13. On the Accuracy of Hypocentre Determination II.

By Shūzō ASANO,

Earthquake Research Institute.

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1. Introduction

In the first paper[1], the writer made use of the accurate observations in a small scale explosion seismic experiment carried out by the Seismic Exploration Group, and tried to gain some clue to the accuracy of hypocentre determination. There he assumed the actually known position and time of shot as unknowns and solved them by the usual method of least squares using the arrival times of *P*-wave just as in the studies of natural earthquakes, and the results were compared with the actual items. Although the span covered by the spread was only 180 m. the velocity in the soil was low while the time accuracy was high correspondingly, so the similitude with the case of a natural earthquake was not so bad. The results obtained were as follows:

in the least square solutions

(1) the epicentre and the value of 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 accurately is the hypocentre determined,

(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.

In this report the author made the same trial as in the first paper by using the data obtained by the Research Group for Explosion Seismology (abbreviated to R. G. E. S. in this paper) which in respect of scale are close to those of natural earthquake and in respect of accuracy ten times as good as in the observations of natural earthquake. Of course, the results obtained furnish only one example under special conditions,

1) S. ASANO, *Bull. Earthq. Res. Inst.*, **32** (1954), 371.

but if those conditions are taken into consideration, we can infer the accuracy of hypocentre determination in case of a natural earthquake.

2. Materials used

Materials used are the data obtained by R. G. E. S. in cases of the second[2] and third[3] Isibuti explosions. As these explosions were carried out at almost the same position (the third one being situated as close as 20 m. south of the second[4]), the data are here regarded as obtained from one explosion. A consistent analysis has been made by R. G. E. S. to cover all the data of the six explosions within the error of 0.1 sec. with the remarkable result of the crustal structure as shown in Fig. 1[5]

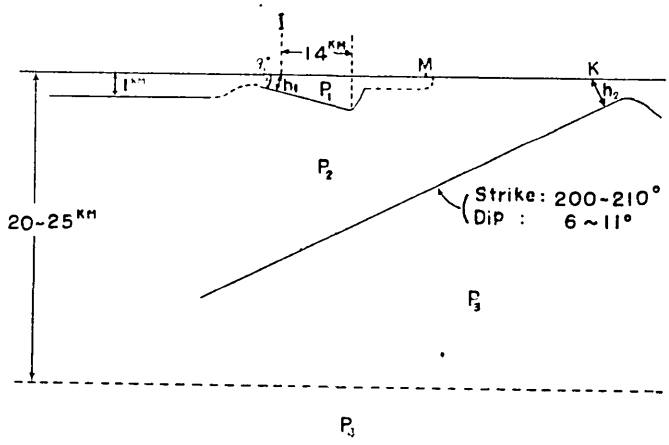

Fig. 1. Underground structure of the north-eastern part of Japan obtained by R. G. E. S.
I: Isibuti shot point; M: Mizusawa; K: Kamaisi; h_1=630m.; h_2=0.5–2.0 km.;
Velocity of P_1 layer: V_{P_1}=2.51 km./sec.;
〃 P_2 〃 : V_{P_2}=5.75–5.85 km./sec.;
〃 P_3 〃 : V_{P_3}=6.10–6.20 km./sec.;
〃 P_4 〃 : V_{P_4}=7.5–8.0 km./sec.;
Strike 200–210° is measured clockwise from north direction.

2) The Research Group for Explosion Seismology, *Bull. Earthq. Res. Inst.*, **30** (1952), 279.
The Research Group for Explosion Seismology, *Zisin*, [*ii*], **6** (1953), 7.
3) The Research Group for Explosion Seismology, *Bull. Earthq. Res. Inst.*, **31** (1953), 281.
The Research Group for Explosion Seismology, *Zisin*, [*ii*], **6** (1953), 84.
4) *Ibid.*, 3).
5) The Research Group for Explosion Seismology, "Crustal Structure in North-East Japan by Explosion-Seismic Observations," Read at the meeting of the Seismological Society of Japan on April 23, 1954 and the general assembly of I.U.G.G. at Rome on Sept. 22, 1954.

which gives the section along the nearly east-west direction of the north-eastern part of Japan. Most of the first arrivals observed within about $\Delta=90$ km. are shown to be the waves passing through the second layer, while those between $\Delta=90$ km. and $\Delta=150$ km. are the waves propagated through the third layer. The shot point and the 18 observation points within about $\Delta=90$ km. are given in Fig. 2. In the above

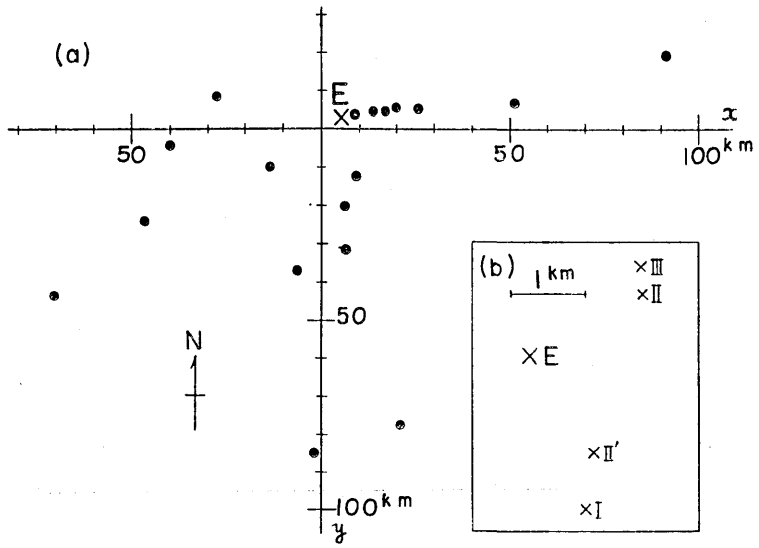

Fig. 2. (a) Shot and observation points.
E: Shot point.
(b) Relative positions of the determined epicentres.

analysis made by R. G. E. S., deviations of the observed travel-times from the calculated one with the velocity of 6 km./sec., that is, the values ($T_{\text{obs.}} - \Delta/6$) were analysed instead of the usual travel-time curve with the result that the waves traveled through not only the first and the second layers but also the second and the third ones were distinguished from each other very easily. On the other hand, from the usual travel-time curve (Fig. 3), the waves related to the second and the third layers cannot be distinguished so clearly. This usual travel-time curve gives the velocity of about 6.1 km./sec. The deviations of observed travel-time from the calculated time for the wave traveled with the velocity of 6.1 km./sec. are within ± 0.5 sec. Therefore, as the effect of the shot depth and the height of observation points on the travel-time is less than observational errors, those quantities were not taken into

consideration in this paper as in the analysis made by R. G. E. S.

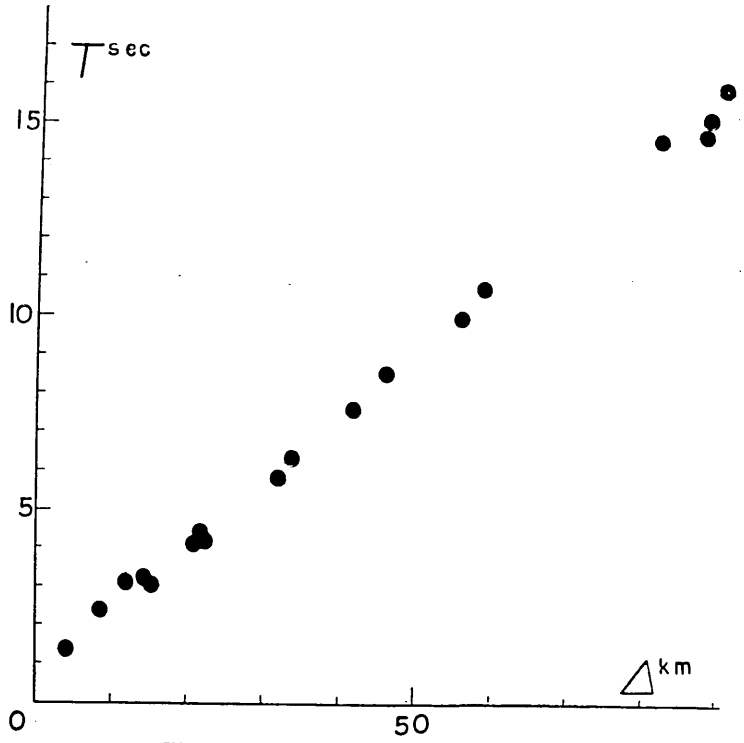

Fig. 3. The actual travel-time curve.

3. The results of hypocentre determination and discussions

In the first place, the coordinates of epicentre of the first approximation were determined as $x_0=6.00$ km. and $y_0=-0.50$ km. by using the time of commencement of *P*-waves, and the travel-time curve derived from the determined epicentre is given in Fig. 4. Although, as may be seen from this travel-time curve, there are some indications of the effect of the layer with velocity of 2.51 km./sec. in the travel-times within $\Delta=15$ km. a uniform structure was assumed for the first approximation, and the velocity and origin time were taken to be 6 km./sec. and 0.8 sec. respectively. These values of the first approximation are tabulated in the column I of Table I. Using the formula

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

the corrections δx_0, δy_0, δt_0 and δv_0 were obtained by the method of least squares. In this calculation 18 observation points were used discarding those at Δ over 90 km. where the first arrivals are presumed

to be the waves passing through the layer with a velocity of 6.2 km./sec. The results obtained are given in the column II of Table I and the position of epicentre relative to the actual one is shown in Fig. 2-(b). The distance between the epicentre of the first approximation and the actual one, Δ_I, is 2.16 km., while that of the second approximation, Δ_{II},

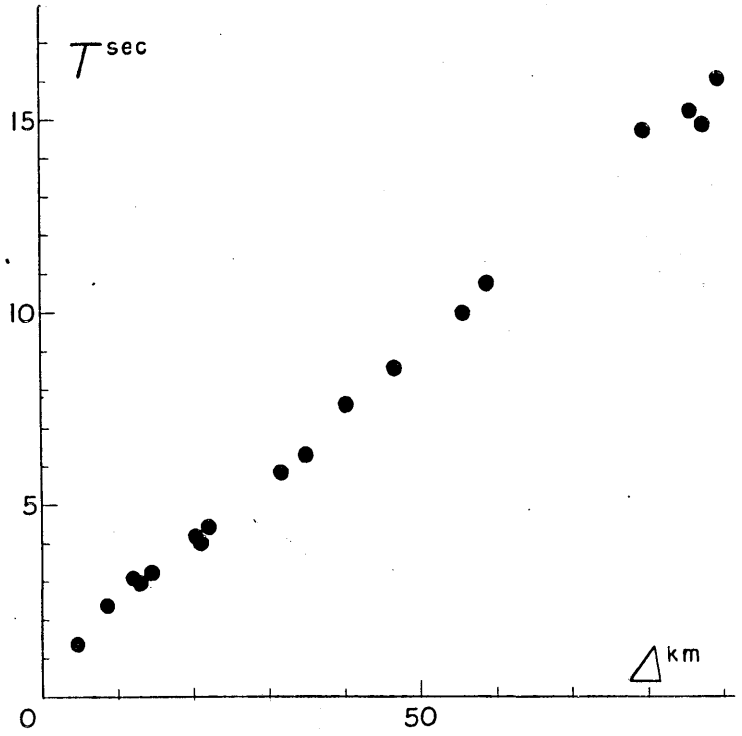

Fig. 4. The travel-time curve of the first approximation.

Table I. The comparison of quantities of successive approximation.

	Actual	I	II	III	II′
x_0	5.26 km.	6.00	6.75±0.37	6.73±0.41	6.11±0.20
y_0	−2.53 km.	−0.50	−3.34±0.57	−3.70±0.66	−1.27±0.38
t_0	0 sec.	0.80	0.51±0.15	0.51±0.19	0.53±0.09
v_0	5.75–5.85 km./sec.	6.00	5.93±0.07	5.94±0.09	5.83±0.07
Δ	0 km.	2.16	1.70	1.88	1.52

is 1.70 km. Thus we see that the epicentre of the second approximation really moved towards the actual one. Furthermore both the position of the origin time and the value of velocity were improved in comparison with those of the first approximation. But as to the velocity, the determined value is larger than the value 5.75–5.85 km./sec. as obtained by R.G.E.S. This difference seems to be due to the simplified assumption of a uniform structure, and partly to the inclusion in the calculation of the observations of the first arrivals of the waves propagated through the lower layer of velocity 6.2 km./sec., etc. The intercept time is reasonable. The resulting travel-time curve is as given in Fig. 5, and the effect of the superficial layer with velocity of 2.51 km./sec. is more clearly seen than in Fig. 4 of the first approximation. As may be seen from Fig. 5,

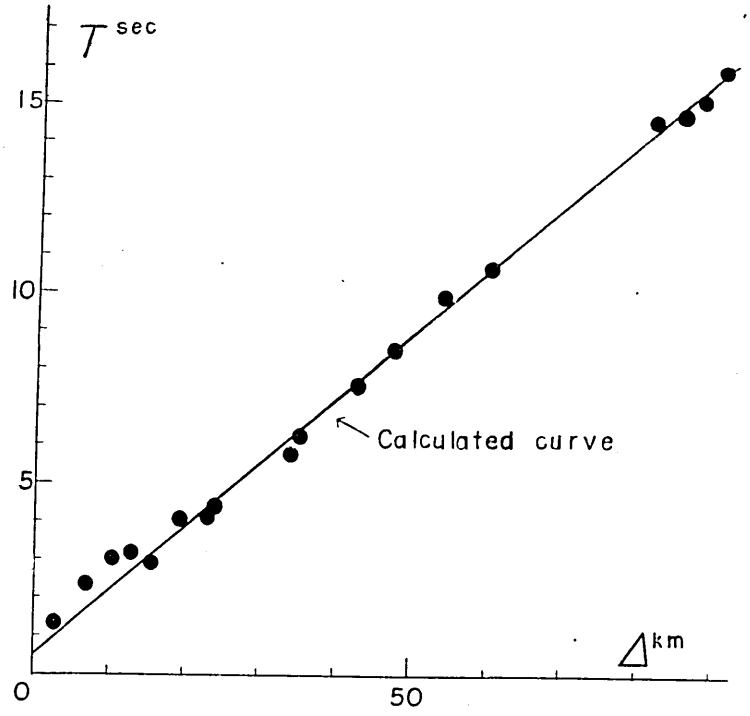

Fig. 5. The travel-time curve of the second approximation.

the observation points where the travel-time was affected by the layer of 2.51 km./sec. show large deviations, $(O-C)$. Therefore, as in the natural earthquake study, five observations with larger $(O-C)$ values were omitted in the following calculation, and the unknowns were again

determined. The results are tabulated in the column III of Table I, and the determined position of the epicentre is shown in Fig. 2-(b). These results agree very well with the values of column II of the same table within the mean errors. The fact that we had almost the same results in the third approximation as those of the second approximation, notwithstanding the neglect of the five observations of the arrival times much affected by the layer with the velocity of 2.51 km./sec., seems to indicate that the discrepancy between the velocity determined in this trial and the actual value obtained by R. G. E. S. was not due to the assumption of a uniform structure.

Next we have to consider the effect of the subjacent layer with the velocity of 6.2 km./sec. on the accuracy of the hypocentre determination. Four observations of arrival times near $\Delta=80$ km. which are presumed to be affected by the lower layer were omitted out of the eighteen in the calculation. The results are entered in column II′ of Table I, and the position of the epicentre relative to the actual one is shown in Fig. 2-(b). It is to be noted that the velocity is well-determined this time and agrees well with that of R.G.E.S. Therefore it may be said that in the hypocentre determination the identification of phase is of the prime importance. In this case the distance ($\Delta_{II'}$) between the determined epicentre and the actual one is 1.52 km. and smaller than Δ_{II}(=1.70 km.).

4. Summary

In the present paper, the author made the same attempt as in the first paper, that is, the attempt to determine the position of shot and shot time assumed to be unknown and compare them with the actual known values. The data used were those obtained by R. G. E. S. on the occasions of the second and third Isibuti explosion. Through this trial we could confirm the results obtained in the first paper, so actually the epicentre and velocity are relatively well determined, while the shot time seems to be sensitive to the nature of the superficial layer. Besides these results, the identification of phase is considered to be much more important in the hypocentre determination than the superficial layer. As to the velocity, when only a certain phase was used, it was determined very well in comparison with the actual one.

5. Acknowledgements

The present author wishes to express his sincere thanks to the members of the Research Group for Explosion Seismology who placed the data at the author's disposal. His hearty thanks are also due to Professor H. Kawasumi for his helpful suggestions and encouragements throughout this study.

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13. 震源決定の精度について (第2報)

地震研究所　浅　野　周　三

第1報に於いて地震探鉱の利点を応用し，実際は既知である爆破点，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，それ等の量を定め，実際の値と比較し自然地震に於ける震源決定の精度に関する目安を得る事を試みたが，本報に於いては，その規模に於いて，より自然地震に近い爆破地震動研究グループの石淵第2回，第3回大爆破地震動観測の資料を用いて，第一報と同様な取扱いを試みた．この2回の爆破は殆んど同一地点で行われてゐるので，一つの爆破と見做し，又爆破点の深さ，観測点の高度に関しては，震源決定の精度に及ぼす効果の考察は省略したが，得られた結果と爆破地震動研究グループによつて決定された地殻構造とを比較すると，震央と速度はよく定まり，震源発震時は，比較的表面層の影響をうけ易い等，第一報の結果を実際に確かめるを得た．更に震源決定に於いては，表面波よりも位相の対応が，より重要であると云う結果が得られた．勿論以上の結果は，地殻構造，観測点の配置，震源決定の方法等の点で，特別な条件の下で得られたもので，これ等についての考察は将来の機会を待ちたいと思つてゐる．

貴重な資料の使用をお許し下さつた爆破地震動研究グループの方々に記して感謝の意を表する．