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*3. Accuracy of the Determination of Earthquake Epicenter and Origin Time in Turkey.**

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Abstract

The accuracy of the determination of earthquake parameters depends upon the observational errors at the recording stations. The geographical distribution of epicenters and station locations, however, also have large effect on this accuracy.

In the present study the Monte Carlo method is applied to express in quantitative terms the errors inherent in the determination of earthquake parameters in Turkey using the data of the existing seismic network. The results enable us to make conclusion about the quality of existing network and may help in the selection of the location of future seismic stations to improve the accuracy of determination of earthquake focus and origin time.

Introduction

Turkey which belongs to the Alpide seismic belt was attacked by many strong earthquakes during her history. In recent years destructive earthquakes are taking place on the average, at least once a year somewhere in the country causing great damage.

Fig. 1 shows the epicentral distribution of the earthquakes that occurred in the period from 11 A.D. to 1970. Seismicity of the country is rather high along the North Anatolian Fault Zone lying from east to west. Earthquake activity is also high in the Aegean region and Western Turkey. Epicenter concentration can also be seen in the SE part of the country. In comparison with the main seismic regions mentioned above, the Central Anatolia can be designated a region with rather low seismicity.

At present there exist two seismic networks in Turkey. One belongs to the Institute of Physics of the Earth, Technical University of Istanbul, which consists of six seismic stations, and the other to the Kandilli Observatory of Istanbul consisting of more than twelve seismic

* Contribution made by the author during her stay at the ERI, in 1975.

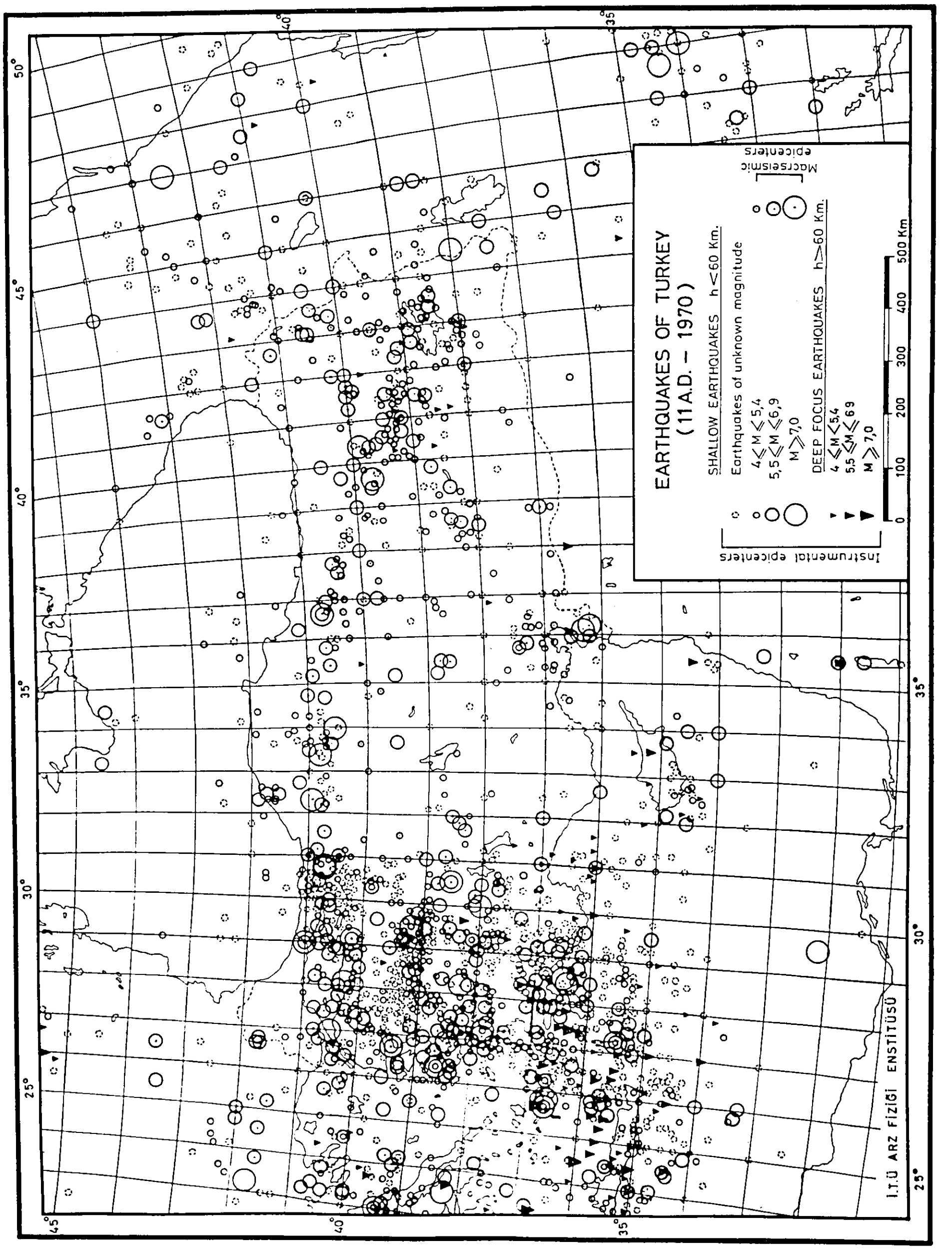

Fig. 1. Epicentral distribution of the earthquakes in Turkey. (From 11 A. D. to 1970)

stations.

The determination of the epicenter location and origin time of an earthquake is usually based upon the arrival times of certain seismic phases at a number of seismic stations. Consequently the accuracy of determination of these earthquake parameters are dependent upon the observational errors at the recording stations. In addition, the geographical distribution of epicenter and station locations also have large effect on the accuracy of earthquake parameters.[1)]

The purpose of the present study is to express the amount of error inherent in the determination of earthquake parameters in Turkey using the data of existing networks by the application of Monte Carlo method.

Formulation of the problem

The observation equation for the errors of epicentral location, hypocentral depth, arrival time and propagation velocity can be expressed in the following form:

$$(X_j - X_0)x + (Y_j - Y_0)y - Hh + D_j v/V + VC_j t = VC_j e_j \qquad (1)$$
$$(j=1, 2, 3, \cdots) .$$

Where

$$D_j = (X_j - X_0)^2 + (Y_j - Y_0)^2 + H^2$$
$$C_j = (D_j)^{1/2}$$

and

j	: index number of each station,
X_j, Y_j	: coordinates of seismic stations,
Y_0, Y_0	: coordinates of the epicenter,
H	: hypocentral depth,
V	: propagation velocity of seismic waves,
e_j	: observational error of arrival times,
x, y, h, t, v	: errors of the location of focus, origin time and the velocity, which result from calculation.

The following assumptions were adopted:

1) The errors x, y, h, t, v are small,
2) stations are on a flat surface,
3) velocity of elastic waves is constant,
4) observational errors, e_j, follow Gaussian distribution with mean value 0.

Since the size of the area under consideration is not very large, geographical coordinates were transformed into Cartesian coordinates with the origin at the center of the region and the axes x(eastward), y(northward) and z(downward). The x and y coordinates of a point (α, β) which refer to the center of the region (α_0, β_0) were given as follows:

[1)] Y. SATÔ and D. SKOKO, "Optimum Distribution of Seismic Observation Points II," *Bull. Earthq. Res. Inst.*, 43 (1965), 451-457.

$$x=1.858\ (\beta-\beta_0)\cos[(\alpha+\alpha_0)/2]$$
$$y=1.850\ (\alpha-\alpha_0)$$
$$(\alpha,\ \alpha_0,\ \beta,\ \beta_0 \text{ in min})$$

Calculation

Calculations are carried out for three cases:

i) First, only the data of the six stations that belong to the network of the Institute of Physics of the Earth, Technical University of Istanbul, were used. The names and the coordinates of these stations are given in Table 1.

Observational errors were allotted to each of these stations from a random number series and the equation (1) was solved using the least square method for a certain epicenter location. A similar calculation is repeated for the same seismic network as many as 200 times adopting different sets of random errors and the standard deviation was calculated for r, h, t and v (r is the vectorial sum of the errors x and y).

The numerical assumptions in the calculations are:

Standard deviation of the errors e_j	$=0.1$ sec
Hypocentral depth	$=30$ km
Wave velocity	$=6$ km/sec

The epicenters were placed at an interval of 1° both in latitude and longitude. Altogether there were 160 epicenters. The calculated values, based on the Monte Carlo method, are shown on the maps. Figs. 2 and 3.

For this case the smallest values of the errors are about

$$(\Delta R)_{\min}=0.62\text{ km} \quad \text{and} \quad (\Delta T)_{\min}=0.05\text{ sec}$$

and the mean values are about

Table 1. Seismic stations of the network belonging to Institute of Physics of the Earth, Technical University of Istanbul.

Station		Latitude				Longitude			
Istanbul	(IST)	41°	02′	44″	N	28°	59′	45″	E
Çine	(CIN)	37	36	00		28	05	12	
Kastamonu	(KAS)	41	22	18		33	46	00	
Ankara	(ANK)	39	55	00		32	49	00	
Erzurum	(ERZ)	39	54	54		41	16	36	
Raman	(RAM)	37	48	52		41	07	22	

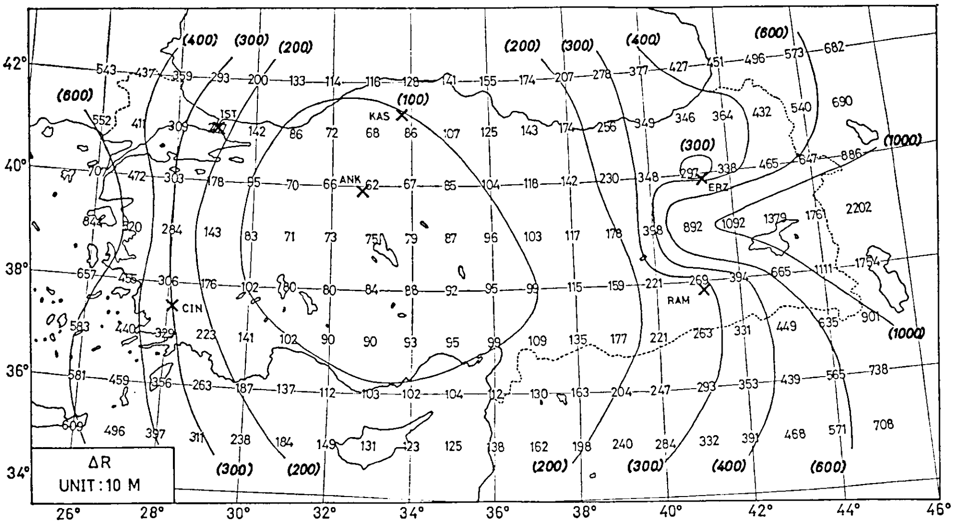

Fig. 2. Distribution of ΔR (error of epicenter location) when there are only six stations given in Table 1.

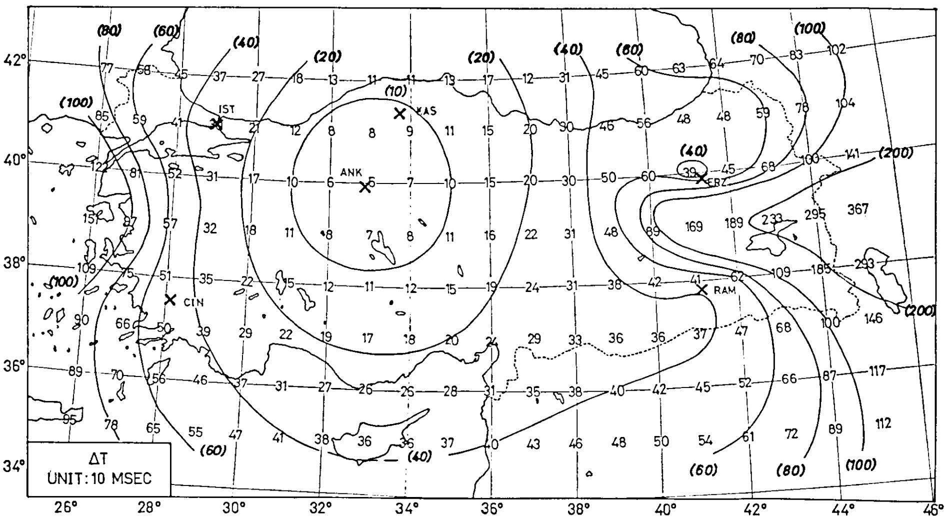

Fig. 3. Distribution of ΔT (error of origin time) when there are only six stations given in Table 1.

$$(\Delta R)_{\mathrm{mean}} = 3.3\ \mathrm{km} \quad \text{and} \quad (\Delta T)_{\mathrm{mean}} = 0.54\ \mathrm{sec}$$

According to the calculation, the errors are small in the central part of the country where the seismicity is comparatively low, whereas areas of higher seismicity, such as the western and the eastern part of the country, have large errors. The amounts of the errors reach $\Delta R=$ 10 km and $\Delta T=2$ sec at the east and $\Delta R=6$ km and $\Delta T=1$ sec at the west of the area.

Table 2. Seismic stations of the network of Kandilli Observatory of Istanbul.

Station		Latitude	Longitude
Dursunbey	(DRB)	39°34.85′ N	28°38.23′ E
Ezine	(EZN)	39 49.53	26 19.53
Gölpazari	(GPA)	40 17.20	30 18.63
Mengen	(MGN)	40 55.42	32 10.84
Demirköy	(DMK)	41 49.30	27 45.45
Altintaş	(ALT)	39 03.30	30 06.63
Izmir	(IZM)	38 23.86	27 15.75
Bucak	(BCK)	37 27.62	30 35.33
Elmali	(ELL)	36 44.90	29 54.50
Yerkesik	(YER)	37 08.08	28 16.96
Keban	(KEB)	38 47.86	38 43.66
Edincik	(EDC)	40 20.80	27 51.81

The distribution of these quantities over the whole region gives a general idea of the errors caused by the specific network and enables us to make conclusion about the quality of the network. Quantitative study of the errors shows us the weak point of the seismic network of six stations.

ii) For diminution of the errors it is necessary to make use of the data at other seismic stations, too. For this purpose, the data from 12 seismic stations that belong to the seismic network of the Kandilli Observatory of Istanbul are also taken into consideration and same calculations are repeated for, in total, 18 stations.

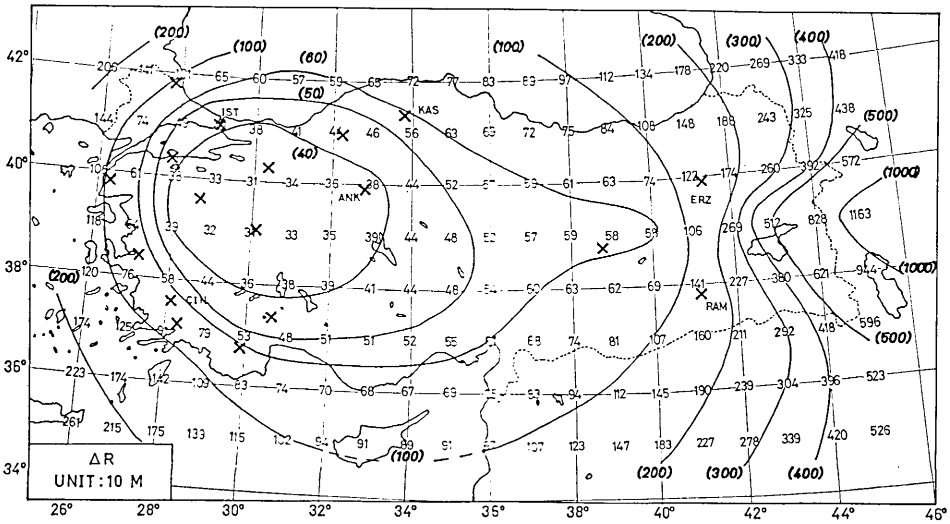

Fig. 4. Distribution of ΔR (error of epicenter location) when there are 18 stations given in Tables 1 and 2.

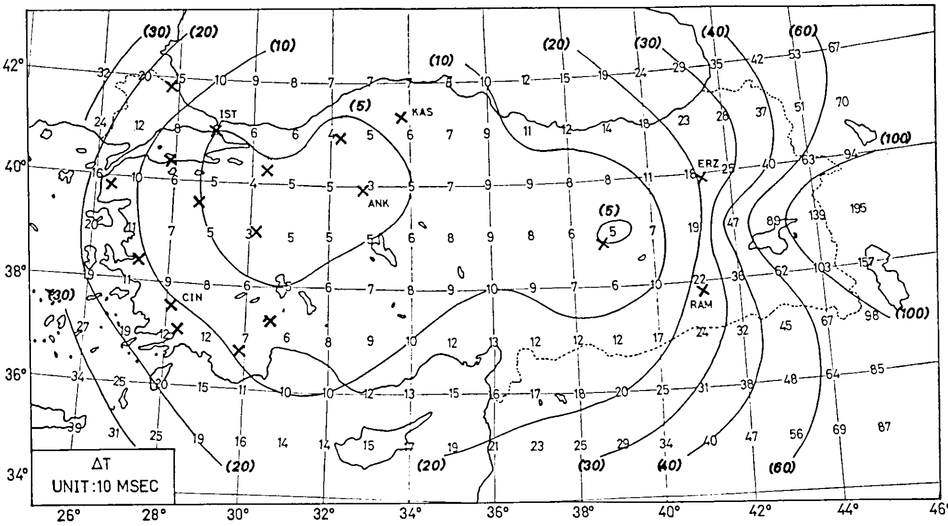

Fig. 5. Distribution of ΔT (error of origin time) when there are 18 stations given in Tables 1 and 2.

The coordinates of the new additional stations are given in Table 2. And the results are shown in Figs. 4 and 5.

From the comparison of two cases, i) and ii), it is clear that the area with small errors is considerably increased. For instance, the area with $\Delta R \leqq 1$ km and $\Delta T \leqq 0.1$ sec covers almost the entire country, except the eastern part where the errors are still high, but decreased about 50% in comparison with the case i).

For this case the smallest values of the errors are

$$(\Delta R)_{\min} = 0.31 \text{ km} \quad \text{and} \quad (\Delta T)_{\min} = 0.03 \text{ sec}$$

and the mean values are

$$(\Delta R)_{\text{mean}} = 1.51 \text{ km} \quad \text{and} \quad (\Delta T)_{\text{mean}} = 0.24 \text{ sec}$$

The mean values, for this case, are 54% and 56% less for ΔR and ΔT respectively.

The addition of the data of the new network has a great advantage with regard to the accuracy of epicenter location and origin time, especially when the earthquakes occur at the central or western part of Turkey.

iii) The data from the nearby foreign stations, such as Athens (ATH, 37° 58′ 20″ N; 23° 43′ 00″ E), Tabriz (TAB, 38° 04′ 03″ N; 46° 19′ 36″ E) and Ksara (KSA, 33° 49′ 25.6″ N; 35° 53′ 30″ E), together with those of the local network of six stations (Table 1), can also be successfully used for the determination of the earthquake parameters

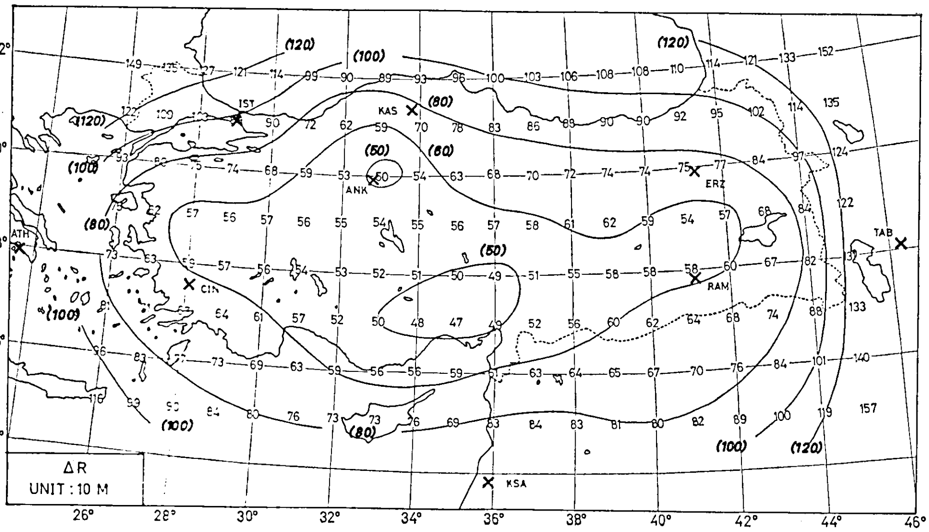

Fig. 6. Distribution of ΔR when there are 9 stations. (Athens, Ksara, Tabriz and local stations given in Table 1).

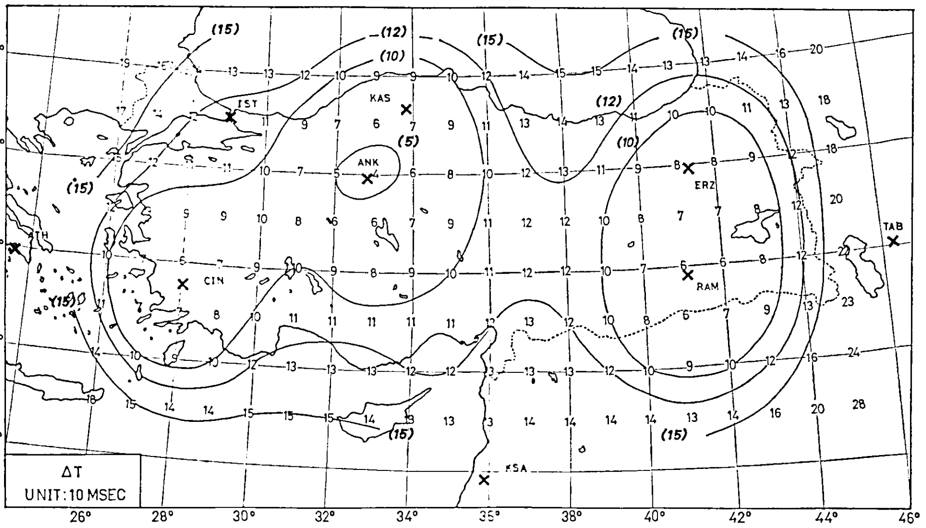

Fig. 7. Distribution of ΔT when there are 9 stations. (Athens, Ksara, Tabriz and local stations given in Table 1).

when the magnitude of the earthquake is large enough to be recorded at these three stations.

The results are shown in Figs. 6 and 7. The smallest errors are:

$$(\Delta R)_{\min} = 0.47 \text{ km} \quad \text{and} \quad (\Delta T)_{\min} = 0.04 \text{ sec}$$

And the mean errors are:

$$(\Delta R)_{\text{mean}} = 0.79 \text{ km} \quad \text{and} \quad (\Delta T)_{\text{mean}} = 0.11 \text{ sec}$$

In comparison with the results of case i), we can see a decrease of about 76% and 80% for mean errors ΔR and ΔT respectively.

The use of these foreign stations in addition to the six local ones improves the weak points of the existing network and enables us to calculate earthquake parameters with much better accuracy over the whole region. The area with small errors of epicenter location ($\Delta R \leqq 1$ km) and origin time ($\Delta T \leqq 0.12$ sec) is the largest, entirely covering the country.

Conclusion

Actual determination of the epicenter and origin time of strong earthquakes is generally made by using data from many stations distributed all over the world and the inherent errors in such determinations will, in general, be low. The calculations of earthquake parameters of local and small shocks, however, are done with data mainly obtained from the local network. The present investigation gives a clue to the estimation of errors inherent in such determinations. Besides, the results of the present study, by outlining the nature of weakness of the existing networks of seismic stations, may help in the selection of desirable locations for future seismic stations in Turkey.

Acknowledgments

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3. トルコにおける地震の震源および発震時決定の精度

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地震観測により，地震の震源，発震時等，地震に関する常数をきめる場合，観測点での測定誤差がその精度を左右するが，この他にも，観測点の地理的分布と震源位置との関係が問題となる．

本報告では，佐藤泰夫等の研究にならい，モンテカルロ法を用いて，現在のトルコ国における地震観測網による，震源および発震時決定精度の検討をおこなった．これは将来における精度向上のための観測網整備について重要な示唆をあたえるものである．