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P TIMES FROM DEEP FOCUS CENTRAL ASIAN EARTHQUAKES

R.C. AGRAWAL

INTRODUCTION

A number of travel-time tables have been constructed by many seismologists using different data and methods. Jeffreys and Bullen (1940) and Gutenberg and Richter (1934–1939) are by far the best travel-time tables made till late thirties.

Since then the number and quality of seismological stations have increased considerably. Nuclear and other kinds of explosions have also contributed greatly in reducing the uncertainties. With these new assets seismologists from western countries, mostly from United States, decided to attempt for a new set of P travel-time tables. They used data from 300 stations recording 400 earthquakes and 30 explosions and employed the method similar to that used in making Jeffreys and Bullen (1940) tables. These finally culminated into Herrin et al. (1968) tables. On comparison with Jeffreys and Bullen (1940) tables, it was revealed that the amount of accuracy achieved in the new tables differs very little from 1940 tables for distances more than 20° epicentral distance. It was thus concluded that efforts in improving upon the 1940 tables will yield little than desirable.

As it is known since long that atleast upto the upper mantle the interior of the earth varies considerably from one region to the other, the construction of regional travel-time tables was taken up (Nuttli, 1963). Following a series of investigations, Jeffreys (1966) was able to tabulate the following velocities for P_n and S_n for different regions for short epicentral distances.

REGIONAL VELOCITIES OF P_n AND S_n

Area	P_n		S_n	
	$dt/d\Delta$ (S/deg)	V_p (km/S)	$dt/d\Delta$ (S/deg)	V_s (km/S)
Europe	13.66±0.07	8.140±0.041	24.28±0.15	4.576±0.028
Japan	14.13±0.04	7.870±0.024	25.26±0.23	4.398±0.041
Central Asia	13.64±0.10	8.146±0.060	24.11±0.10	4.608±0.018
Pacific	13.65±0.04	8.145±0.024	24.11±0.10	4.608±0.018
W. North America	13.95±0.16	7.966±0.091		
E. North America	13.59±0.10	8.176±0.060	23.66±0.17	4.696±0.033
J.B. Tables	14.08	7.90	25.09	4.29

*School of Research and Training in Earthquake Engineering, University of Roorkee, Roorkee 247 672.

Jeffreys (1954) studied P times from 6 Japanese and 6 European earthquakes and constructed tables for earthquakes in Europe and Japan. Arnold (1965) made a detailed study of Japanese earthquakes and Gogna (1967) studied Pacific times. Agrawal (1975) made a thorough study of deep focus Indian earthquakes. In this paper, an attempt has been made to study the Central Asian deep focus earthquakes to calculate P travel times.

SELECTION OF DATA

Originally sixty deep focus earthquakes having latitudinal extent 36°-39°.5N and longitudinal extent 69°.9-74°.5E were selected from the bulletins of International Seismological Summary (I.S.S.). On recalculation of parameters, using method of Uniform Reduction (Jeffreys 1961) and I.B.M. 360 Computer of Delhi University, the solution of only fifth four earthquakes converged.

REVISION OF DATA

The parameters of the earthquakes as given in I.S.S. are taken as trial values and are recalculated using European times (Jeffreys, 1954). This is necessary because parameters calculated by I.S.S. involve J.B. times (Jeffreys and Bullen, 1940), which are world average, and European times represent much better this region (central asian region) as has been shown by Jeffreys (1954) with norml earthquakes. The method of recalculation of the parameters has been described by Agrawal (1975) in detail. Arnold (1965) noticed that there was a systematic variation of residuals with azimuth beyond 15° epicentral distance and he attributed this to an error in the travel times at large distances due to faulty depth allowances. To avoid this, the solutions of all the earthquakes were revised by using data only upto 15° epicentral distance. These revised parameters were finally accepted for further use in the analysis.

SYNTHESIS OF EARTHQUAKE DATA

For combining the data from all the earthquakes, it was necessary to bring them at one common depth. Therefore, all the earthquakes were brought to surface by using a technique (modified method due to S. Mohorovicic, 1925) which has been described in Agrawal (1975).

UNSMOOTHED TRAVEL TIMES

The data was now combined and weighted means at 1° interval were calculated for the entire range which are given in Table 1.

SMOOTHING

It has been observed that there is a prominent discontinuity around 20° epicentral distance by a number of authors (Agrawal, 1977). Therefore for smoothing the travel times, the data was divided into two ranges (i) times for $\Delta > 20°$ and (ii) times for $\Delta < 20°$.

P TIMES FOR $\Delta > 20°$

Method of summary values (Arnold, 1968) was employed in smoothing the data in this range. The whole data was divided in ten ranges and the twenty summary points (Table 2) were used in calculating the times for the range of epicentral distance $20° < \Delta \leqslant 100°$. Use of third divided differences was made in interpolation. The value of χ^2 was found to be 79.0 on 61 degrees of freedom. This is on the larger side. On checking it was found that at 60° epicentral distance, the value of χ^2 is 21.05. This indicates that there is a sharp discontinuity in the lower mantle at the corresponding depth. Similar discontinuity in the lower mantle has been found by a number of authors (Julian and Sengupta, 1973). Omitting this point, we find that χ^2 is within acceptable limits (72 on 60 degree of freedom).

We know that $dt/d\Delta$ for P times must not increase with distance. This condition was not met at an epicentral distance of 30° and therefore times in the range $26° \leqslant \Delta \leqslant 37°$ were smoothed again, but not more than their standard error.

It was found that $dt/d\Delta$ attains a minimum at $\Delta = 100°$ and then increases with Δ. Taggart and Engdahl (1968) explain this behaviour and suggest that this minimum value of $dt/d\Delta$ should be retained for times upto 105°. They further remark that this freezing creates an artifical diffraction boundary but the velocity distribution above this boundary is not affected.

Therefore the value of $dt/d\Delta$ at $\Delta = 100°$ i.e. 4.56 s/deg was kept constant for $100° \leqslant \Delta \leqslant 105°$. Thus the finally obtained P times for $20° < \Delta \leqslant 105°$ are contained in Table 4.

P TIMES FOR $\Delta < 20°$

Times for this range of distance are plotted and it is observed that these can be fitted by a straight line upto 16° epicentral distance. Many authors have already established a shift in the location of 20° discontinuity (Agrawal, 1977). Thus least square method was used in fitting the observations upto 16° to a straight line. The following solution was obtained.

$$t = a + b\Delta' \qquad \ldots(1)$$

where

$$a = (171.49 \pm 0.097)s$$

$$b = (134.98 \pm 0.321)s$$

$$10\Delta' = (\Delta - 12°.0)$$

With $\chi^2 = 16.99$ on 10 degrees of freedom. The value of χ^2 is large at epicentral distances 8° and 12°. Similar large values of χ^2 were found by Agrawal (1977) at corresponding distances. They may be due to the anomalous regions inside the Earth (upper mantle) at corresponding depths.

Times for distances upto 16° were calculated by using (1) and times for the remaining distances 17°, 18°, 19° were found by interpolation. All these times are given in Table 3.

The value of $dt/d\Delta$ at short distances is 13.50 s/deg which shows that this region has a higher P_n velocity. On comparison with different regions (see introduction) it is found that the region under investigation has a lower value of $dt/d\Delta$.

The smoothed travel-times for the range $0° \leqslant \Delta < 105°$ have been given in Table 3 and shown in figure 1 (a). The deviation of these times from Jeffreys and Bullen (1940) travel times have been shown in Figure 1 (b).

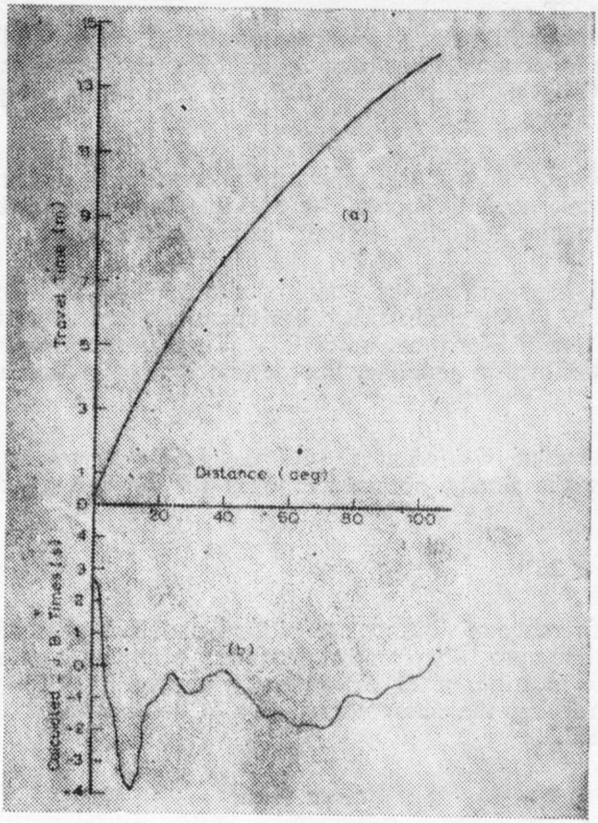

Fig. 1 (a) P times for central asian region
(b) Deviations of central asian times (a) from J.B. P times

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TABLE I

UNSMOOTHED TRAVEL TIMES OF P

Δ (deg)	Weights	Mean correction (s)	Unsmoothed Times (s)
5	6.378	0.9151±1.5891	77.0151
6	9.065	0.4723±1.8023	90.2723
7	9.048	0.2063±0.2063	103.7063
8	11.866	−0.5496±1.4184	116.6504
9	20.429	0.2004±0.8952	131.0004
10	23.174	−0.0351±1.0617	144.4649
11	20.433	−0.1434±0.8210	157.9566
12	31.040	0.3743±1.7263	172.1743
13	59.003	−0.4009±1.1813	184.9990
14	90.903	−0.2591±1.3381	198.6409
15	123.635	−0.3119±1.2058	212.0881
16	121.060	−0.2052±1.3718	225.1948
17	38.246	−0.6978±1.5367	237.3022
18	15.087	−0.4778±2.6907	249.8222
19	41.638	1.3771±1.6449	263.5771
20	76.297	2.1937±1.7324	275.9937
21	68.186	2.1264±1.4621	286.7263
22	69.556	1.5491±2.0660	296.4490
23	89.955	2.2066±1.7704	307.1064
24	32.733	1.9605±1.9184	316.7605
25	12.421	2.4135±1.4799	327.0134

Δ (deg)	Weights	Mean correction (s)	Unsmoothed Times (s)
26	22.365	1.3103±2.1775	335.5103
27	26.726	1.8721±7164	345.3721
28	11.753	1.3614±1.7426	354.0613
29	16.305	0.8844±1.8881	362.7842
30	79.988	1.0467±1.4232	371.9465
31	76.038	0.4002±1.1122	380.5000
32	13.090	0.5023±2.5262	389.3022
33	13.215	0.8184±2.2142	398.4185
34	17.339	0.7758±1.7094	407.0757
35	29.036	1.1282±1.8557	416.1282
36	40.372	0.8267±1.5156	424.3264
37	36.569	0.9930±1.5610	432.9929
38	36.014	0.7109±1.4614	441.2109
39	66.689	0.2721±1.2525	449.1719
40	55.326	0.9681±1.5944	458.1680
41	76.027	0.9757±1.5497	466.4756
42	66.343	0.1769±1.2369	473.8767
43	81.021	0.6193±1.3307	482.4192
44	101.332	0.7073±1.4673	490.6069
45	133.816	0.0215±1.5442	497.9211
46	69.395	0.4686±1.3687	506.3684
47	108.036	0.3157±1.3528	514.1157
48	93.148	0.4740±1.3691	522.0740

Δ (deg)	Weights	Mean corrections (s)	Unsmoothed Time (s)
49	47.953	0.1305±1.3905	529.4302
50	22.369	0.0724±1.0289	537.0723
51	32.295	−0.0184±1.0961	544.6814
52	39.937	−0.0801±1.2117	552.1199
53	43.839	−0.6959±1.2556	559.0039
54	29.930	−1.2395±0.8502	565.9604
55	36.061	−0.7880±1.6809	573.7119
56	49.252	−0.3585±1.6485	581.4414
57	9.797	−0.6756±1.8464	588.3242
58	66.215	−0.7603±1.5508	595.3396
59	34.416	−1.1509±1.7305	601.9490
60	31.478	0.0637±1.7078	610.0637
61	7.016	−1.2060±1.0332	615.5940
62	8.339	−1.0903±1.0248	622.5093
63	4.165	−0.8390±1.8379	629.3608
64	2.863	0.0643±1.1885	636.8643
65	8.377	−1.8267±1.4208	641.4734
66	1.840	−1.5970±1.2489	648.0029
57	0.934	−1.0454±	654.0999
68	1.900	−1.0454±0.5500	661.0547
69	5.716	−0.6122±0.8801	667.5876
70	21.047	−0.4158±0.5594	673.7842
72	5.742	−0.4123±0.7225	685.6877

Δ (deg)	Weights	Mean correction (s)	Unsmoothed Times (s)
73	0.962	0.3000	692.1997
74	7.675	0.5625±0.6553	698.2622
75	36.268	−.01638±8595	703.2361
76	17.234	0.6442±0.9228	709.6440
77	14.067	0.7168±1.5900	715.3167
78	4.780	1.1581±0.8870	721.2581
79	18.661	0.3304±1.3398	725.9304
80	0.946	2.0000	732.9998
81	13.319	1.2188±0.8202	737.5188
82	4.780	0.5787±1.0622	742.0786
85	6.653	1.6228±0.6433	758.6226
86	55.714	−0.6281±0.6498	761.3718
89	0.953	1.5000	778.0999
90	5.048	0.5551±1.7998	782.0549
91	24.637	0.2540±1.4192	786.5540
92	17.132	0.4969±1.2397	791.5969
93	15.211	0.8670±0.9266	796.6670
94	22.992	0.1868±0.7979	800.6868
95	15.842	0.3636±0.3515	805.4626
96	35.451	−0.0516±0.9868	809.6482
97	5.565	0.7964±1.6392	815.0962
98	9.589	0.3707±0.6426	819.1707
99	13.377	0.0568±0.9374	823.4565

Δ (deg)	Weights	Mean correction (s)	Unsmoothed Times (s)
100	11.907	−0.0862±1.7775	827.8818
101	2.811	−0.4761±1.7346	831.8237
102	0.950	−1.0000	835±8000
103	9.523	−0.2919±1.1550	841.0081
104	7.617	0.9476±1.1813	846.6475
105	12.095	1.7013±1.1831	851.8013

TABLE 2

SUMMARY VALUES

Range (deg)	First Summary point Δ	t	Second summary point Δ	t
20−24	20.5040	281.3340±0.0767	23.1325	308.2544±0.0774
25−29	25.7968	334.1033±0.1423	28.3719	357.3518±0.1558
30−35	30.4708	375.8945±0.0783	34.8293	410.0479±0.1242
36−41	36.8871	431.7891±0.0884	40.3508	460.9402±0.0739
42−49	43.3721	485.2354±0.0531	47.5138	518.1179±0.0537
50−57	51.3583	547.1377±0.0882	55.4319	576.9817±0.0861
58−66	58.5983	599.5923±0.0869	63.6802±	633.7061±0.1757
67−75	69.5267	670.8146±o.9782	74.6978	701.6287±0.1432
76−86	77.3371	717.1860±0.1303	83.9576	752.3997±0.1915
89−105	93.0015	796.0708±0.0861	101.8607	836.6897±0.1173

TABLE 3

TRAVEL TIMES OF P FOR CENTRAL ASIAN REGION

Δ (deg)	t m	t s	dT/dΔ (S/deg)	Cal—J.B. (s)
0	0	9.52		2.72
			13.49	
1		23.01		1.91
			14.50	
2		36.51		1.11
			13.50	
3		50.01		0.31
			13.50	
4	1	03.51		−0.39
			13.49	
5		17.00		−1.10
			13.50	
6		30.50		−1.70
			13.50	
7		44.00		−2.30
			13.50	
8		57.50		−2.80
			13.49	
9	2	10.99		−3.21
			13.50	
10		24.49		−3.51
			13.50	
11		37.99		−3.71
			13.50	
12		51.49		−3.81
			13.49	
13	3	04.98		−3.72
			13.50	
14		18.48		−3.42
			13.50	
15		31.98		−3.02
			13.50	
16		45.48		−2.52
			13.42	
17		58.90		−1.80
			13.07	
18	4	11.97		−1.23
			12.47	
19		24.44		−1.06
			11.60	
20		36.04		−0.96
			10.46	
21	4	46.50		−0.90
			10.31	

Δ (deg)	t m	t s	dT/dΔ (S/deg)	Cal—J.B. (S)
22		56.81	10.12	−0.69
23	5	06.93	9.92	−0.47
24		16.85	9.70	−0.25
25		26.55	9.35	−0.25
26		35.90	9.15	−0.30
27		45.05	8.97	−0.35
28		54.02	8.89	−0.48
29	6	02.91	8.87	−0.59
30		11.78	8.86	−0.72
31		20.64	8.85	−0.66
32		29.49	8.83	−0.61
33		38.32	8.81	−0.48
34		47.13	8.66	−0.37
35		55.79	8.51	−0.31
36	7	04.30	8.48	−0.30
37		12.78	8.46	−0.22
38		21.24	8.44	−0.16
39		29.68	8.35	−0.12
40		38.03	8.19	−0.07
41		46.22	8.06	−0.08
42		54.28	8.01	−0.22
43	8	02.29	8.00	−0.41
44	8	10.29	7.99	−0.51
45		18.28	7.95	−0.62
46		26.23	7.87	−0.57

Δ (deg)	t m	t s	dT/dΔ (S/deg)	Cal−J.B. (s)
47		34.10		−0.60
			7.75	
48		41.85		−0.75
			7.62	
49		49.47		−0.83
			7.54	
50		57.01		−0.99
			7.47	
51	9	04.48		−1.12
			7.42	
52		11.90		−1.30
			7.37	
53		19.27		−1.43
			7.32	
54		26.59		−1.41
			7.27	
55		33.86		−1.54
			7.23	
56		41.09		−1.51
			7.18	
57		48.27		−1.53
			7.11	
58		55.38		−1.42
			7.00	
59	10	02.38		−1.42
			6.86	
60		09.24		−1.46
			6.76	
61		16.00		−1.50
			6.67	
62		22.67		−1.63
			6.60	
63		29.27		−1.63
			6.53	
64		35.80		−1.70
			6.49	
65		42.29		−1.71
			6.42	
66		48.71		−1.69
			6.36	
67		55.07		−1.73
			6.28	
68	11	01.35		−1.75
			6.22	
69		07.57		−1.73
			6.12	
70		13.69		−1.71
			6.02	
71		19.71		−1.79
			5.97	

Δ (deg)	t m	t s	dT/dΔ (S/deg)	Cal—J.B. (s)
72		25.68		−1.82
			5.93	
73		31.61		−1.79
			5.92	
74		37.53		−1.67
			5.91	
75		43.44		−1.56
			5.90	
76		49.34		−1.36
			5.89	
77		55.23		−1.07
			5.70	
78	12	00.93		−0.87
			5.55	
79		06.48		−0.82
			5.43	
80		11.91		−0.79
			5.32	
81		17.23		−0.77
			5.21	
82		22.44		−0.76
			5.13	
83		27.57		−0.83
			5.06	
84		32.63		−0.87
			5.02	
85		37.65		−0.85
			4.97	
86		42.62		−0.88
			4.91	
87		47.53		−0.87
			4.87	
88		52.40		−0.80
			4.81	
89		57.21		−0.79
			4.76	
90	13	01.98		−0.72
			4.73	
91		06.71		−0.59
			4.69	
92	13	11.40		−0.50
			4.66	
93		16.06		−0.44
			4.64	
94		20.70		−0.40
			4.61	
95		25.31		−0.39
			4.59	
96		29.90		−0.40
			4.58	

Δ (deg)	t m	s	dT/dΔ (S/deg)	Cal−J.B. (s)
97		34.48		−0.32
			4.58	
98		39.06		−0.24
			4.57	
99		43.63		−0.17
			4.56	
100		48.19		−0.21
			4.56	
101		52.75		−0.15
			4.56	
102		57.31		−0.09
			4.56	
103	14	01.87		+0.07
			4.56	
104		06.43		+0.23
			4.56	
105		10.99		+0.39

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