A STUDY OF LONGITUDINAL WAVE VELOCITY VARIATION IN THE CRUST

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SYNOPSIS

In different parts of the earth seismic wave velocities in the crustal layers have been determined from mainly two sources (1) Seismic refraction technique as applied in explosion seismology (2) The observational or Earthquake Seismology. For the Indian Region, travel time curves have been drawn for different parts which show different velocities of transmission of longitudinal waves in the crustal layers under these parts.

INTRODUCTION

Various Geophysical and Geological investigations have shown that the crust of the earth can be divided into layers of varying thicknesses. It has been shown on the basis of the velocities of seismic waves obtained either from a natural earthquake or explosion seismology, that the crust can be divided into various layers. The main layers above the Mohorovicic discontinuity are called (1) Granitic Layer (2) Intermediate layer and below these layers is the Mantle and termed as Basaltic layer. The thicknesses of these layers vary accordingly as the thickness of the crust varies from 33 Km. to 50 Km. under the continents (exceptional thickness under the mountain ranges upto 70 Km.) to 16 Km. under the sea.

The longitudinal waves travelling through these three layers are termed as P_g, P^* and P_n. It is known that the crust possesses large amount of lateral inhomogeneities i.e. the elastic constants vary according to the distribution of material and thus accounting for the different velocities of P_g, P^*, P_n with which these waves have been found to travel in different parts of the earth's crust. Subsequently, from the calculated velocities of these waves, from observed travel times, give us an idea about the elastic inhomogeneities in the crustal structure.

DETERMINATION OF SEISMIC VELOCITIES IN THE CRUSTAL STRUCTURE

Seismologists have resorted to various measuring techniques in order to determine the crustal structures and the seismic wave velocities under the continents and oceans. Refraction techniques in explosion seismology and travel times in earthquake seismology have been used in the determination of these wave velocities.

I. Seismic Refraction Technique in Explosion Seismology as Applied in the Oceans

Seismic-Refraction Measurements in the Atlantic ocean, in the Mediterranean Sea, on

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*Senior Scientific Officer, Regional Research Laboratory, Jorhat, Assam—Attached to School of Research and Training in Earthquake Engineering, University of Roorkee, Roorkee (India) the Mid-Atlantic Ridge, and in the Norwegian Sea, have shown the following values for seismic wave velocities and the crustal structure under the oceans.

(i) Western Basins of the North Atlantic Ocean

(a) Crustal section of 1/2 to 1 Km. thick of low velocity sediments.

(b) Crustal rock 4 to 6 Km. thick and of seismic velocity is about 6.5 Km/Sec;

(c) Sub bottom reflections have shown that there is a layer of 1–2 Km. thick and of 4.5 – 5.5 Km/Sec. between layers (a) and (b).

(d) Below these layers is the mantle with a velocity of 8 Km/sec. at the Mohorovicic discontinuity.

(ii) Measurements in the eastern basin show similar values except a velocity of 7.7 – 7.8 Km/sec. at the Moho's discontinuity.

(iii) Measurements in the Mediterranean Sea show only low velocity sediments underlain by a refracting layer in which the average velocity is about 4.5 Km/sec.

(iv) On the Mid Atlantic Ridge the sediments are underlain by two refracting layers with velocities averaging 5.6 and 7.4 Km/sec. respectively. The results indicate that the ridge has been built by the upwelling of the great amounts of basalt magma come from convection currents deep in the mantle. Low velocity layer 1.70 – 1.80 Km/sec. is assumed.

(v) Between North America and Mid Atlantic Ridge.
5.15 Km. of water
1.49 Km. of sediments velocity 1.7 to 4.5 Km/sec.
4.02 Km. of "Oceanic-Layer" rocks,
Mean velocity 6.36 – 6.88 Km/sec.
Subcrustal mantle has a velocity 7.81 to 8.08 Km/sec.

(vi) Seismic refraction measurements in the Gulf of Mexico show that the layers with velocities between 2.25 and 6.0 Km/sec. are the only additions to a standard Atlantic Oceanic column. The third layer has been found to be of 5.0 Km/sec. velocity and predicted to be a thin limestone underlain by huge thicknesses of sediments, because the wave with the velocity of 5.0 Km/sec. disappears from the travel time curves after greater distances.

II. Seismic Refraction Technique in Explosion Seismology as Applied in the Continents

(i) *Measurements over Emerged and Submerged Atlantic Coastal Plain*

Seismic refraction profiles shot on the continental rise and slope south of the Grand banks show great sediments thickness which reaches a maximum of 10 Km. and thins down under the banks. These sedimentary layers are present, with average velocities of 1.83, 2.47, and 3.97 Km. per second. The basement is thickest under the south edge of the continental shelf and thins down to 2 or 3 Km. to the north and to the south. Its average velocity is 5.77 Km/sec. and on the southernmost profile where it is 6.70 Km/sec. Sub-basement is reached at a depth of about 13 Km. and has velocity of about 7.76 Km/sec. to 7.24 Km/sec.

Unconsolidated sediments have got a thickness of 0.5 Km. and an average velocity of 1.83 Km/sec. Semiconsolidated sediments are of 2.7 Km. thickness and average velocity 2.47 Km/sec. Consolidated sediments have an average velocity of 3.97 Km/sec. and the thickness is 6.8–3 Km. The average basement and sub-basement velocities are 5.73 Km/sec. and 7.53 Km/sec. respectively.

(ii) *Measurements on the floor of Yosenite Valley California*

The uppermost layer in the valley fill has a velocity of 1.7 Km/sec. and is only 150 m. in thickness. The intermediate layer in the valley fill has a velocity of 2.5 Km/sec. and 220 m. in thickness and at the Bridalveil Meadow where it becomes the surface layer having a velocity of 2.1 Km/sec. The basal layer is 300 m. in thickness and of 3 Km/sec. velocity.

(iii) *Seismic Explosion and refraction measurements in the Vancouver Island-strait of Georgia area of western Canada.*

The average structure derived for the area consists of a layer of volcanic and granite strata less than 5 Km. in thickness and an intermediate layer with a constant velocity for compressional waves of 6.66 Km/sec, 46 Km. thick. A velocity of about 7.7 Km/sec. for the mantle has been observed.

(iv) *A seismic survey in the Canadian shield*

Average velocity for the intermediate layer has been found to be 6.234 ± 0.012 Km/sec.

(v) *Rock bursts at Kirkland Lake Ontario*

'P' velocities for the intermediate layer and at the Mohoronicic discontinuity are 6.246 ± 0.015 Km/sec. and 7.913 ± 0.125 to 8.176 ± 0.013 Km/sec. respectively. The average crustal thickness of this crust, based on the 'P' waves is 35.4 ± 5.5 Km.

III. Nuclear Detonations and their Recording at Seismological Observatories

Seismological Records of Nuclear detonations have been analysed for crustal investigations. Some measurements have also been done by this technique in Japan. The Seismic Refraction technique has been more successfully and commonly employed than the Earthquake Seismology in determining the seismic waves velocities and thicknesses of different crustal layers. Many more examples of the successful application of this particular technique in this field can be cited.

VI. Earthquake Seismology

Determination of seismic wave velocities and crustal structure from the earthquake records can be carried out with the help of different phases of the record. P_g, P^*, P_n waves velocities can be calculated from the records of earthquakes and then used for determination of crustal thickness. Shear wave velocities have also been used along with longitudinal wave velocities to determine the thicknesses of the crustal layers. Dispersion curves of surface waves have also been used to find out the thicknesses of the crustal layers.

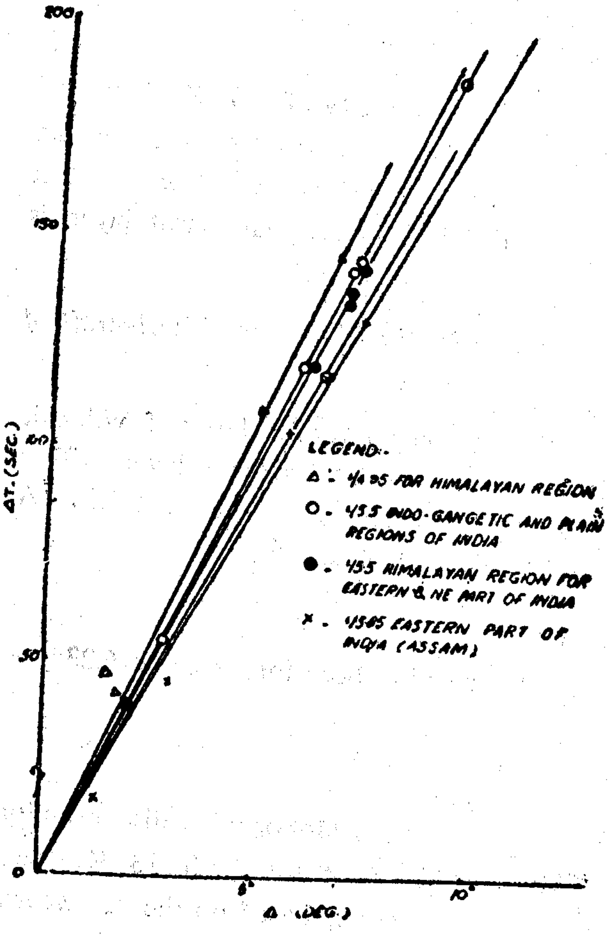

Figure 1 T Vs. Δ° For P_g.

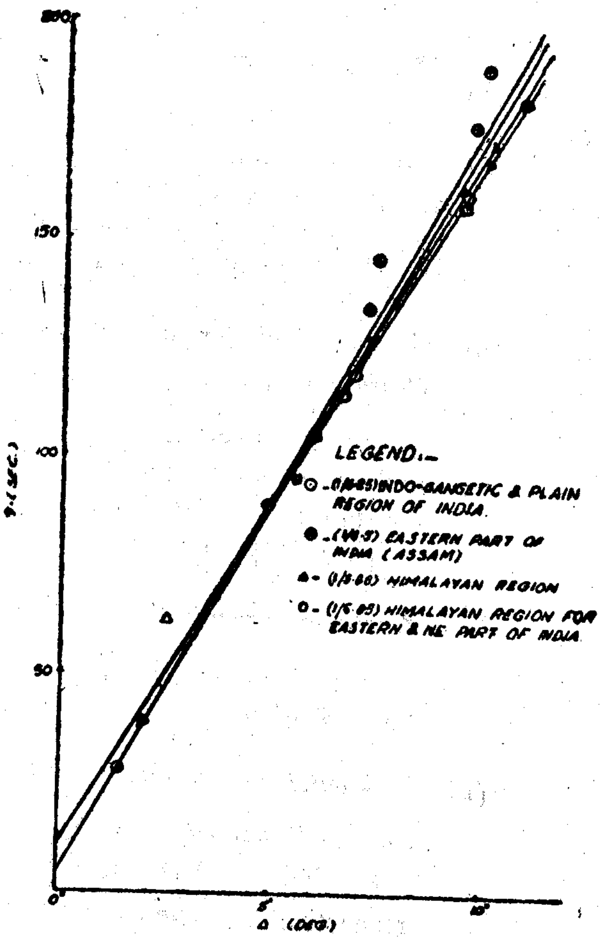

Figure 2 T Vs. Δ° For P^*

Velocities for the longitudinal waves propogated through different crustal layers can be known by plotting travel time curves for a region. If the distances involved are small then the travel-time curves are straight lines which is quite a good approximation. It is evident that these different phases known as P, P^*, P_g were discovered from the observation of earthquake records. A. Mohorovicic (1909) found out from earthquake records of Kulpa Valley, Grotia, on 1909 October 8, that two distinct P and two S pulses were present. The faster pair were indentified with the P and S traceable to large distances. The new pair were denoted by $\overline{P}$ and $\overline{S}$, a notation still extensively used and this has been termed as P_g and S_g for convenience, P and S, however were refracted down into the deeper layers and propogated at a greater velocity and later on refracted upto the surface.

After this work of A and S. Mohorovicic and Gutenberg the next great advance was made by V. Conrad (1925) in a study of the Tavern (Austria) earthquake of 1923 Nov. 28. He discovered a fifth phase P* in addition to the above mentioned phases. This appeared to have travelled in a intermediate layer having a velocity of propogation between P and P_g. P.L. Willmore (1949) made a detailed study of the Heligoland explosion of 1947 April 18. His results for the velocities were in Km/sec. P, 8.18 ± 0.14, P*, 6.4 ± 0.16, P_g variables.

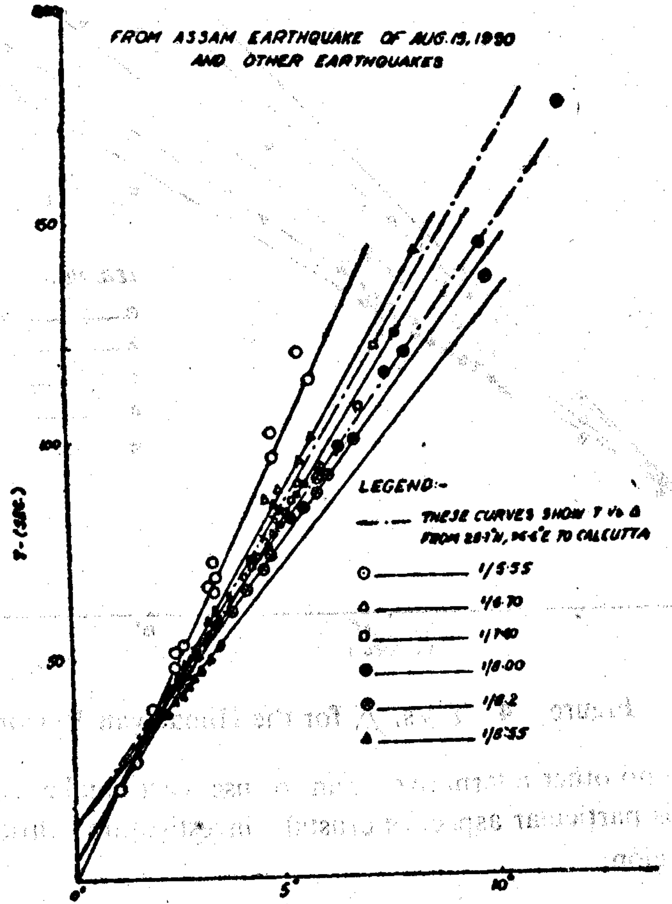

Figure 3 T Vs. △ For Plains, Brahmputra Valley & Assam Plateau

Extensive studies of near earthquakes have been made by Gutenberg, Byerly and their collaborators in California. Gutenberg's data (1932) for P_g correspond to 5.58 ± 0.023 Km/sec. for P, 7.92 ± 0.05 Km/sec. For intermediate layers Gutenberg associated two velocities of 6.83 and 6.05 Km/sec. Extensive studies of near earthquakes in Japan have been made by Matuzawa etal (1928). Velocities in Km/sec. are given as : P_g, 5.0 P*, 6.2, P, 7.5.

Many more seismologists have made some studies regarding the velocities of these phases, in Japan, England and California.

INDIAN REGION

In this continental part of the earth no Seismic Refraction Technique in explosion seismology has been used to investigate the crustal layers. Seismologists engaged in such studdies are left with no other alternative than to use earthquake seismology as their only tool. As regards this particular aspect of crustal investigation little amount of work has been done for this region.

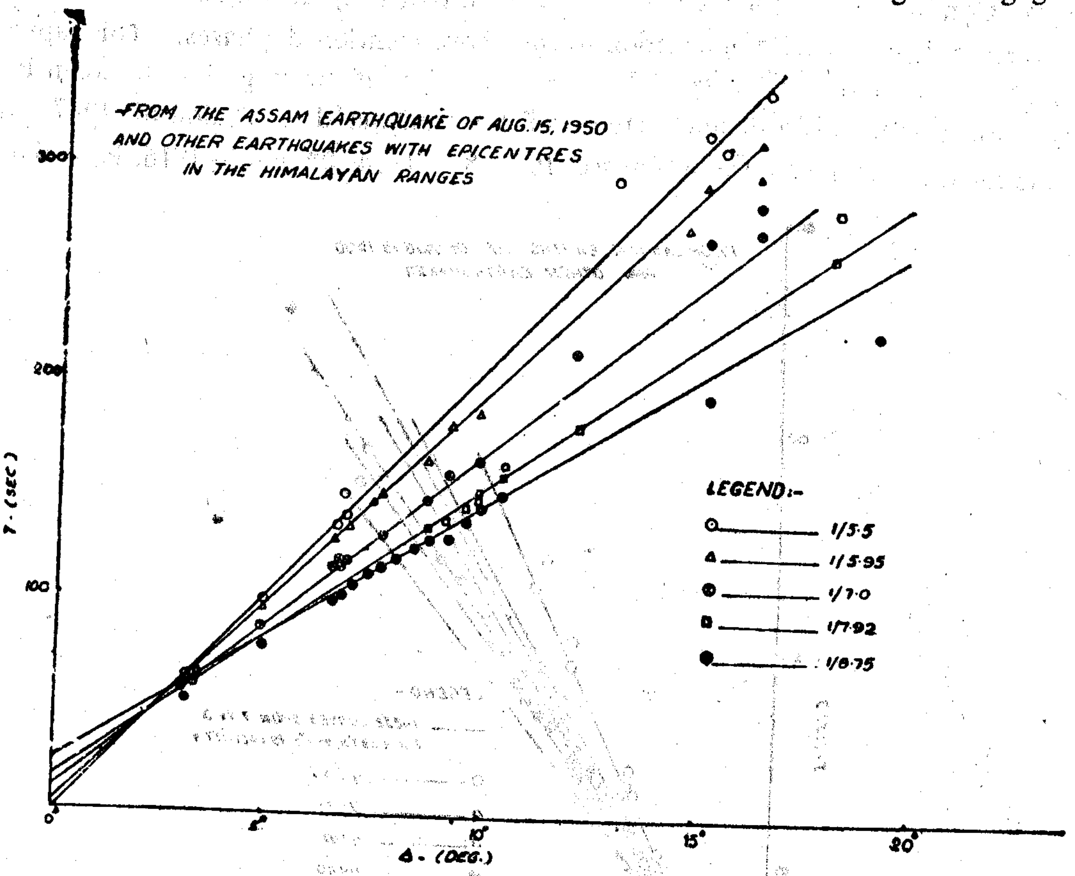

Figure 4 T Vs. Δ for the Himalayan Region

A.N. Tandon (1955) carried out his studies on this subject of crustal investigations mainly from the Assam Earthquake of 1950, August 15 and its fiftyfour aftershocks. From the travel-time curves, he showed the values of velocities in Km/sec. as shown : P, 7.91, P*, 6.55, P_g 5.58. In the Asian continent, values of these velocities vary quite considerably. P_g 3.56 to 5.55 Km/sec., P 5.95 to 6.30 Km/sec. P 7.4 to 8.5 Km/sec. The author has made investigation for the velocities of longitudinal waves in the crustal layers in the Indian Region. This study has been done on the basis of data obtained from the Assam earthquake of 1950, Aug. 15 and its fiftyfour aftershocks and thirty more near earthquakes as listed in the Table 1.

It has been attempted to divide the Indian sub-continent into different parts such as the Himalayan Region, Indo-Gangetic plains, Assam Region etc. This has been done for the purpose of drawing travel-time curves separately for these regions. The object of this study is to get an idea about the behaviour of the crustal layers in different regions, to the longitudinal wave velosities.

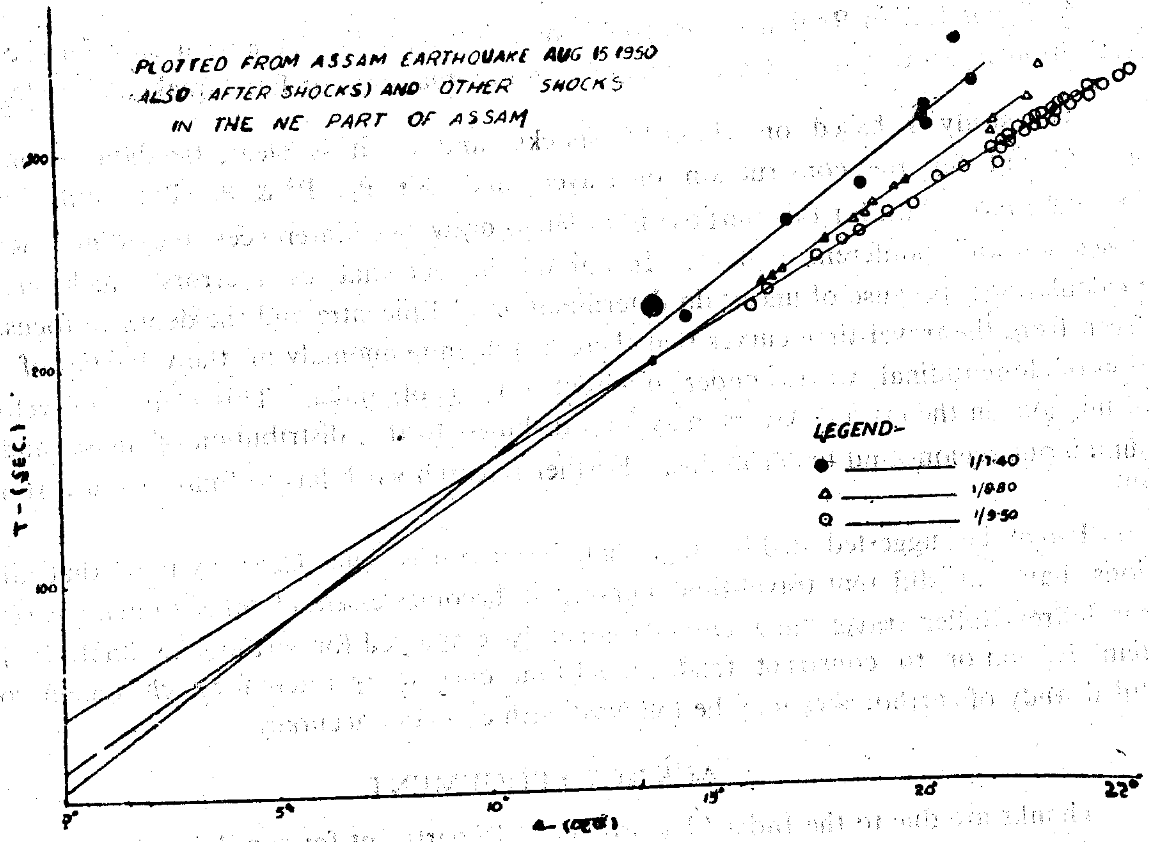

Figure 5 T Vs. Δ for the Directions of Propagation from NE Assam to Bombay, Poona and Hyderabad

Travel-time curves for P_g has been constructed as shown in figure 1. It is quite evident that different regions have got different velocities of P_g. Himalayan region has been found to have P_g to be 4.95 Km/sec. and the Indo-Gangetic plains region has a velocity of 5.5 Km/sec. as a value of P_g. It may be indicated that this indirectly supports the theory of isostasy which enunciates deficit of material under the mountains and excess of mass under the oceans. Atleast the first part of this theory can be supported by the anomaly obtained from the values of P_g and P^* (figs. 1&2) under the Himalayan Region and under the Indo-Gangetic plains. For the region of Assam, it is noted that the velocities of P_g and P^* (figures 1 & 2) are greater than these velocities in other regions. This indicates better transmission of elastic energy to the surface and thus to some extent accounts for gteater damage. Also, this may be one of the reasons why even small local shocks which otherwise may not be felt are frequently felt in Assam. Values for velocities in different crustal layers are found to a good approximation in Km/sec. as : P_g 4.95 - 5.80, P* 6.5 - 6.85, P 7.4 - 8.35. (figs. 3, 4, & 5).

DISCUSSION AND CONCLUSION

In Earthquake Seismology, for almost any type of study to be made, we require accurate observational data in a large amount. This helps in making out some inferences from the study.

As for as Indian Region is concerned, no seismic profiles have been shot for the crustal investigations. So this study depends mainly on observational or Earthquake Seismology.

This study is based on about 85 shocks, and as it is clear, the data seem to be just sufficient for the construction of travel times for P_g, P* & P. But, still it will be safer to use more data for this purpose in order to draw some inferences regarding velocity of propogation under different regions. Inspite of the fact that usual errors which creep into the calculations, because of uncertain determination of Epicentre and the depth of focus, it can be seen from the travel-time curves that there is a definite anomaly in the velocities of propogation of longitudinal waves under different regions of India. This change in velocity of transmission in the crustal layers may be attributed to the distribution of mass under the mountainous regions and under plains. Further research work has to follow to ascertain this point.

It may be suggested at this stage that because it is quite clear by now that different regions have got different travel-time curves, it becomes essential either to make corrections to the Jeffrey-Bullen travel time curves frequently employed for earthquake analysis in the Indian Region or to construct fresh travel-time curves seperately for each region so that detailed study of earthquakes may be followed with ease and accuracy.

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TABLE 1

Data from the following earthquakes have been used for drawing the travel time curves for different regions of India.

Sl.No.	Epicentre	Date	Remarks
1	2	3	4
1.	28.7° N, 96.6° E	Aug 15, 1950	Assam earthquake with 54 aftershocks.
2.	29.0° N, 95.0° E	Jan 3, 1951	From Seismological Bulletin of India Meteorological Department.
3.	29.0° N, 95.0° E	Jan 4, 1951	do
4.	27.2° N, 95.0° E	Feb 8, 1951	do
5.	30.8° N, 97.0° E	Feb 15, 1951	do
6.	28.0° N, 93.5° E	Feb 21, 1951	do
7.	29.3° N, 94.8° E	Mar 6, 1951	do
8.	28.2° N, 94.0° E	Mar 12, 1951	do
9.	31 4° N, 96.7° E	Mar 16, 1951	do
10.	32.0° N, 96.5° E	Mar 17, 1951	do
11.	26.0° N, 90.5° E	Apr 17, 1951	do
12.	19.2° N, 70.8° E	Apr 8, 1951	do
13.	33.3° N, 82.4° E	Jan 28, 1955	Taken from International Seismological Summary.
14.	33.0° N, 83.0° E	Feb 9, 1955	do
15.	30.3° N, 67.1° E	Feb 19, 1955	do
16.	28.0° N, 85.5° E	Feb 23, 1955	do
17.	28.5° N, 85.3° E	Feb 24, 1955	do
18.	36.8° N, 71.3° E	Mar 5, 1955	do
19.	38.1° N, 72.9° E	Mar 6, 1955	do
20.	34.0° N, 78 0° E	Mar 10, 1955	do
21.	34.6° N, 74.2° E	Mar 12, 1955	do
22.	23.8° N, 93.0° E	Mar 15, 1955	do
23.	29.9° N, 90.2° E	Mar 27, 1955	do
24.	32.4° N, 76.1° E	Apr 14, 1955	do
25.	26.5° N, 90.0° E	Apr 17, 1955	do
26.	32.5° N, 78.6° E	Jun 27, 1955	do
27.	36.8° N, 71.0° E	Jun 3, 1955	do
28.	30.8° N, 86.4° E	Aug 2, 1955	do
29.	31·0° N, 71.5° E	Aug 23, 1955	do
30.	25.2° N, 90.8° E	Aug 29, 1955	do
31.	27.0° N, 91.0° E	Nov 23, 1955	do