27. *On the Accuracy of Hypocentre Determination I.*

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1. Introduction.

Recently the structure of the earth's interior which is the field of earthquake occurrence has been discussed widely and vigorously on the theoretical basis of the property of material. Owing to the light thrown by the elucidation of the mechanism of earthquake occurrence and the propagation of seismic waves and so forth much importance is being attached to these studies by the seismologists at large. It is well known that most of the fundamental physical quantities used in these studies, such as density, pressure, elastic constants, etc., are basically dependent on the velocity distribution of seismic waves within the earth as derived from the travel-time curve. It is also known that incessant efforts have hitherto been made to derive a standard travel-time curve by senior investigators, among which the names of H. Jeffreys, K. E. Bullen, B. Gutenberg and C. F. Richter are to be specially mentioned. However, the discrepancies between the velocity distributions as worked out by these authorities are not small enough to be discarded from the above point of view. It is therefore necessary to examine the main causes of the inaccuracies of the travel-time curve, among which those of hypocentre determination are deemed to be of the prime importance. Among the difficulties in the accurate determination of hypocentre, such inevitable factors as the finite and irregular shape of hypocentral region may perhaps be counted, but there must be other factors which can be eliminated by modifying our method concerned. To contribute to this problem, the writer intended to carry out some critical examinations of the current procedure in these studies, and here in this paper the writer wishes to report a part of his study.

Now, in natural earthquakes, difficulties arise from the fact that we cannot control the time and position of earthquake occurrence, while in seismic prospecting, these factors are within our control so that we can arrange to carry out our observation as accurately as possible. The writer therefore made an experimental study to infer the accuracy of hypocentre determination, taking the advantages of the field experiments of prospecting by the teams of "Jisin-Tankō Jikken Group" (Seismic Exploration Group). For providing this opportunity the writer is thankful to the members of this group. In this trial the position of shot point and shot time are assumed to be unknown and, using the time of arrival of P waves, they are determined by the usual method of least-squares as in natural earthquakes. Thus if we compare such items as the position of hypocentre and origin time as determined in this way with the actual values, we can gain some clue as to the accuracy of hypocentre determination.

2. Materials used.

The records used in this study were obtained by the experiments carried out in Feb., 1954 at the Tanasi experimental farm of the Tokyo University by courtesy of "Jisin-Tankō Jikken Group". Both vertical electro-magnetic seismographs of about 20 c/s in natural frequency and

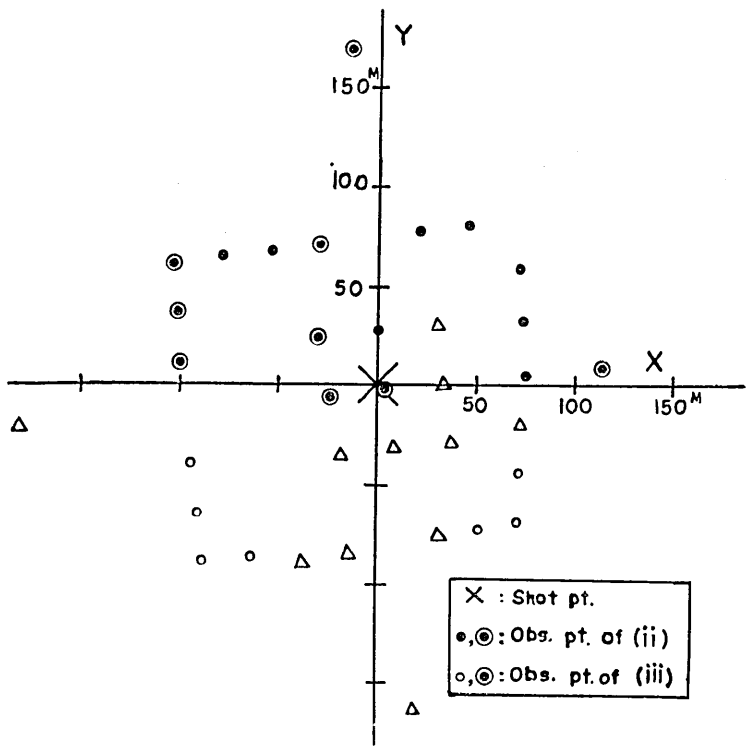

Fig. 1. Shot and observation points.

oscillographs used in this experiment were of the E. T. L.- and Tōsiba-type. Fig. 1 shows the positions of shot and seismographs. The spread was extended to about 180 m. from the origin. The exact positions of shot and seismographs were determined by plane table survey and the uncertainty of coordinates of a point is less than 20 to 30 cm. The oscillograph-paper speed was about 0.4 mm. per 1 millisec. and time signal is marked every 10 milliseconds on the records by means of a tuning fork. Fig. 8 is an example of the records.

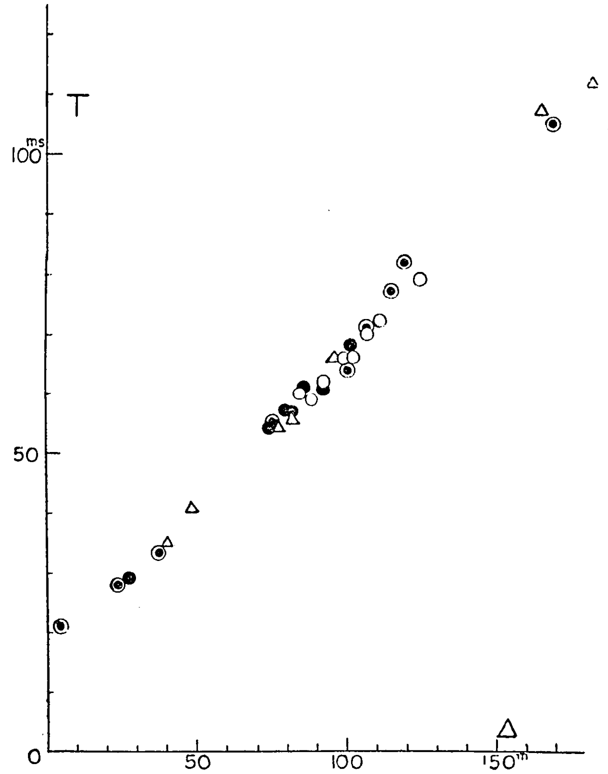

Fig. 2. The actual travel-time curve (The same marks as in Fig. 1 are used).

Using 281 g. or 70 g. of dynamite with a piece of blasting cap, the explosion was carried out at the bottom of a hole with a diameter of about 10 cm. and depth of 14 m. The oscillograms obtained gave very clear onsets and we can easily read off the phase from almost all the traces, although some of the traces were disturbed by some inductions and ground noises. Three pairs of available data under almost same conditions were obtained, and the mean travel-time curve obtained from them is given in Fig. 2. Fluctuations of each observed travel-time are less than 3 millisec. and the allowable breadth of travel-time curve may thus be considered to be less than 5 millisec. as seen from Fig. 2. So the uncertainty of shot time, that is, the irregularity in delay time of blasting cap which seems to be a few millisec. is negligible in this study.

3. The results of hypocentre determination and discussions.

At present, the weak point in seismic exploration in comparison with the natural earthquake, in spite of its great advantages as mentioned above, is the non-existence of clear shear wave in the ground

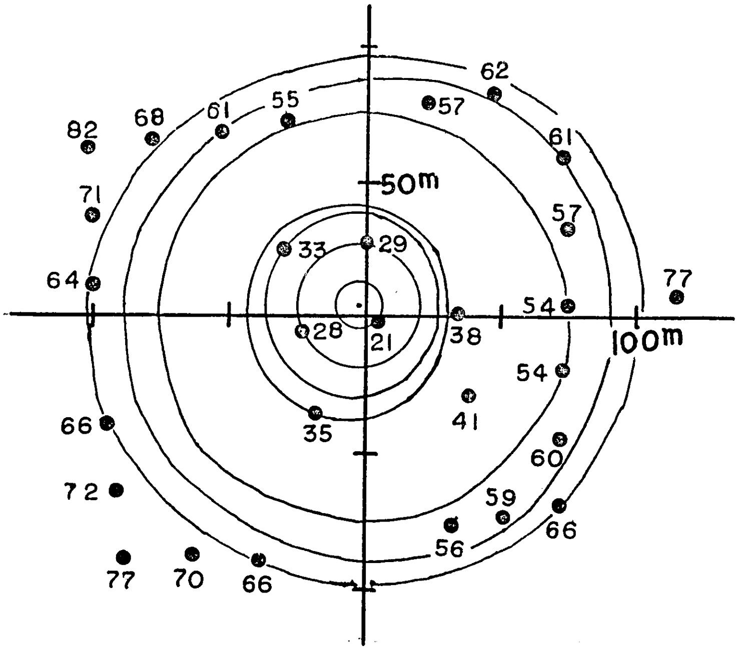

Fig. 3. Isochronals with arrival time in millisecond.

motion caused by explosion, and therefore we can not make use of P~S interval to estimate the epicentre approximately. So the epicentre of first approximation was estimated as $x_0 = -3.00$ m. and $y_0 = 3.00$ m. by using isochronals (Fig. 3) and the travel-time curve was drawn. From this travel-time curve the velocity, origin time and focal depth were determined to be 1.8 km/sec., 11 millisec., and 16 m. respectively, on the assumption of a uniform structure. The least-squares solution was obtained by using the formula

$$(x_0-x_i)\delta x_0+(y_0-y_i)\delta y_0+z_0\delta z_0+v_0^2(t_i-t_0)\delta t_0-v_0(t_i-t_0)^2\delta v_0=v_0^2(t_i-t_0)\delta t_i$$

where suffix 0 and i gives the quantities concerning the hypocentre and i-th observation point respectively.

Table I. The comparison of each case.

	(i)	(ii)	(iii)	Actual value
x_0	−1.50m ± 0.66	0.43 ± 0.90	−0.83 ± 0.89	0
y_0	0.38m ± 0.64	2.05 ± 2.06	−1.77 ± 1.10	0
z_0	27.9m ± 12.7	16.2 ± 14.6	13.8 ± 17.3	14
t_0	7.1ms ± 2.3	10.9 ± 3.0	11.2 ± 3.8	0
v_0	1.79km/s ± 0.04	1.77 ± 0.06	1.81 ± 0.07	

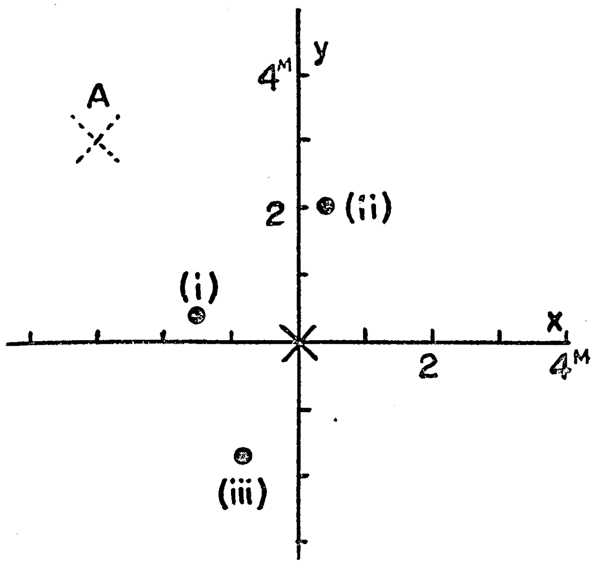

Fig. 4. The relative position of determined epicentre to the actual one. (A: epicentre of first approximation)

Three interesting cases were treated and the observation points used in each case were shown in Fig. 1 and Fig. 2:—

(i) In the first trial all observation points except four at which large deviations from the mean travel-time curve are observed, that is, 31 seismographs were used. The results obtained are given in the column (i) of Table I and the relative place of determined epicentre to the actual one is shown in Fig. 4.

From the results we see that (1) the epicentre is relatively well-determined, while (2) the determination of focal depth and origin time is not so accurate as might have been expected. For example the focal depth is twice as deep as the actual one and this is probably due to the assumption of uniform structure. Fig. 5 gives the final travel-time curve based on this hypocentre.

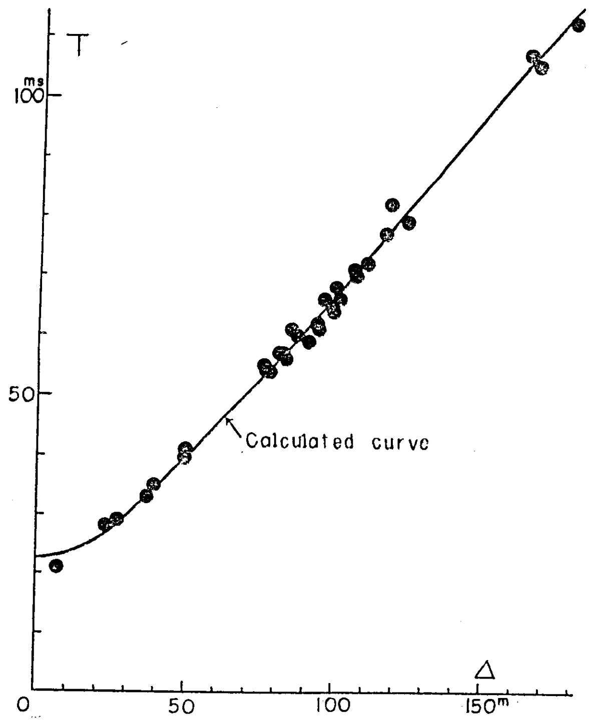

Fig. 5. The final travel-time curve in the case (i).

(ii) In the second example 17 observation points located in the first and second quadrants were used. This trial provides an example of asymmetric distribution of observatory relative to epicentre. The results in this case are entered in the column (ii) of Table I, from which we can see that in comparison with (i) the shot time is determined later and the focal depth is shallow and apparently close to the actual value, but its probable error is larger. Furthermore the place of epicentre deviates more from the actual one than in (i) (Fig. 4). Fig. 6 gives the final travel-time curve.

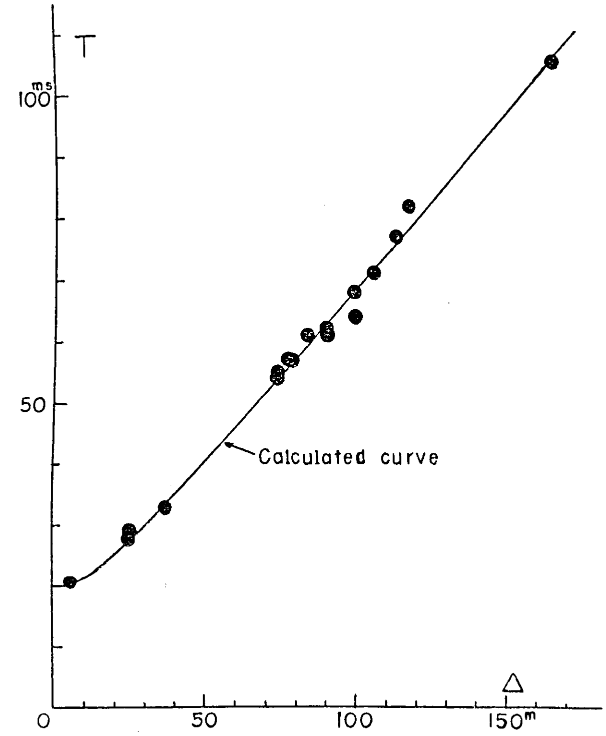

Fig. 6. The final travel-time curve in the case (ii).

(iii) In the third trial 17 observation points were picked up at random by using a table of random numbers and a similar analysis was then made. In this way the dependency of the accuracy of hypocentre determination on the number of observations used is inferred. And the result (as seen from the column (iii) of Table I) shows a marked fact that the probable errors are larger than those in the case (i) as is expected from the statistical theory. The tendencies relative to the first case resembles those obtained in the case (ii), especially in respects of shot time, focal depth and their probable errors. On the other hand, if we compare the results of (iii) with those of (ii), the place of epicenter in the case (iii) is closer to the actual one than in the case (ii) (Fig. 4) and its probable error in (iii) is a little smaller than that in (ii) although equal numbers of observations were used in both cases. This is what we have expected from the distribution of observing points. Fig. 7 gives the final travel-time curve.

It is to be noticed from Table I that in all cases the velocity is well-determined.

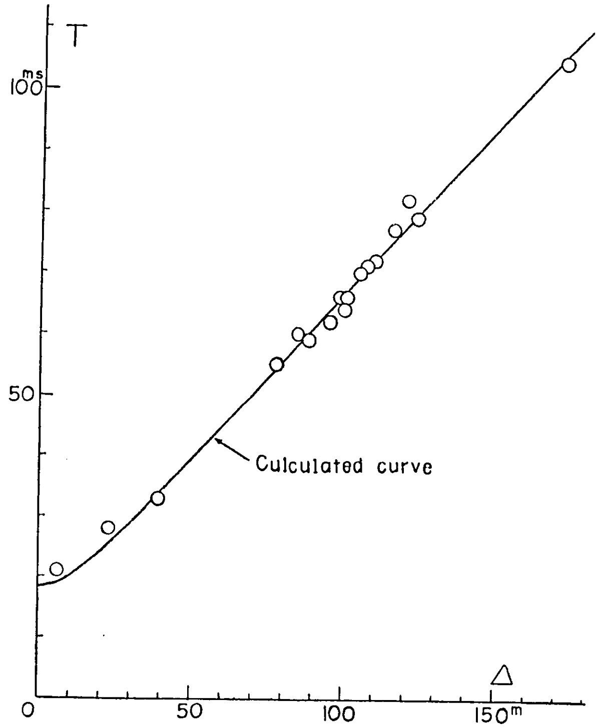

Fig. 7. The final travel-time curve in the case (iii).

These three cases give only a few examples under special conditions depending on the crustal structure of the experimental field, the shot depth, the amount of explosives, and the distribution of errors, etc., and also on the method of hypocentre determination. Throughout the above trials, the assumption of uniform structure was adopted, but if the effect of superficial layer is taken into account, the results will be expected to approach to the actual one. The writer hopes to examine the effects of superficial layer, methods of hypocentre determination, dimension of hypocentre and inclined structure, etc., on the accuracy of hypocentre determination, and reports will be given in near future.

4. Summary.

In view of the importance of the examination of accuracy of hypocentre determination a few examples were worked out by the usual method of least-squares with the following results:

1) the epicentre and velocity are relatively well-determined,

2) the shot time and focal depth affect each other and seem to be sensitive to a superficial layer,

3) the larger the number of observations, the more accurate is the hypocentre determined, and

4) when the effect of superficial layer is not taken into consideration, the probable error does not always represent the extent of discrepancy between the actual and determined values.

But it must be borne in mind that the results mentioned above were obtained from a few examples under special conditions. Such effects on the accuracy of hypocentre determination as those of the superficial layer, methods of hypocentre determination, dimension, the amount of explosives, distribution of observation points and inclined structure will be examined at the earliest opportunity.

5. Acknowledgement.

The present writer wishes to express his sincere thanks to the members of "Jisin-Tankō Jikken Group" who showed a deep understanding of this study and placed the data at the writer's disposal. He also cordially expresses thanks to Asst. Prof. S. Omote who gave him the chance and encouragements to carry out this study. To Prof. H. Kawasumi for his helpful suggestions and encouragements, the writer's hearty thanks are also due.

27. 震源決定の精度について（第一報）

地震研究所　浅野周三

爆発物を利用する地震探鉱では予め爆破点，爆破時刻，地震計の配置等を適当にし得るが，此の利点を生かし爆破点の位置，爆破時刻を未知と仮定し自然地震に於けると同様に最小自乗法により其等を定め実際と比較し自然地震で行われている震源決定の精度に関する目安を得る事を試みた．地殻構造，震源決定の方法，爆破点の深さ，薬量，地震計の配置等の点で単なる一例にすぎないが次の如き結果が得られた．

(1) 震央と速度は比較的よく定まる．

(2) 深さと発震時はお互に影響し合い表面層に敏感である様である．

(3) 同じような配置なら地震計の数の多い方がよく定まる．

(4) 蓋然誤差は定められた値と実際との相違に対する目安を必ずしも与へない様である．

以上の結果は一様の構造を仮定して得られたものであるが，表面層，震源決定の方法，爆破点の深さ，薬量，震源の大きさ，地震計の配置等の影響の考察は近い将来行つてみたいと考へている．

尚用いられた材料は「地震探鉱実験グループ」によつて得られたもので記して感謝の意を表する．

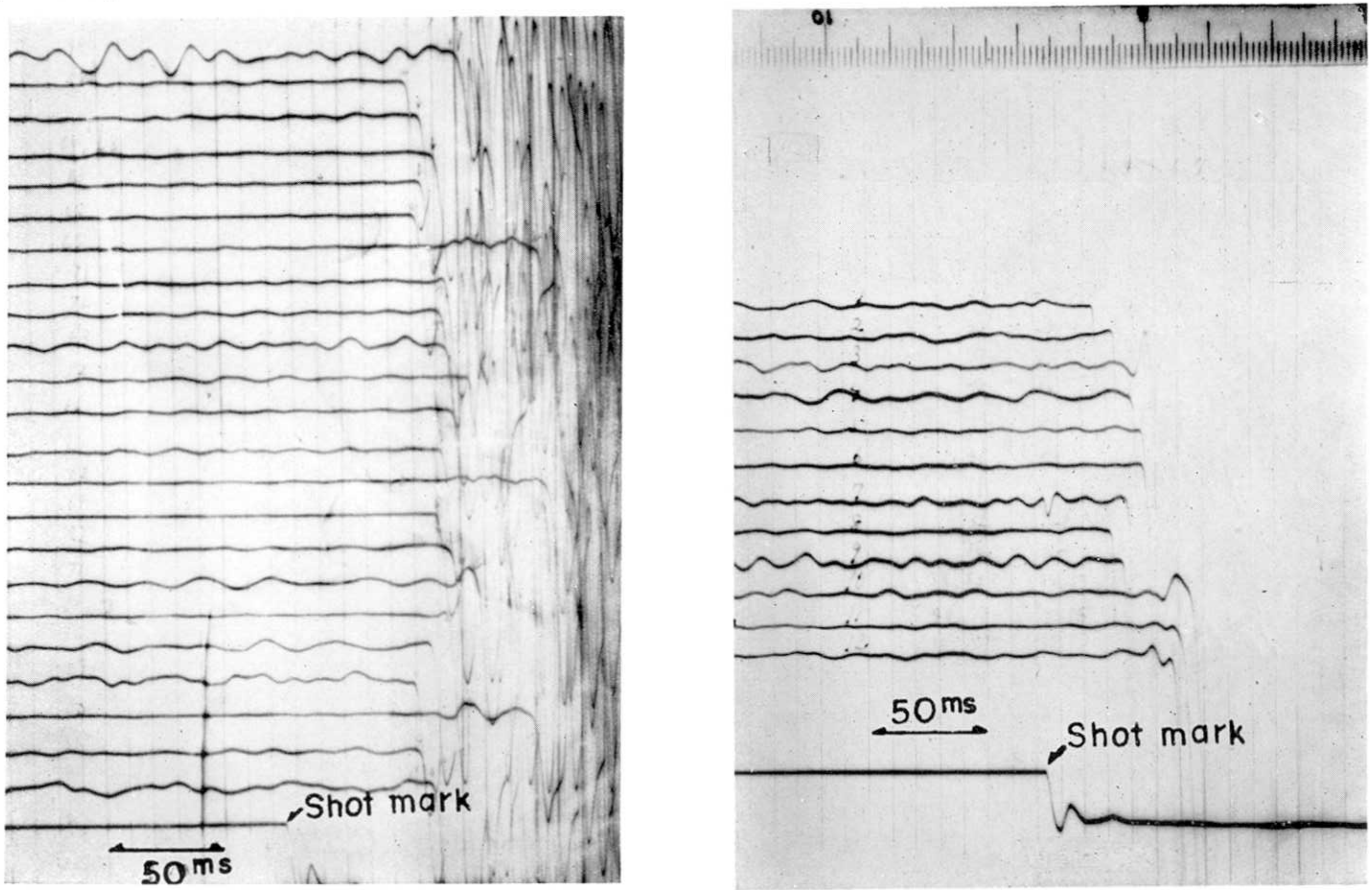

Fig. 8. An example of a pair of oscillograms.
A: an oscillogram obtained by the oscillograph of E. T. L.-type.
B: 〃 〃 〃 〃 of Tōsiba-type.