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46. *Accuracy of the Determination of Earthquake Source Parameters as Determined by Monte Carlo Method.*

Observation on Indian Network.

By Dragutin SKOKO,
Department of Geophysics, Zagreb University,
Zagreb, Yugoslabia;
Yasuo SATÔ,
Itsue OCHI,
Earthquake Research Institute
and
Tarun Kanti DUTTA,
International Institute of Seismology and Earthquake Engineering,
Tokyo.*

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Introduction

Determination of earthquake source parameters are usually based upon arrival time recordings of certain seismic phases observed at a number of seismograph stations. Consequently the accuracy of determination of those parameters are dependent not only upon the observational errors at the recording stations but also upon the geographical distribution of epicentre and station locations. The latter factor plays an important and significant role in the measure of errors expected in the determination of parameters such as epicentre location, focal depth, origin time and wave velocity. The purpose of the present study is to apply the Monte Carlo method for expressing in quantitative terms,[1] the amount of error inherent in the determination of earthquake source parameters in the Indian region, for all determinations done with the help of data from 15 Indian seismological stations only. (See Fig. 1) On the basis of such

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*) On leave from Regional Research Laboratory, Jorhat, India.

[1] E. HERRIN, "Errors in Epicenter Locations," *Symposium of Geophysical Theory and Computers*, Moscow, June, 1963.

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

determinations it then becomes possible to delineate different epicentral tracts of the region with varying degrees of inherent errors of epicentral location.

It is hoped that this study will supply the clue for the location of future seismograph stations in the area with a view of yielding optimum results for epicentral determinations of earthquakes in this part of the globe.

Formulation of the problem

The names of Indian seismological stations, their latitudes, longitudes

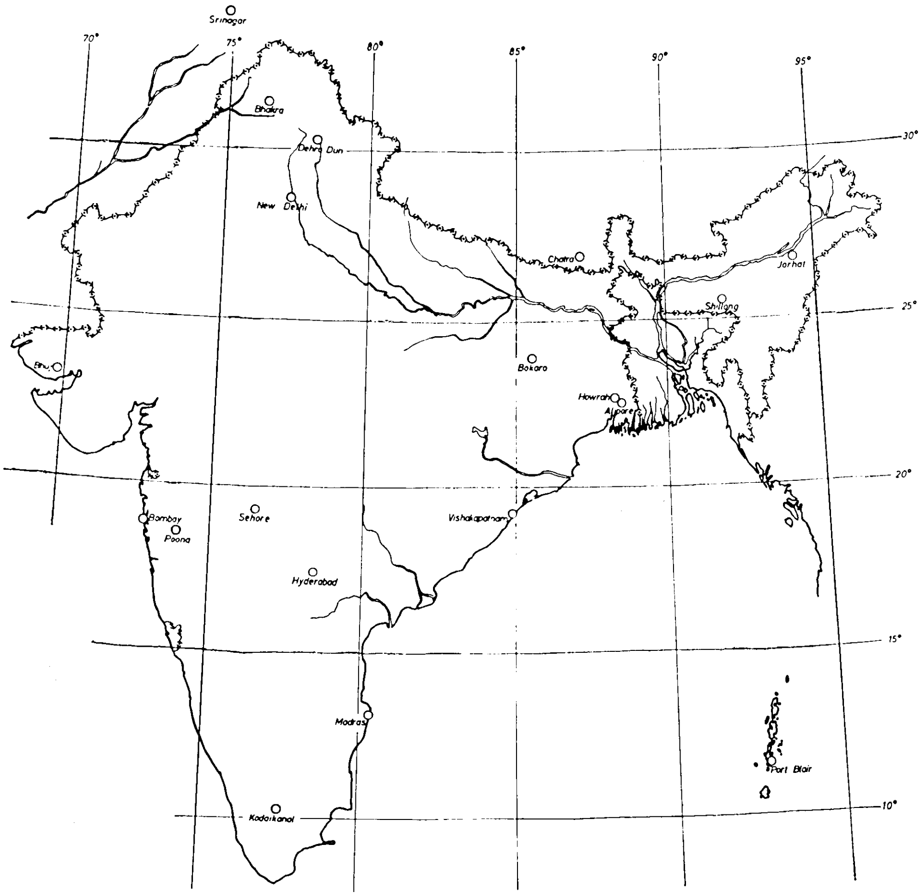

Fig. 1. Map of India with seismic stations.

Table 1. Seismic stations in India

	ABRV.	STATION	LATITUDE (NORTH) DEG MIN	LONGITUDE (EAST) DEG MIN	ELEVATION METER	INSTRUMENT
1	JHT	JORHAT (TOCLAI)	28 45	94 45		WOOD-ANDERSON (EW)
2	SHL	SHILLONG (WWSSS)	25 34	91 53		MILNE-SHAW (NS) BENIOFF (Z),(EW),(NS) (SHORT PERIOD SYSTEM) PRESS-EWING (Z),(EW),(NS) (LONG PERIOD SYSTEM) WOOD-ANDERSON (EW),(NS) SPRENGNETHER (EW) WENNER ACCELEROGRAPH SMAC ACCELEROGRAPH
3	CHT	CHATRA	25 50	87 10	151	MILNE-SHAW (EW),(NS) WOOD-ANDERSON (EW),(NS) BENIOFF (Z) SHORT PERIOD WENNER ACCELEROGRAPH
4	ALP	ALIPORE (CALCUTTA)	22 32	88 22		MILNE-SHAW (EW) WOOD-ANDERSON (NS) OMORI-EWING (EW),(NS)
5	HOW	HOWRAH (CALCUTTA)				BENIOFF (Z),(EW),(NS) (SHORT PERIOD SYSTEM)
6	BOK	BOKARO	23 50	85 48		SPRENGNETHER (EW) WOOD-ANDERSON (EW),(NS) MILNE-SHAW (EW),(NS)
7	VIZ	V1AZ (V1SHAKAPATNAM)	18 07	83 27		SPRENGNETHER (EW),(NS) WOOD-ANDERSON (EW),(NS)
8	NDL	NEW DELHI (WWSSS)	28 31	77 13	207	BENIOFF (Z),(EW),(NS) (SHORT PERIOD SYSTEM) PRESS-EWING (Z),(EW),(NS) (LONG PERIOD SYSTEM) WOOD-ANDERSON (EW),(NS) MILNE-SHAW (NS) SPRENGNETHER (EW)
9	PNA	POONA	18 32	73 51	560	MILNE-SHAW (NS) WOOD-ANDERSON (EW) SPRENGNETHER (Z)
10	BMB	COLABA (BOMBAY)	18 54	72 40		MILNE-SHAW (EW),(NS) SPRENGNETHER (EW) BENIOFF (Z) SHORT PERIOD
11	HYD	HYDERBAD	17 25	78 27	536	MILNE-SHAW (EW),(NS)
12	MDS	MADRAS	13 00	80 11	15	SPRENGNETHER (EW)
13	KDK	KODAIKANAL	10 14	77 29	2345	MILNE-SHAW (EW)
14	DDN	DEHRA DUN	30 19	78 02	682	WILSON-LAMISON(Z) SHORT PERIOD WOOD-ANDERSON (EW),(NS) MILNE-SHAW (EW),(NS)
15	PBL	PORT BLAIR	11 49	92 43		MILNE-SHAW (EW) WOOD-ANDERSON (EW),(NS) BENIOFF (Z) SHORT PERIOD
16	SHR	SEHORE	23 10	77 08		WOOD-ANDERSON (EW),(NS)

and elevations, together with instrumental setup at each station, are shown in Table 1. As will be seen from this table, each station is equipped with different kinds of seismographs, consequently the errors at each of these stations for the recording of earthquake phase will be different. However, for the sake of simplicity we assume that the observational accuracy of all these stations is the same and the error follows the Gaussian distribution with the mean value 0 and dispersion ε^2.

If ε is small, the equation that connects the error of different parameters, the location of seismograph station and the travel time of seismic wave, can be obtained, after a little mathematical calculation, in the following form:

$$\left(\frac{\partial f}{\partial \Delta}\right)_k \cos\theta_k \cdot \Delta R \cos\theta + \left(\frac{\partial f}{\partial \Delta}\right)_k \sin\theta_k \cdot \Delta R \sin\theta + \Delta T = \varepsilon_k \tag{1}$$

where

$f(\Delta)$	travel time.
θ_k	azimuthal angle of station k, the true epicentre being the origin.
ΔR	distance between true and calculated epicentres.
θ	azimuthal angle of calculated epicentre.
ΔT	error of the occurrence time of the earthquake.
ε_k	observational error of the arrival time at each station.
k	index number of the station.

Now since $f(\Delta)$ gives the travel time, $(\partial f/\partial \Delta)^{-1}$ is the apparent velocity. It is however not possible to determine this value unless we actually know the function $f(\Delta)$. However as the above equation is only intended to be used for the brief estimation of the error amount, irrespective of complication introduced in the actual determinations by the nature of complexities of travel times, any simple and plausible assumption for the travel time appears justified in view of the restricted nature of the problem that is covered by the present investigation. On the basis of such simplifying assumptions, the above equation was solved for the three unknowns; namely $\Delta R \cos\theta$, $\Delta R \sin\theta$ and ΔT for a homogeneous medium. Thus the results of the present series of computations do not take into account the effect of focal depths and the heterogenity of the medium. The errors introduced due to these factors will be in addition to the computed results of the present study.

Calculation

For the purpose of actual computation, epicentre locations are assumed at intervals of 1°15′ both in longitude and in latitude. There are 319 epicentres for which computations were made and these are illustrated in Figs. 2 and 3. For each assumed position of an epicentre the coefficients of the left hand side of the equation (1) were first determined. Right hand side terms of the equation were determined by giving values out of a series of normally distributed random numbers with mean value zero and standard deviation 0.1 second. The velocity was assumed to be 7 km/sec. For each epicentre determination there are fifteen observation equations corresponding to the same number of seismograph stations from

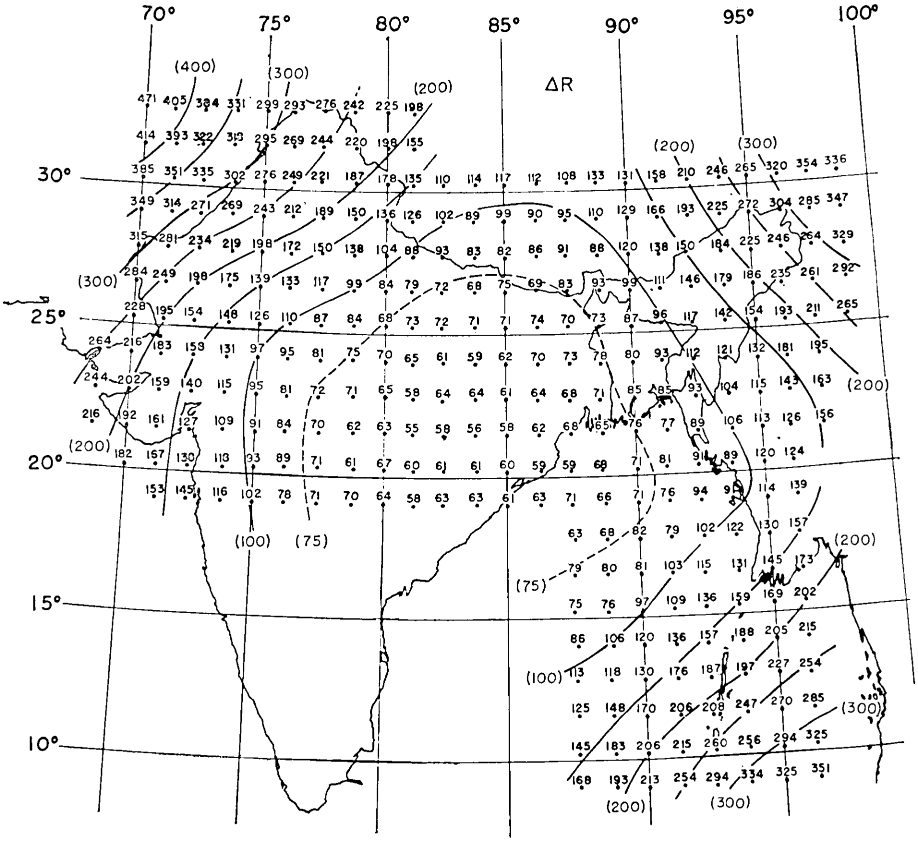

Fig. 2. ΔR, Error of epicentre locations. Unit: 7.5 m.

which data for the calculation are supplied. From these equations, the normal equations, with three unknows $\Delta R\cos\theta$, $\Delta R\sin\theta$, and ΔT are first obtained and then solved.

This procedure gives only a single set of answers corresponding to a certain distribution of observational errors. Similar calculations were repeated 200 times in order to get a smoothed result, which shows the general feature of the error, in source parameters of earthquakes in the region covered by the present study, as functions of epicentre locations.

Result

Figures 2 and 3 show ΔR, the error of epicentre estimation, and ΔT, the error of origin time, as functions of epicentral location in different

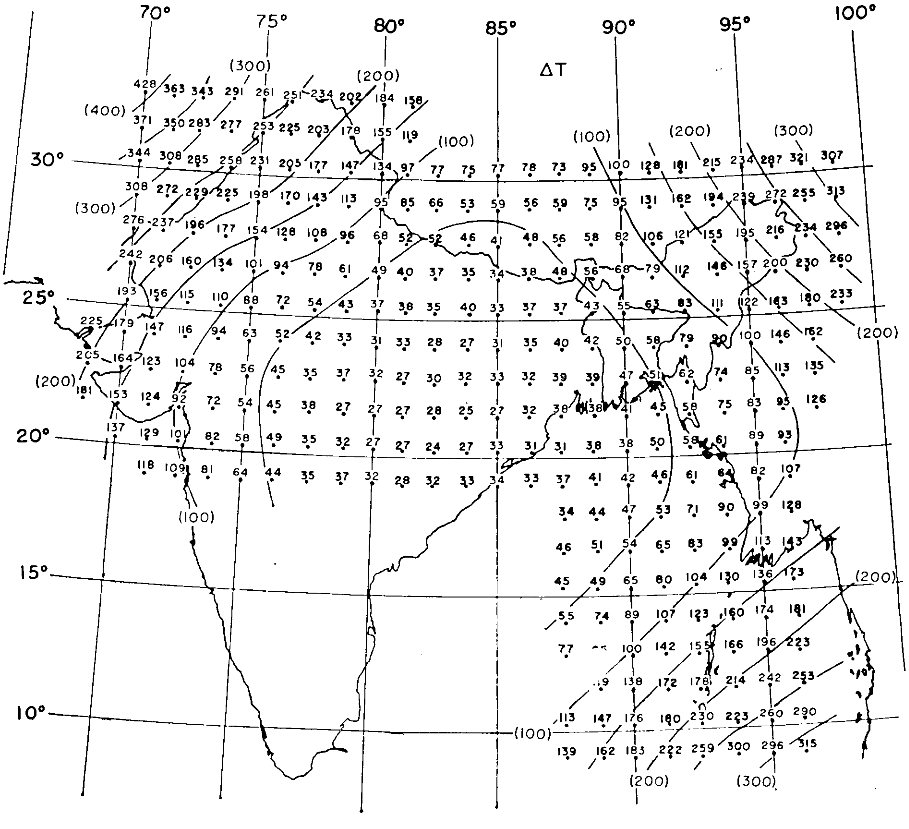

Fig. 3. ΔT, Error of origin times. Unit: 1.07 msec.

parts of the region. Contour lines are drawn based on the above values, indicating different zones of error characteristics for the determination of epicentres and origin times of earthquakes in the regions. From these two diagrams we can get some idea on the accuracy of the determination of earthquake parameters based on observations recorded by Indian stations only.

Actual determination of the epicentre and origin time of major shocks are 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 source parameters of local and small magnitude shocks, however, are done with data mainly obtained from local network and the present investigation gives a clue to the magnitude of errors inherent in such determinations. Besides, the results of the present investigation by outlining the nature of weakness of the existing network of seismological observatories in India may help in the selection of desirable locations for future seismological stations in India and obtain optimum results out of the network of observational facilities.

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46. 発震時・震央等の決定精度をモンテ・カルロ法によって推定すること

インドに於ける観測の場合

Department of Geophysics Zagreb University　Dragutin SKOKO
地震研究所　佐藤泰夫
越智五江
建築研究所国際地震工学部　Tarun Kanti DUTTA

1）　地震の発震時・震央等の決定精度は，観測所の地理的分布および地震の起った場所によって大きな影響をうける．そして上記諸量を計算する際の誤差の期待値は，観測所の位置を固定して考えれば，震央の関数として定まって来る．この種の問題の一つとして，インドにある地震観測所のデータを用いて，この地方に起った地震について解析を行うならば，どの様な結果（誤差の地理的分布）が得られるかを調べて見た．

2）　方法としては，現存するインドの15の観測所のP波発震時を用いて計算する事とし，その発震時に，観測誤差として平均値0，標準偏差0.1秒，正規分布の乱数を分布させてみた．こうした誤差を含むデータをもとにし，最小二乗法によって，震央および発震時を計算して，真の値と比較した．この様な操作はその時たまたま使用した乱数の値の組合せに強く影響されるので，約200組の同様な計算を行い，2乗の平均値をとって誤差の期待値とした．

3）　インドの観測所の地図は第1図に，計算の結果は第2図および3図に示してある．これらの図には誤差の値の等高線が書き込まれているから，これによって大体の傾向を知ることができるであろう．地震の起ることのまれなインド中央部では誤差が小さくなっているのに反して，地震活動の盛んな周辺部ではその値が比較的に大きくなっていることがわかる．たゞし大地震の場合には世界各地の観測が使用されるから，結果はことなって来るであろう．上の結果は又新しい観測所の位置を定める際の参考になるであろう．