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Determining earthquake epicentre from a single 3-component seismological station

M. TAID, A. C. LYNGDOH† and A. K. GHOSE*

Central Seismology Observatory, India Meteorological Department, Shillong, India

**Seismology Division, India Meteorological Department, New Delhi, India*

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†**e mail : lyngdoh_ac@rediffmail.com**

सार – इस अध्ययन में शिलांग स्थित केन्द्रीय भूकंप वेधशाला के एकल स्टेशन से विश्वव्यापी मानकित भूकम्प लेखी संजाल (डब्ल्यू. डब्ल्यू. एस. एस. एन.) के बेनीऔफ लघु अंतराल भूकम्प लेखी द्वारा पृथ्वी के गति के तीन अवयवों के पंजीकरण द्वारा त्रिकोणमितीय विधि से भूकम्प के अधिकेन्द्र के निर्धारण का प्रयास किया गया है। त्रिकोणीय विधि, विश्वव्यापी मानकित भूकम्प लेखी संजाल (डब्ल्यू. डब्ल्यू. एस. एस. एन.) के भूकम्प अभिलेख के समतल अवयवों पर पंजीकृत तरगों के विस्तार के अनुपात द्वारा प्राप्त दिककोण पर आधारित हैं। इस विधि की यथार्थता जानने के लिए भारत मौसम विभाग, भूकम्पीय संजाल, नई दिल्ली तथा एकल स्टेशन अर्थात केन्द्रीय भूकम्प वेधशाला शिलांग द्वारा निर्धारित भूकम्प अधिकेन्द्र की तुलना की गयी है। भूकम्पीय संजाल, नई दिल्ली एवं केन्द्रीय भूकम्प वेधशाला शिलांग द्वारा प्राप्त भूकम्प अधिकेन्द्रीय परिवर्तन में तुलनात्मक दृष्टि से आंचलिक भूकंपों की तुलना में स्थानीय भूकम्पों में थोडा परिवर्तन दिखता है। इसमें केन्द्रीय भूकंप वेधशाला शिलांग आधार स्टेशन हैं। खासकर शिलांग पठार में भूकंप अधिकेन्द्रीय परिवर्तन की विशेषता कम से कम देखी गयी है। स्थानीय एवं आंचलिक दोनों भूकंप की घटनाओं के लिए भूकंप के अधिकेन्द्र मजबूत सह संबंध को देखा गया हैं।

ABSTRACT. An attempt has been made in this study to determine the epicentres by trigonometrical method from a single station using the three components of the ground's motion recorded by the Benioff Short Period Seismograph of the World Wide Standardized Seismograph Network (WWSSN) at Central Seismological Observatory (C.S.O.), Shillong. The trigonometrical method is based on the angle of bearing obtained from the ratio of the amplitudes of waves recorded on the horizontal components of the WWSSN seismograms. A comparison of recorded epicentres from the I.M.D. Seismological Network of Seismo, New Delhi with that of a single station *i.e.*, C.S.O., Shillong has been made to estimate the accuracy of the method. The characteristics of the epicentral variations obtained from the Seismological Network of Seismo, New Delhi with that of C.S.O., Shillong are relatively small for local earthquakes compared to regional earthquakes with C.S.O., Shillong as the reference station. The characteristics of the epicentral variations particularly in the Shillong plateau are observed to be minimum. Strong correlations of epicentres are observed for both local as well as regional earthquake events.

Key words – Local and regional events, NE India, Epicentre determination.

1. Introduction

Locating the epicentre of an earthquake event as soon as it is recorded at a particular station is an utmost priority for providing earthquake information. This information is very important to the decision making authorities in a way that they can identify the site, district, region etc. in which the earthquake has occurred and thereby enabling them to plan and dispatch their relief operations accordingly.

At present, IMD is maintaining a network of 51 digital and analog seismological observatories in the country. Out of these, there is a network of 29 Seismological stations operating in digital mode. As far as the stations in the Northeastern part of India are concerned, C.S.O., Shillong is monitoring the earthquake activity with the analog World Wide Standardized Seismograph Network (WWSSN) Short Period and Long Period (SP & LP) along with a 3-component digital broadband seismograph (B.B.S).

The nearest digital seismological stations to C.S.O., Shillong are Kolkata and Bokaro at a distance of ~ 500 km away from Shillong (Fig. 2). After upgrading the 29 digital stations to provide wave form data in real time mode to the Central Receiving Station (C.R.S) at New Delhi, earthquakes of magnitude 3.0 can be located almost for the entire country except at some bordering regions of Rajasthan, Gujarat, Arunachal Pradesh and north part of J&K [(Srivastava *et al.*, (2005)]. This poses a problem since C.S.O., Shillong is the only digital station in the NE region. As and when an earthquake of magnitude less than 3.0 occurs in the NE region, the C.R.S at New Delhi can download only the data recorded at C.S.O., Shillong since the other stations nearest to NE region *e.g*., Kolkata and Bokaro do not show any trace of the record or if recorded, the trace would be insignificant.

In view of the above, the method of determining the epicentre by trigonometrical method from a single station can be analysed for its usefulness in this study.

There have been many instances in which very localised felt shocks have been picked up by the sensitive instruments of C.S.O., Shillong only. Even though the direction and the distance can be obtained immediately at a glance from the seismograms, it is necessary to get the location of the epicentre with a reasonable degree of accuracy from a single station. Here we propose to determine the epicentres by trigonometrical method from a single station with a reasonable degree of accuracy using the 3-component of the ground's motion recorded by the Short Period Seismographs of the WWSSN at C.S.O., Shillong.

Generally, to determine an epicentre, data from at least three stations are required to locate the epicentre. Mathematically, the problem is solved by setting up a system of linear equations, one for each phase. A model of the crustal velocities under the seismic network is required to calculate the travel times of waves from an earthquake at a given depth to a station at a given distance. The system of linear equations can be solved by the method of least squares which minimizes the sum of the squares of the differences between the observed and calculated arrival times.

The recorded amplitude of an earthquake should not only depend on magnitude and distance, but should also vary with physical conditions along the path and ground conditions at the recording stations as well as with the characteristics of the seismograph used. Moreover, in records of earthquakes, there are strong directional effects particularly due to source mechanism.

C.S.O., Shillong is one of the permanent stations in the WWSSN since 1965 and has been equipped with the three-component Benioff short period seismograph and the three-component Press Ewing Long period seismograph.

The Benioff short period seismograph with inbuilt electronic devices consisting of three components is the most adequate instrument to serve the purpose of this study.

The Benioff short period seismograph is a visible recording system which records ground motions of periods less than 2 seconds along Vertical (Z), East-West (E-W) and North-South (N-S) directions. The parameters of the Benioff short period seismograph are described by the amplification factor 100K, free period of the seismometer (Sensor) 1.0 second and h (damping factor) 0.7 respectively. This instrument gives better records for earthquakes within the range of 1000 km. The Benioff short period seismograph is designed with a peak dynamic magnification in the period range up to 1 second for detection of all seismic waves from local and regional events and also teleseismic waves.

The Press-Ewing Long period seismograph is again a visible recording system which records 3-component ground motions of periods between 10 to 30 seconds. The parameters of the Press-Ewing Long period seismograph are described by the amplification factor 1.5K, free period of the seismometer (Sensor) 15 seconds and h = 0.7. This seismograph therefore records distant earthquakes (i.e. >1000 km) comparatively better. The recording mechanism is the same as that of the short period seismograph.

According to Bormann (2002), digital data are superior to analog data in many respects, both for advanced routine analysis and even more for scientific research. However, for the rare big and thus unique earthquakes, in areas with significant seismic risk, the preservation and comprehensive analysis of these classical analog and historic seismograms will remain of the utmost importance for many years. In this context, an attempt has been made here to determine the epicentres from a single station using analog data.

A number of studies were made worldwide to determine the epicentres from a single station using different methods both from analog and digital data respectively. However a comparison for the accuracy of the epicentres through a single station, the trigonometrical method has been compared quantitatively with those obtained through a network of stations.

2. Methodology

This study is aimed at finding a method to determine an earthquake epicenter by exclusively using single

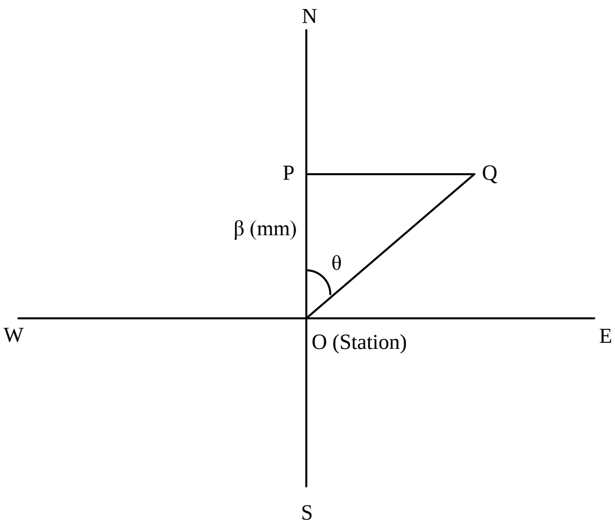


Fig. 1. Determining epicentre (Q) of an earthquake by the trigonometrical method based on angle of bearing θ and ratio of amplitudes α and β of the first impulsive longitudinal waves recorded on the N-S and E-W horizontal components of WWSSN seismograms at C.S.O., Shillong with dilatation on vertical component

WWSSN station data. As such a good number of events (except clipped) were taken from the WWSSN SP seismograms. No digital waveforms were introduced in this study.

However in comparison with a network of stations, this method being confined to single station data, the accuracy may be comparatively less. But, the purpose of this study is to test the applicability of a single WWSSN station in locating epicentres. However, the limitation of this study is that when the trace amplitudes of P phases reach the maximum limit (Clipped) on the horizontal components of the seismograms, the events were not considered for this study.

The trigonometrical method used in this study is based on the angle of bearing or back azimuth. The bearing angle 'θ' measured in degrees, can be calculated from the ratio of amplitudes of the first impulsive longitudinal waves recorded on the N-S and E-W horizontal components of SP seismograph as shown in Fig. 1.

In the vertical component, the direction of the ground motion of the first impulsive P- wave will be away from the epicentre if it is compressional (upward) and towards the epicentre if it is dilatational (downward). The direction of the epicentre obtained from the horizontal components will be the same if the vertical component shows dilatation; but direction is opposite if the vertical component shows compressional.

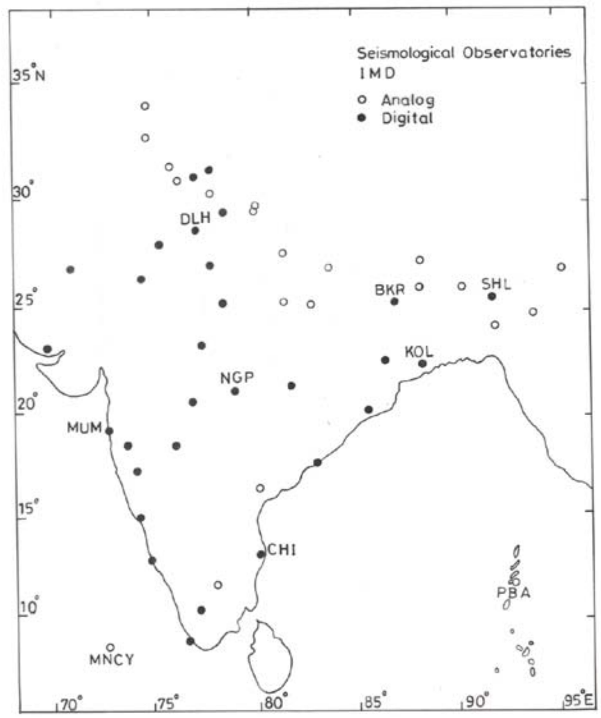


Fig. 2. Seismological observatories of the existing national network of IMD, recording earthquake of magnitude 3.0

Let α, β and γ be the amplitudes of the first P-wave motion in the east, north and vertical components. α is positive if the motion is eastward, β is positive if the motion is northward and γ is positive if the motion is downward. Let us first consider that α, β and γ are positive (Fig. 1). The angle of bearing or epicentral direction N θ° E from the station is

$$\theta = \tan^{-1}(\alpha / \beta) \qquad (1)$$

The epicentral distance OQ is obtained from the difference of P and S waves at the recording station. Thus from Fig. 1,

$$PQ = OQ * \sin\theta, \; OP = OQ * \cos\theta \qquad (2)$$

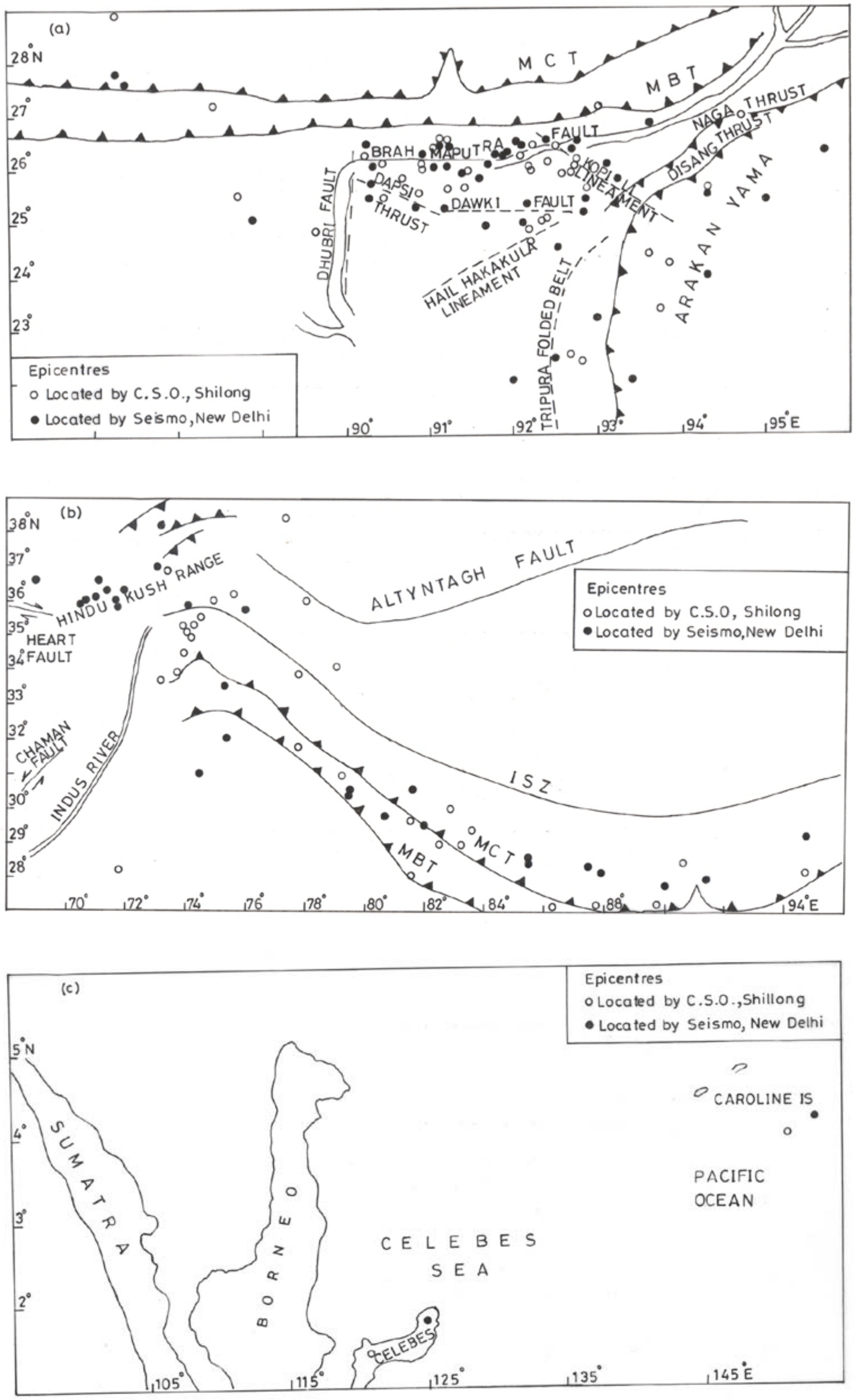
and we can obtain epicentre latitude and epicentre longitude as

$$\text{Epicentre latitude} = \text{Station latitude} + OP \qquad (3a)$$

$$\text{Epicentre longitude} = \text{Station longitude} + PQ * A \qquad (3b)$$

Where A is a longitudinal correction along the latitudes of the station. We know 1° of epicentre distance = 111.111 km while arc of 1° parallel to the latitude of Shillong is 100.487 km (Richter, 1958). Thus,

$$A = 111.111 / 100.487 = 1.1057.$$



Figs. 3(a-c). Epicentral map of (a) near events, (b) regional events and (c) teleseismic events

For general signs of α, β and γ, we obtained,

$$\theta = \tan^{-1} \; (| \alpha | / | \beta |) \quad (4)$$

We evaluate PQ and OP from Eqn. (2) and we get,

Epicentre latitude = Station latitude + sign (β) * sign (γ) * OP (5a)

Epicentre longitude = Station longitude + sign (α) * sign (γ) * PQ * A (5b)

In the example of 2001, August 12, γ is negative, α = -2.2mm, β = 5.5mm.

Hence, $\theta = \tan^{-1} (0.4) = 21.8°$. We have OQ = 1.08°; thus PQ = 0.4° and OP = 1.0°

From Eqn. 5(a)

Epicentre latitude = Station latitude +*(+)*(-) * 1.0°
= 25.56° – 1.0° = 24.56°

since sign (β) is positive and sign (γ) is negative and from Eqn. 5(b)

Epicentre longitude = Station longitude
+ * (-) * (-) * (0.4) * (1.1057)

= 91.85° + (0.4°) * (1.1057) = 92.29°

since sign (α) is negative and sign (γ) is negative.

3. Data and analysis

The data for this study are taken from the period 1998 to 2005 and are collected from the horizontal components of Short Period Seismograms of the WWSSN at C.S.O., Shillong and the seismological network of Seismo, New Delhi (Fig. 2). There are 37 near/ local events, 27 regional events and 3 teleseismic events with respect to C.S.O., Shillong that are taken for this study.

The Karl Pearson Coefficient Correlation (KPCC) is calculated for near/local events and regional events recorded by C.S.O., Shillong and the seismological network of Seismo, New Delhi.

The KPCC is given by

$$r = \Sigma\, (X' * Y') / \sqrt{(\Sigma X'^{\,2} * \Sigma Y'^{\,2})} \quad (6)$$

Where X' and Y' are the deviated values of the latitude (or longitude) of epicentres obtained respectively by the seismological network of Seismo, New Delhi and by C.S.O., Shillong after subtracting the corresponding arithmetic mean values. The arithmetic mean X_m and Y_m are calculated from the 37 near/local events and 27 regional events.

TABLE 1

Variations of KPCC (*r*) and regression coefficients

Local/Regional events	Longitude/ Latitude	*r*	Regression coefficient
Local events	Longitude	0.995	0.895
	Latitude	0.991	0.881
Regional events	Longitude	0.995	0.873
	Latitude	0.972	0.938

4. Results and discussions

The Figs. 3(a-c) show the epicentres obtained from C.S.O., Shillong and the seismological network of Seismo, New Delhi. Fig. 3(a) shows the epicentral map of near/ local events *i.e.*, those nearer with respect to C.S.O., Shillong and Fig. 3(b) shows the epicentral map of regional events. Fig. 3(c) shows the epicentral map of teleseismic events. The solid circles represent the epicentres recorded by the seismological network of Seismo, New Delhi and the open circles are the corresponding epicentres obtained from records of C.S.O., Shillong through the present method.

From the figures, it is observed that the scattering pattern of epicentres near to Shillong plateau is almost tallying with that of the seismological network of New Delhi [Fig. 3(a)]. It is noticed that the scattering pattern of epicentres in the Indo-Myanmar Border shows a difference of about 1°, mostly in longitudes. However there is a small variation in latitudes. It is seen in the eastern sector of the map [Fig. 3(a)], the epicentres recorded by C.S.O., Shillong are lying westward relative to the epicentres recorded by the seismological network of Seismo, New Delhi. The difference in the epicentres on the Shillong plateau is very marginal both in the latitudinal and longitudinal senses.

It is seen in the Northwestern sector of the map [Fig. 3(b)], the epicentres recorded by C.S.O., Shillong are lying eastward relative to the epicentres recorded by the seismological network of Seismo, New Delhi, especially in the Hindukush region.

The epicentral difference within the grid between Latitudes 27° N to 39° N and Longitudes 90° E to 68° E is about 2.5° in average (mainly latitudes). However there is a small variation in longitudes. The epicentral difference for teleseismic events [Fig. 3(c)] shows mix variation.

The KPCC (*r*) values and regression coefficients obtained from the epicentral latitude (or longitude) of the

37 near/local events and 27 regional events are given in Table 1.

From the statistical findings (Table 1), it is seen that the regression coefficient is stronger for regional events with respect to the epicentral latitudes. The regression coefficient is stronger for near events with respect to the epicentral longitudes.

It is seen in Fig. 3(a), the epicentres in the Shillong plateau show least variation with those recorded by the seismological network of Seismo, New Delhi. The seismic waves travelling beneath the Shillong plateau experience almost same crustal structure. Therefore the amplitudes suffer very less or no attenuation within these close epicentral distances from C.S.O., Shillong. According to Kayal and Zhao (1988), the average P-wave velocity in the Shillong plateau and the Assam valley is 6.52 km/sec down to depths of 46.5 km. In the investigation of Pathak *et al*., (2006), it is reported that the depths of the hypocentres in the Shillong plateau are generally less than 30 km above the basement of the Shillong plateau.

It is interesting to note that C.S.O., Shillong is located on the Shillong Plateau which is bounded to the east by the NW-SE Kopili Lineament, to the south by the Dawki fault, to the west by the Dapsi thrust and to the north by the Brahmaputra fault [Fig. 3(a)]. The Shillong plateau behaves as an independent tectonic entity, with its own style of faulting, seismic productivity, and hazard potential [Rajendran *et al.*, (2004)].

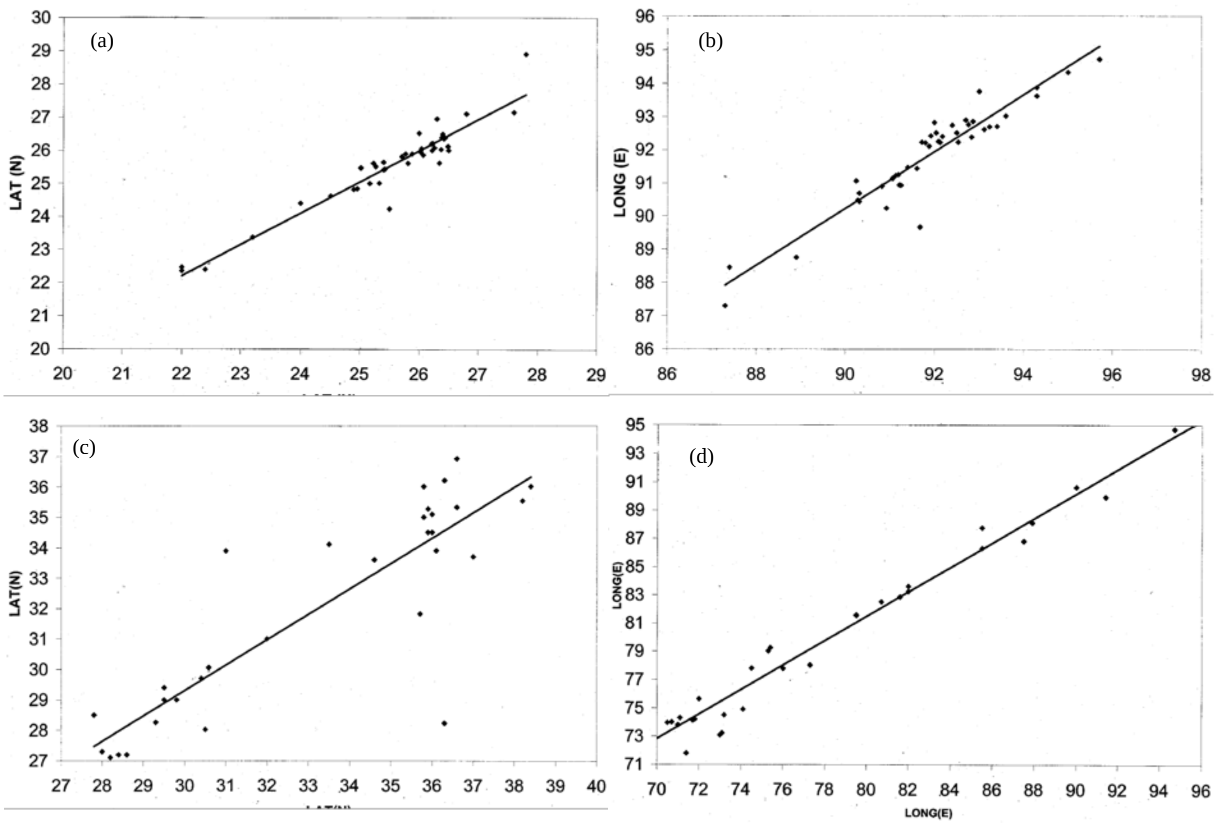
For very small earthquakes of magnitude <3.0 , in NE region, the nearest digital recording stations are C.S.O., Shillong, Kolkata (B.B.S) and Bokaro (G.S.N) and the later two stations are about ~500 km away from C.S.O., Shillong. However, if the earthquake event is not significant or if it is not recorded by Kolkata (B.B.S) and Bokaro (G.S.N), only C.S.O., Shillong will provide the epicentre predominantly as compared to the other stations. This can be seen in a number of low magnitudes earthquakes having their epicentres in the Shillong plateau where the data of C.S.O, Shillong gets more weightage. Since the same parameters from C.S.O., Shillong are used for both methods of determining the epicentres *i.e*., the general method and the trigonometrical method, the epicentral variations are the least in the Shillong plateau. Hence, the epicentral variations determined by the three stations show less variation with the trigonometrical single station method. Also, for such small epicentral distances, the Earth's curvature factor is negligible.

The collision of the Indian plate with the Eurasian plate has resulted in appreciable seismicity all along the margin of the Indian plate including the Andaman and Burmese arc on the east, the Assam syntaxial region on the NE, Himalaya to the north, Kohistan-Hindukush region on the NW and Suleiman-Kirthar ranges on the west (Verma, 1991). Further, Verma (1991) reported that the collision movements propagating from north to south in the Himalayan region are identified by two major thrusts, the Main Central Thrust (MCT) and the Main Boundary Thrust (MBT).

The epicentres obtained in this study are confined within the latitudes 21° N to 39° N and longitudes 68° E to 96° E [Figs. 3(a-b)]. It may also be noted that the study covers the seismic activities mainly occurring near the Hindukush region, entire Himalayan range, Indo-Myanmar Border region, Shillong Plateau and the entire NE-region of India. This study touches the tectonic features like MCT, MBT, Subduction zone in the Indo-Myanmar Border region, etc.

There is an almost E-W variation of <1° in the Sub-duction zone in the Indo-Myanmar border region [Fig. 3(a)]. Kulhanek (1990), documented that earthquakes in subduction zones generally generate intermediate to deep focus earthquakes *i.e*., > 70 km. It may be assumed that since the Indian plate is subducting eastwards into the Burmese plate, the epicentral characteristics show almost E-W variation. In Fig. 3(b), the epicentral characteristics show relatively more variation as compared to Fig. 3(a). This may be attributed mainly to geological aspects. With regard to distance, the velocities and amplitudes of P & S waves are varying due to heterogeneous structure within the crust. The entire route from Hindukush region to north of the Shillong plateau is mainly a thrust zone where similar characteristics of epicentral variations are observed [Figs. 3(a-b)]. The top formation like soft alluvial provides longer amplitudes of motion in the short period range than in rock formations (Neumann, 1959). This can be seen when waves pass through the Gangetic and Brahmaputra basins. Moreover, the amplitudes of any wave die out with distance. For larger epicentral distances, the Earth's curvature factor also plays a role.

The N-S variations are seen in the Himalayan region [Figs. 3(a-b)]. The depths of hypocentres in some areas are generally greater than the epicentral distances with respect to C.S.O, Shillong. This gives rise to larger amplitudes both in the vertical and horizontal components of the seismograms. It may be assumed that since the Indian plate is thrusting northwards to the Eurasian plate, the epicentral characteristics show N-S variations as shown in Figs. 3(a-b). Applying this analogy, the thrusting features in the Hindukush region may show characteristics in the NW direction since the epicentral variations show a N-W variation. The northern boundary of the Indian plate across the foothills of the Himalayas generally indicates thrusting with varying amounts of strike slip movements



Figs. 4(a-d). (a) Latitude regression line of near events (b) longitude regression line of near events and (c) latitude regression line of regional events and (d) longitude regression line of regional events recorded by Seismo, New Delhi network and C.S.O., Shillong.

(Srivastava and Chaudhury, 1979). The contribution of C.S.O, Shillong data in the northwestern part of India gets lower weightage since there are many digital seismograph stations located in that part of the country. This explains the relatively large epicentral variations [Fig. 3(b)]. For teleseismic distance, Fig. 3(c) shows a mix characteristic of epicentral variations. These waves have travelled large distances through interlayer interfaces etc, and hence may display very low amplitudes. As stated earlier, this study uses only the Benioff Short Period Seismograph for earthquakes up to 1000 km. Further, we have used flat earth with plane trigonometry, but for teleseismic distances we need to use spherical trigonometry. Therefore only three teleseismic events are selected to see the variations [Fig. 3(c)].

For local distances, Fig. 4(a) shows the Regression coefficient to be 0.881 as compared to Regression coefficient of Fig. 4(b) which is 0.895. The KPCC also shows relatively small E-W variations as compared to latitudes for near events. This is mainly contributed by epicentres in the Shillong Plateau and northwestern sector of Fig. 3(a) where most epicentres have comparatively small E-W variations as compared to the subduction zone in the eastern sector of Fig. 3(a). For regional distances, Fig. 4(c) shows the Regression coefficient to be 0.938 as compared to Regression coefficient of Fig. 4(d) which is 0.873. This is observed in the north part especially in the northwestern part (Hindukush region) where most epicentres have comparatively small N-S variation as compared to a portion of the Himalayan region stretching from Uttaranchal to Sikkim. However, the KPCC shows relatively small E-W variations as compared to latitudes for regional events also. It is also interesting to note that the KPCC for longitudes of near/local and regional are equal to 0.995. This may be because both longitudes (near and regional) have the same rate of variation. This is evident as equation (6) may be described as the ratio of the differentiation of the product of the variables X' and Y' to the product of the increment of the same variables. This may be attributed to the fact that the variation in the ratio of the numerator to the denominator in all cases is very small which ultimately leads to strong correlations in all four cases.

5. Conclusion

Considering the statistical results, this method has given reasonable degree of accuracy in locating epicentres from a single station especially those near to the recording station. The nearer the events from the recording station, lesser is the epicentral variation with the seismological network of Seismo, New Delhi. This can be seen especially for those epicentres lying in the Shillong plateau. This study is taken with C.S.O., Shillong as the reference station. Therefore in general, the variation in the epicentral distances is more for distant earthquakes than those nearer with respect to C.S.O., Shillong. This method can be applied to any observatory equipped with three components to locate epicentres of earthquake events particularly at local and regional distances. In particular, the method of determining the epicentre by trigonometrical method from a single station can be rendered useful as far as locating epicenters especially in the NE region of India is concerned.

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Appendix I

Computer program

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real op,oq,pq,a,b,c,d,e,v,t,stnlat,stnlon,eplat,eplon
stnlat=25.56
stnlon=91.85
open(1,file='seismoin.txt',status='old')
open(2,file='seismoout.txt',form='formatted')
read(1,*)a,b,c,d,v,t
oq=v*t/111
x=ATAN(abs(b)/abs(c))
pq=oq*sin(x)
op=oq*cos(x)
eplat=stnlat+(abs(c)/c)*(abs(d)/(d))*op
eplon=stnlon+(abs(b)/b)*(abs(d)/(d))*pq*a
write(2,2)eplat,eplon
2 format(2f10.2)
stop
end
```