S in Three European Earthquakes

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Summary

Readings have been made of records of three European earthquakes, with the object of testing the behaviour of S between 10° and 20°. In the earthquake of 1950 September 5, a linear formula fitted up to about 9°, but there appeared to be a jump of about 4 s at that distance. There were too few observations in the range in question on 1951 May 15 to give useful information. The Dalmatian earthquake of 1962 January 7, however, had 16 S readings between 10° and 20°. They showed no sign of a jump and were substantially earlier than the J.B. Table of 1940. It appears that a linear function of distance may fit the times of S in Europe up to 20°.

In a recent study (Jeffreys 1962) S was traced in shallow European earthquakes to about 9°; \( dt/d\Delta \) was found, on an average, to be about 0.6 s/deg less than in the J.B. Table of 1940. At greater distances the readings became ragged; there were signs of three different phases, but gaps over some ranges of distance made it impossible to see how these should be connected. Inspection of original records seemed required. The Italian earthquake of 1950 September 5 had a very long series of readings in the I.S.S. and these had already been discussed in a study by Lehmann (1961). That of 1951 May 15 had exceptional features. S was a few seconds early in comparison with P, and \( P \) at large distances also a few seconds early in comparison with short distances. These suggested a slight focal depth (in the lower layer). But a considerable number of stations reported \( Pg \) and \( Sg \), suggesting an upper layer focus. It seemed worth while to check the readings. Lehmann called our attention also to a recent earthquake in Dalmatia, 1962 January 7, which seemed to have been well recorded.

We applied for seismograms from stations that had given what appeared to be satisfactory readings of P. Miss Lehmann visited Cambridge and gave valuable assistance and instruction in the readings. Other stations sent their records after her departure.

Epicentres were recomputed on the basis of the 1953 P times in Europe (Jeffreys 1953). Those for the 1950 and 1951 earthquakes had already been done in the form (Jeffreys 1962)

\[ Y = \text{correction to } t_0; \]
\[ \xi = \text{correction for displacement of epicentre to south}; \]
\[ \eta = \text{correction for displacement to east}. \]

Up to 20° or so, the corrections for epicentre are sufficiently nearly independent of distance, and permit corrections according to azimuth without recomputation of

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distances. \( S \) is compared with the formula \( 13.3 + 24.28\Delta / f \), the solution for a surface focus.

In most cases our readings agreed with the I.S.S. within a second, but in a few there were differences up to 48. In some we could not see anything readable at the times given in the I.S.S., and in others there were definite movements not given in the I.S.S.

The trial, not the corrected \( t_0 \), has been subtracted from all observed times. Results for 1950 September 5 are given in Table 1.

<table>
<thead>
<tr>
<th>Station</th>
<th>( \Delta ) (I.S.S.)</th>
<th>Azimuth (O-C)</th>
<th>( P ) m</th>
<th>( S ) s</th>
<th>( S ) (O-C)</th>
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</table>

The negative residuals at Rome and Rocca di Papa may be due to a small foreshock; such a phenomenon has been noticed in other earthquakes.

The break in the \( S \) residuals at Potsdam and beyond is clear. On account of the fact that \( d^2t/d\Delta^2 \) is normally negative the negative residuals at Pulkovo and Moscow may be regarded as simply due to departure from a linear formula. Against the 1940 Table they become: Pulkovo -7s, Moscow 0s. But allowance for such a curvature would increase the residuals from Potsdam to Helsinki.

For 1951 May 15 results are in Table 2.

The original solution was based on \( P \) at thirty-eight stations, and the string of slightly negative residuals from 2° to 6° may be an accidental selection. The positive residual at Salo might be regarded as further slight evidence for focal depth. Little new information is derived for \( S \); the previous negative residuals are confirmed by our readings, but we received no records that gave satisfactory readings of \( S \) beyond 8°. On the other hand, if our negative \( P \) residuals can be interpreted as a correction of -2s to \( t_0 \), it will be possible to fit the data both for \( P \) and \( S \) with a focus near the base of the lower layer after all.
For 1962 January 7 there were no published data, and the solution is based on our own readings. We were greatly helped by thirteen records from Russian stations collected by Dr N. Kondorskaya and one from Zagreb, which greatly reduced the uncertainty in longitude of the epicentre and also provided direct information about the range between 10° and 20°. The solution as given in Table 3 is $t_0 = 10h 3m 13.9\pm 0.2s$, latitude $43.25\pm 0.06^\circ$N, longitude $17.02\pm 0.04^\circ$E, standard deviation of one $P$ observation 1.91s. In the table, as readings were made to one second, the observed times given are $t = 10h 3m 14s$, but 139s has been used in calculating the residuals.

The $S$ residuals against the linear formula are mostly small, but, unlike those in the 1950 earthquake, show no recognizable jump at any distance. In fact the linear formula fits reasonably well up to 20°. This was totally unexpected. The standard deviation up to 20° is 2.4s (queried readings being omitted). In comparison with previous sets of readings they are unusually consistent. Negative residuals appear beyond 20°, indicating a considerable change in $dt/d\Delta$ about that distance.

For comparison we give residuals against the 1940 Table. They give a standard deviation of 4.6s, so the linear formula is very much better.

Figure 1 is a reproduction of the Simferopol record for the earthquake of 1962 January 7 and illustrates the difficulties encountered in reading $S$ between 10° and 20°. Readings were taken at 10h 8m 41s, 44s, and 51s on the N–S, E–W, and vertical seismograms, yielding travel times of 5m 13s, 16s, and 23s respectively. On the principle that the earliest reading is usually correct and because the other records appear to be disturbed after that time the reading of 5m 13s was taken to be $S$. We have replaced Russian abbreviations for “compression” and “rarefraction” by A and K as used in the I.S.S.

It is hoped that further work, using deep focus earthquakes, may give additional information, particularly on Lehmann’s interpretation in terms of a layer of low velocity.

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Fig. 1.—Simferopol 1962 January 7. 44°98’N, 34°12’E; Δ = 12°41’
### Table 3

1962 January 7d 10h 3m 13°9 ± 0°528  
43°25° ± 0°06° North, 17°02° ± 0°04° East

<table>
<thead>
<tr>
<th>Station</th>
<th>Δ</th>
<th>Az.</th>
<th>P</th>
<th>S</th>
<th>Scale. (linear)</th>
<th>Sun.</th>
<th>S1840</th>
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### References