calculate the strain rate field in mainland China and other regions [12,14].

3.3. Weighted Average Earthquake Recurrence Interval

According to the reliability of the data, the equal weight of the geologic method and the geodetic method are given to calculate the average recurrence interval of the major active fault in Marmara Sea region, refer with Table 1.

3. EARTHQUAKE CONDITION PROBABILITY CALCULATION METHODS

The probability of recurrence of earthquakes in the future may be expressed as a conditional probability (Figure 3):

$$Pc(t_e \le t \le t_e + \Delta t) = \frac{\int_{t_e}^{t_e+\Delta t} f(t)dt}{\int_{t_e}^{\infty} f(t)dt} = \frac{F(t_e+\Delta t) - F(t_e)}{1 - F(t_e)} \quad (4)$$

$Pc(t_e \le t \le t_e + \Delta t)$ is conditional probability; *f*(*t*) is the probability density function of the recurrence interval; *F* (*t*) is the cumulative probability distribution function; *t* is the recurrence interval; t_e is the elapsed time; Δt is the forecast period, taking as 10year, 30year, 50year or 100year as examples.

There are many probabilistic models for seismic hazard analysis. In this study, Logarithmic Normal distribution models, BPT model and Poisson model are used to calculate the earthquake probability. Their probability density functions are as seen below. The meaning of each parameter can be seen in WGCEP (2008).

$$f_{LOGN}(t/T) = \frac{T}{t\sqrt{2\pi}} \exp\left(\frac{-[\ln(t/T) - u]^2}{2\sigma^2}\right) \quad (5)$$

$$f_{BPT}(t) = \sqrt{\frac{T}{2\pi\alpha^2 t^3}} \exp\left[-\frac{(t-T)^2}{2tT\alpha^2}\right] \quad (6)$$

$$f_{EXP}(t) = \lambda e^{-\lambda} \quad (7)$$

In the case of the available data, the sample size is too small, and the reliability of the single model exists. Therefore, this study also gives the comprehensive evaluation of the above three probability models, that is, the joint model. WGECP (2008) used the expert opinion to score the weight of each probability model for San Andreas. The weight of each model was given as follows: BPT model was 0.72, Poisson model was 0.28. Since the Logarithmic Normal model and the BPT model are the time-dependent probability models related to the elapsed time, and the Poisson model has nothing to do with the elapsed time, the weight of the model is given to the above three models respectively by 0.36, 0.36 and 0.28 [21]. The joint model is calculated as follow:

$$P = 0.36P_{LONG} + 0.36P_{BPT} + 0.28P_{EXP} \quad (8)$$

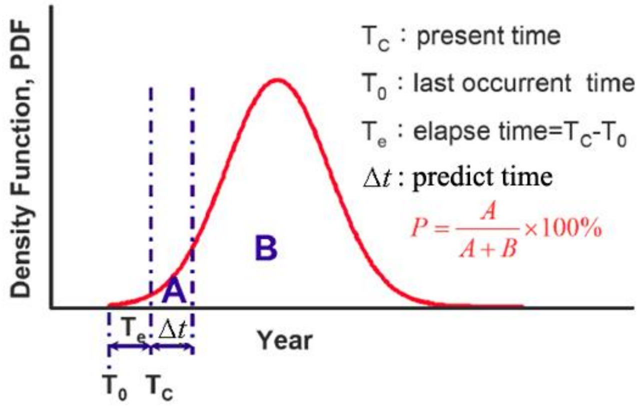

Figure 3: Illustration of earthquake probability calculation

4. RESULTS AND ANALYSIS

According to the above technical route, the recurrence interval and earthquake probability of the major fault in the Marmara Sea region is calculated. The conditional probability of logarithmic normal model, BPT model, Poisson model and joint model are obtained for the next 10 years and 30 years. See in Table 1 and Figure 4.

Table 1: The recurrence interval and conditional probability of the major faults in the Marmara Sea region

Fault No	Length (km)	Slip Rate (mm/yr)	Mw	Recurrence Interval	Probability	
					10 yr	30 yr
F1	31	20	6.8	105	11%	27%
F2	44	20	7.0	135	9%	23%
F3	42	20	7.0	130	9%	23%
F4	51	20	7.1	130	9%	23%
F5	62	20	7.2	147	8%	21%
F6	51	20	7.1	130	9%	23%
F7	20	20	6.6	150	8%	22%
F8	16	20	6.5	67	15%	36%
F9	57	20	7.1	161	7%	20%
F10	20	20	6.6	78	14%	33%
F11	41	20	7.0	130	10%	23%
F12	36	20	6.9	118	10%	25%

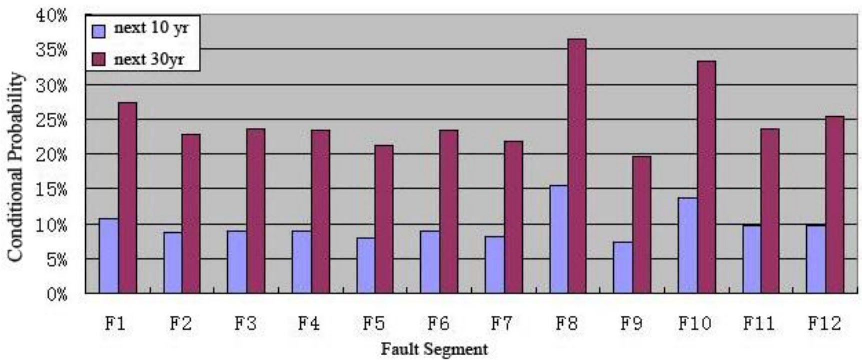

Figure 4: Characteristic earthquake probabilities of major active faults in Marmara Sea region in the next 10yr and 30yr

The results of this document are similar to those of Stein (1997) for the pre-earthquake probability (about 12% of the probability in the next 30 years). Compared with the results of Parsons (2004) (the probability in the next 30 years is about 30%), this document results are significantly small. The main reason is that this document did not consider the impact of the 1999 Izmit earthquake.

The time-dependent probability model (BPT and Logarithmic Normal) has a certain regularity compared with the non-time-dependent probability model (Poisson): when the elapsed time of the characteristic earthquake is smaller than the earthquake recurrence interval, the probability of BPT model and Logarithmic Normal model are larger than those of Poisson model. The results obtained by BPT model and logarithmic normal model are smaller than those of Poisson model when the earthquake elapsed time is larger than the earthquake recurrence interval. The BPT model and the Logarithmic Normal model take into account the accumulation process of the elapsed time and strain energy, while the Poisson model considers that the occurrence of the earthquake is random and independent of the elapsed time.

This document attempts to incorporate GPS data into medium and long-term seismic hazard analysis, which shows some meaningful research prospects. However, the study of the interaction between the cascade rupture and the interaction between faults is needed to be strengthened. In the future, it is necessary to strengthen the application of GPS data in the quantitative study of fault activity parameters and to consider the stress interaction between different faults.

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