

ADA036443

(12)
B.S.

COPY AVAILABLE TO DDC DOES NOT
PERMIT FULLY LEGIBLE PRODUCTION

(6) IMPROVED PROCEDURES FOR DETERMINING SEISMIC
SOURCE DEPTHS FROM DEPTH PHASE INFORMATION.

(9) QUARTERLY REPORT. 1 Jul - 30 Sep 76

(15) F08606-76-C-0003
ARPA Order - 2551

Edward / Page
Richard / Houck
Robert / Bauman



(11) Sep 76

July 1, 1976 to
September 30, 1976

(12) 19P.

Sponsored by:

Advanced Research Project Agency
ARPA Order No. 1620

LB
DDC DOES NOT
PERMIT FULLY LEGIBLE PRODUCTION

APPROVED FOR PUBLIC RELEASE.
DISTRIBUTION UNLIMITED.

1473

1406 167

Notice of Disclaimer

The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the Advanced Research Projects Agency, the Air Force Technical Applications Center, or the U.S. Government.

ACCESSION FOR
NTIS
DDC
UNCLASSIFIED
JUSTIFICATION

White Section
Buff Section

BY
DISTRIBUTION/AVAILABILITY CODES
0st. AVAIL. and/or SPECIAL

A

16 April 1973

F234.7

DEPARTMENT OF DEFENSE FORMS

F-200.1473 DD Form 1473: Report Documentation Page

SECURITY CLASSIFICATION OF THIS PAGE (If Other Than Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Improved Procedures for Determining Seismic Source Depths from Depth Phase Information		5. TYPE OF REPORT & PERIOD COVERED Quarterly Report
7. AUTHOR(S) Edward A. Page		6. PERFORMING ORG. REPORT NUMBER F08606-76-C-0003
9. PERFORMING ORGANIZATION NAME AND ADDRESS ENSCO, INC., 5408A Port Royal Rd., Springfield, Virginia 22151		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS VT/6710
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE September 1976
13. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) VELA Seismological Center 312 Montgomery Street Alexandria, Virginia 22314		14. NUMBER OF PAGES
15. DISTRIBUTION STATEMENT (of this Report) APPROVED FOR PUBLIC RELEASE. DISTRIBUTION UNLIMITED.		16. SECURITY CLASS. (of this report)
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 30, if different from Report)		18. DECLASSIFICATION/DE-ENCLOSURE SCHEDULE
19. SUPPLEMENTARY NOTES		
20. KEY WORDS (Continue on reverse side if necessary and identify by block number) Seismic depth, depth phase, echo detection		
21. ABSTRACT (Continue on reverse side if necessary and identify by block number) Differential travel times for the propagation modes SP-P, SPP-PP, SPPP-PPP and SPCP-PcP were computed and polynominal surface fitted for computer access.		

DD FORM 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (If Other Than Entered)

F-200.1473

ARMED SERVICES PROCUREMENT REGULATION

SUBJECT: Improved Procedures for Determining Seismic
Source Depths from Depth Phase Information

AFTAC Project No..... VELA T/6710
ARPA Order No..... 2551
ARPA Program Code No..... 6F10
Name of Contractor..... ENSCO, INC.
Contract No..... F08606-76-C-0003
Effective Date of Contract 1 September 1975
Reporting Period..... 1 July 1976 to
30 September 1976
Amount of Contract..... \$73,963
Contract Expiration Date..... 30 September 1976
Project Scientist..... Edward A. Page
(703)321-9000

Introduction and Summary

During the last quarter of this contract, differential travel time information for the propagation modes sP-P, sPP-PP, sPPP-PPP, and sPcP-PcP were computed and represented for computer access using a polynominal surface fit. Utilization of this additional travel time information should improve the constructive use of seismic depth phase information contained throughout the coda thereby increasing the percentage of events for which accurate source depth determinations can be obtained. The accuracy of the polynominal surface representation of the computed travel times as well as the accuracy of these travel times in comparison with known sP-P travel times were very good.

Major Accomplishments

A seismic ray tracing program was used to determine the differential travel times for the propagation modes sP-P, sPP-PP, sPPP-PPP, and sPcP-PcP for source depths of 5, 15, 20, 25, 30, 40, 50, 70 and 100 km, and epicenter distances of 10° , 15° , 20° , 30° , 40° , 50° , 60° , 70° , 80° , and 90° . The average earth velocity model assumed was that used to compute the BSSA travel times and the shear wave velocity was determined assuming a Poisson ratio of .25. The ray tracing program was modified to account for the nonspecular reflection at the earth's surface associated with the s-to-P mode conversion. This was done using Snell's law modified for the mode conversion. The remainder of the propagation path was then traced using the P-wave velocity profile.

In Figures 1 through 4 are plots of the differential travel times for sP-P, sPP-PP, sPPP-PPP and sPcP-PcP versus depth and epicenter distance. Comparison of sP-P and pP-P times taken from events in which these phases are clearly defined is in excellent agreement with these computed travel time differences. Figure 5 shows the (sP-P)-(pP-P) delay times for these depths and distances. Tables 6 through 9 show the coefficients for the polynomial fits (which are fourth order in depth and ninth order in epicenter distances) and differences in these surface fits from the computed values. Although these differences occasionally are over .2 seconds, we believe the surface representation to be more accurate than the computed values since the layered earth model often introduces nonphysical discontinuities in the travel time variations.

The addition of these travel times will allow the source depth determination procedure to utilize cepstrum amplitudes associated with these shear wave surface mode conversions and thereby involve more of the available depth phase information in the source depth determination procedure.

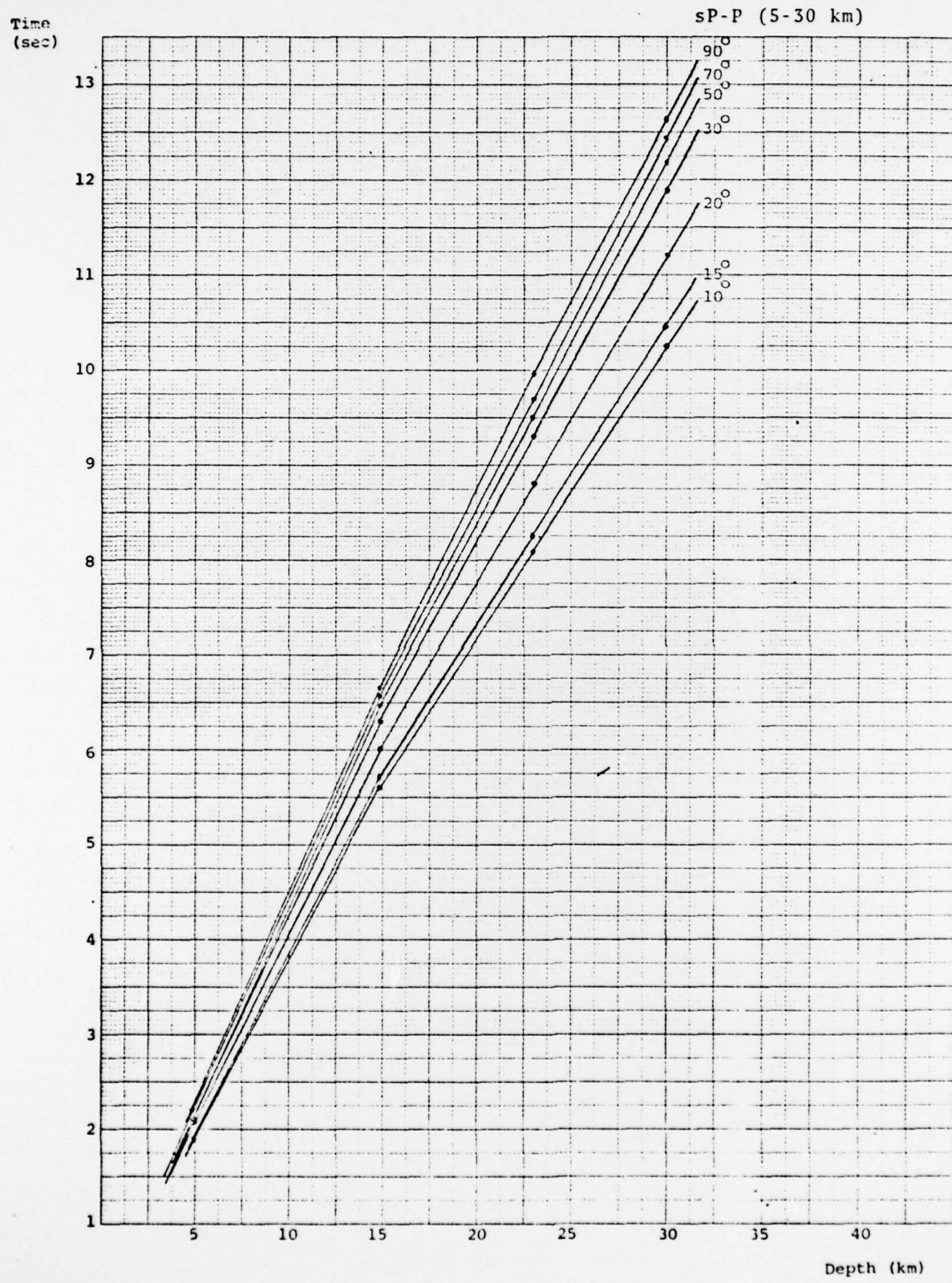


Figure 1a

sP-P (23-100 km)

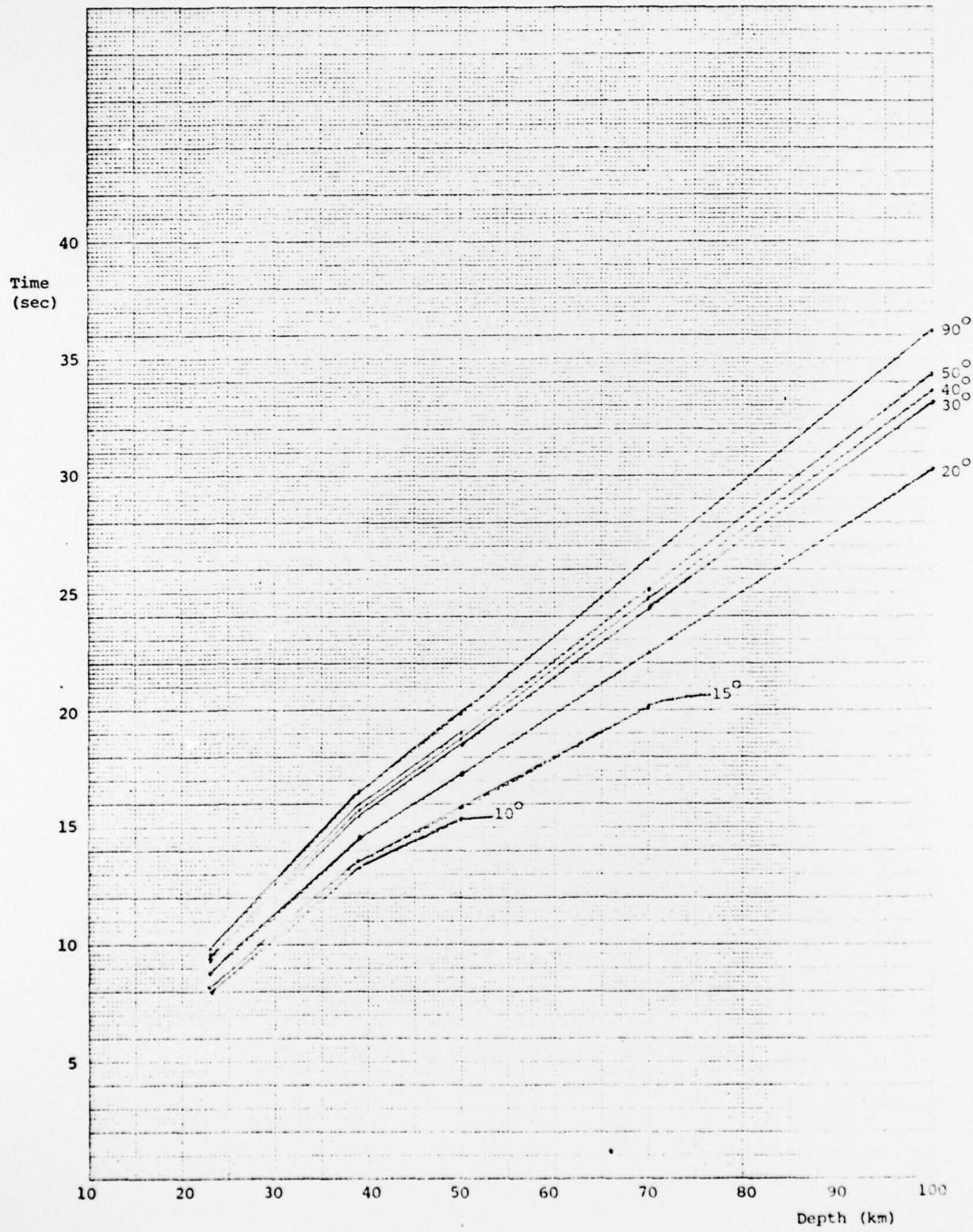


Figure 1b

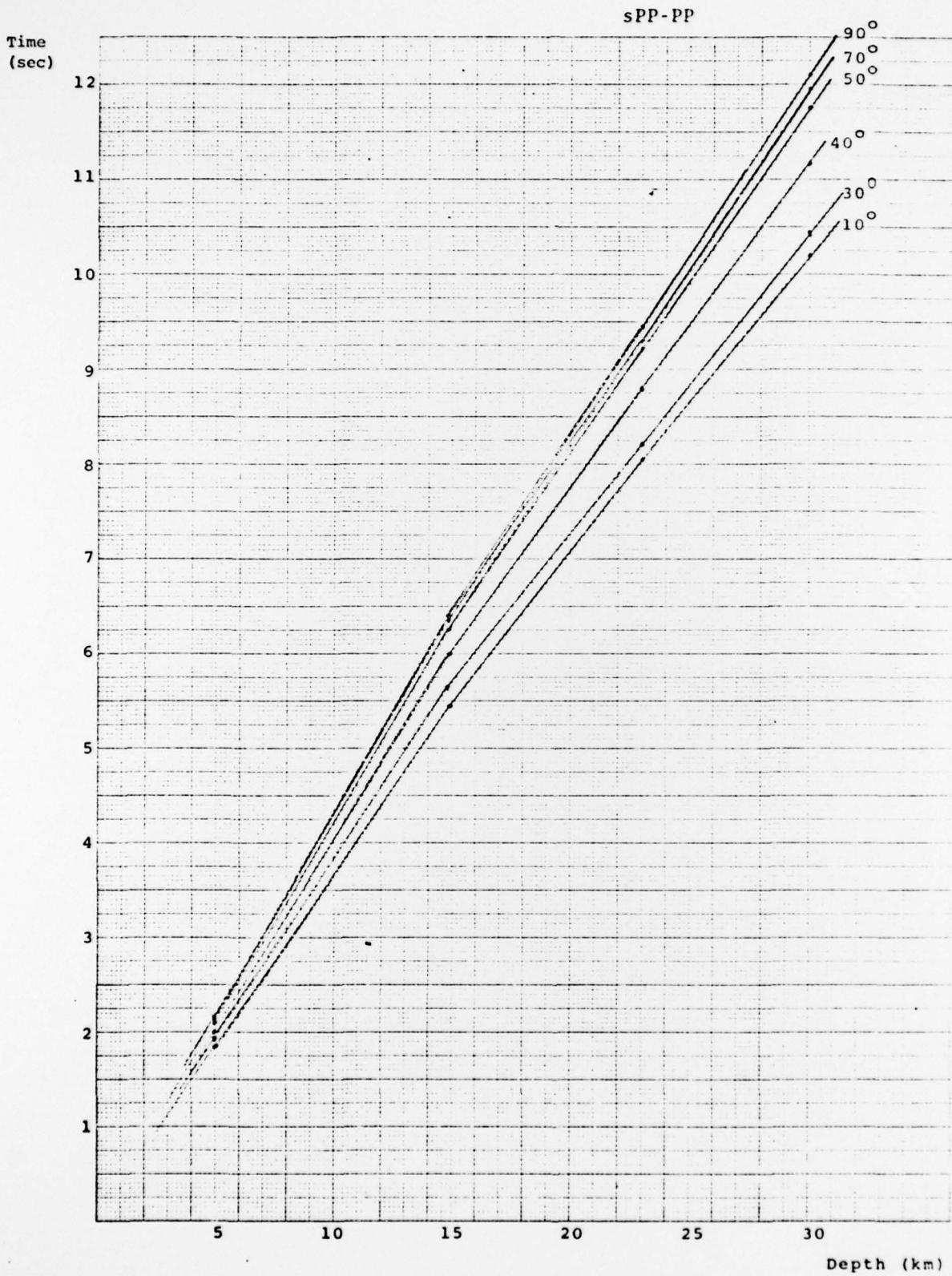


Figure 2a

sPP-PP

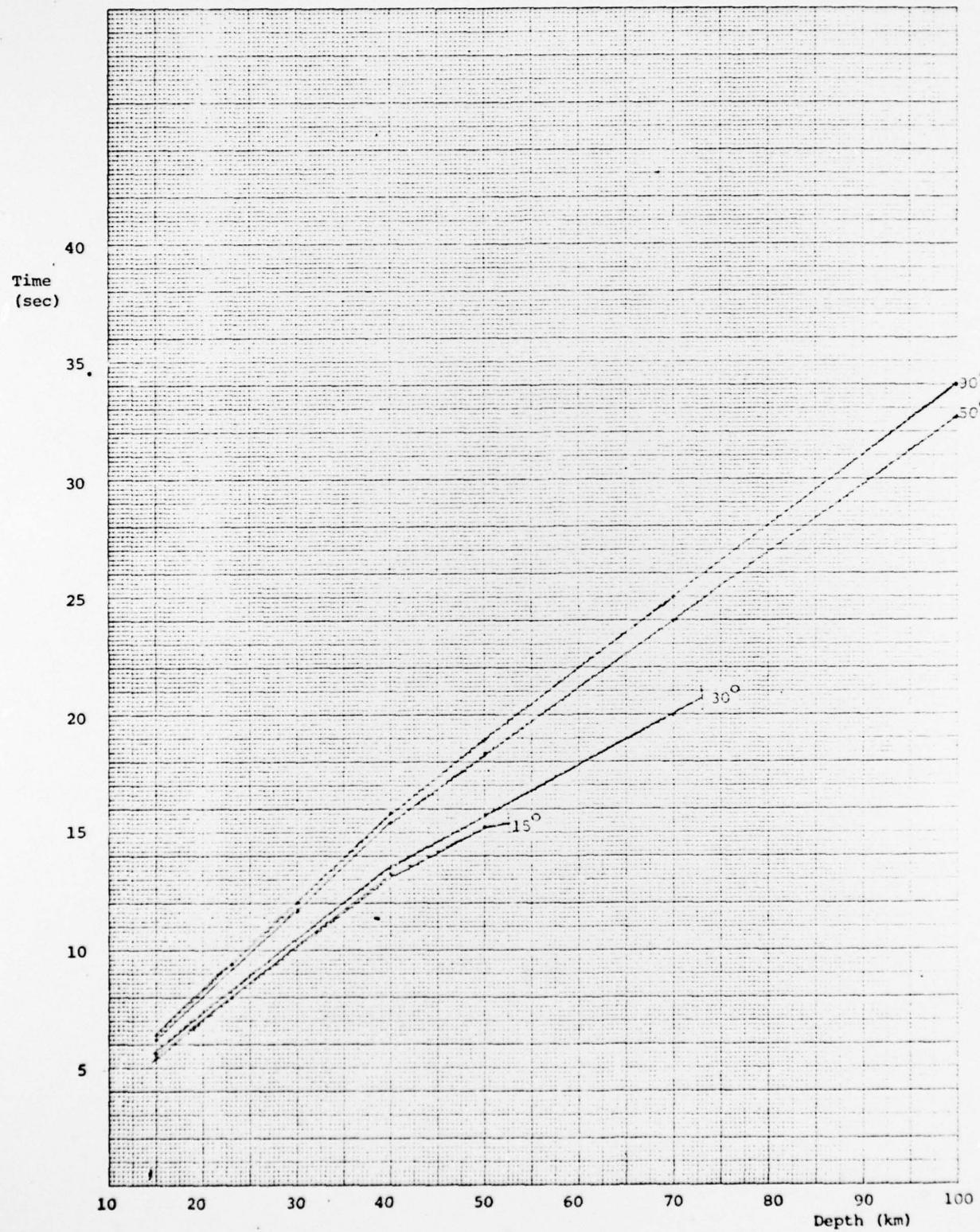


Figure 2b

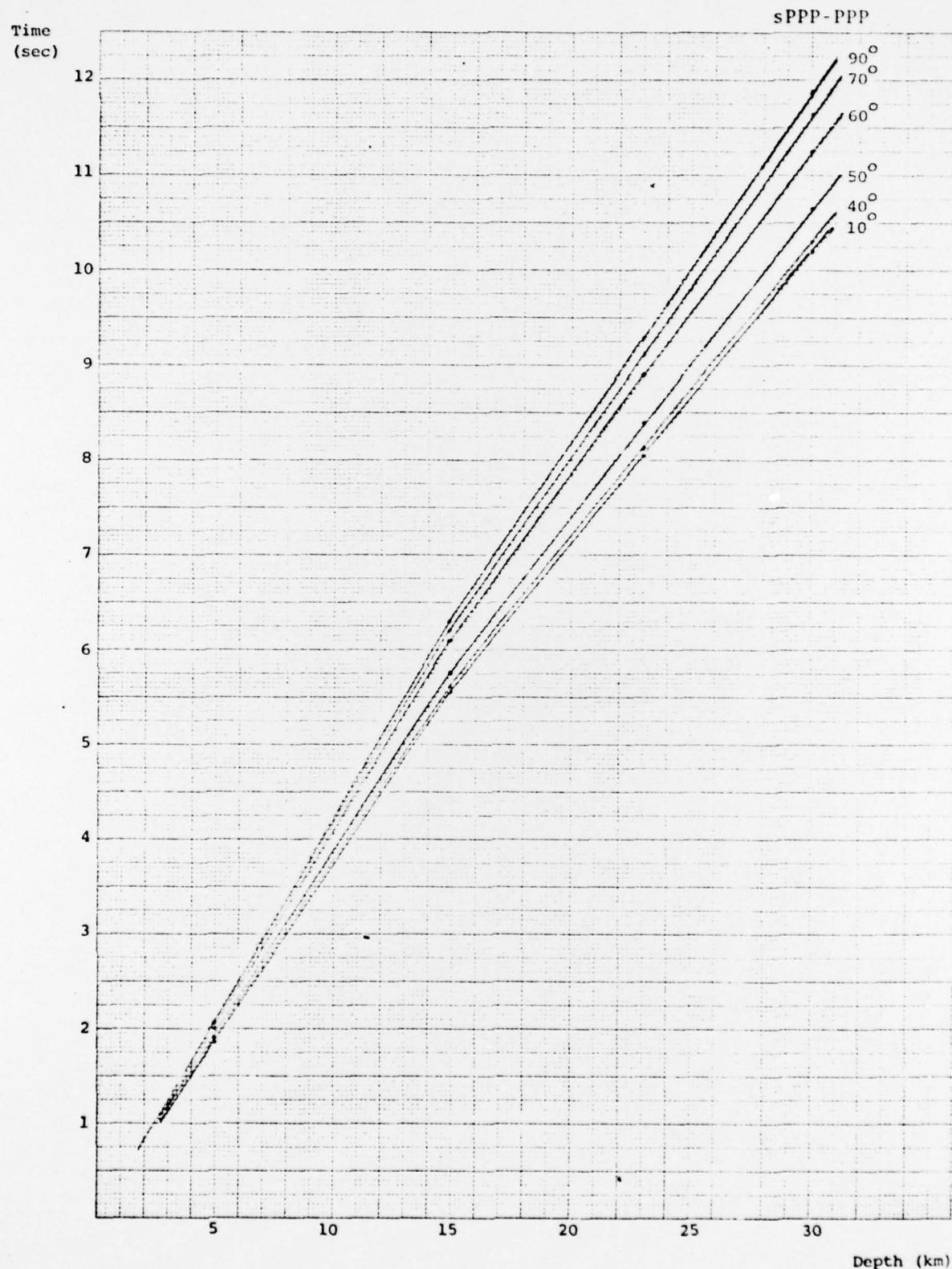


Figure 3a

sPPP-PPP

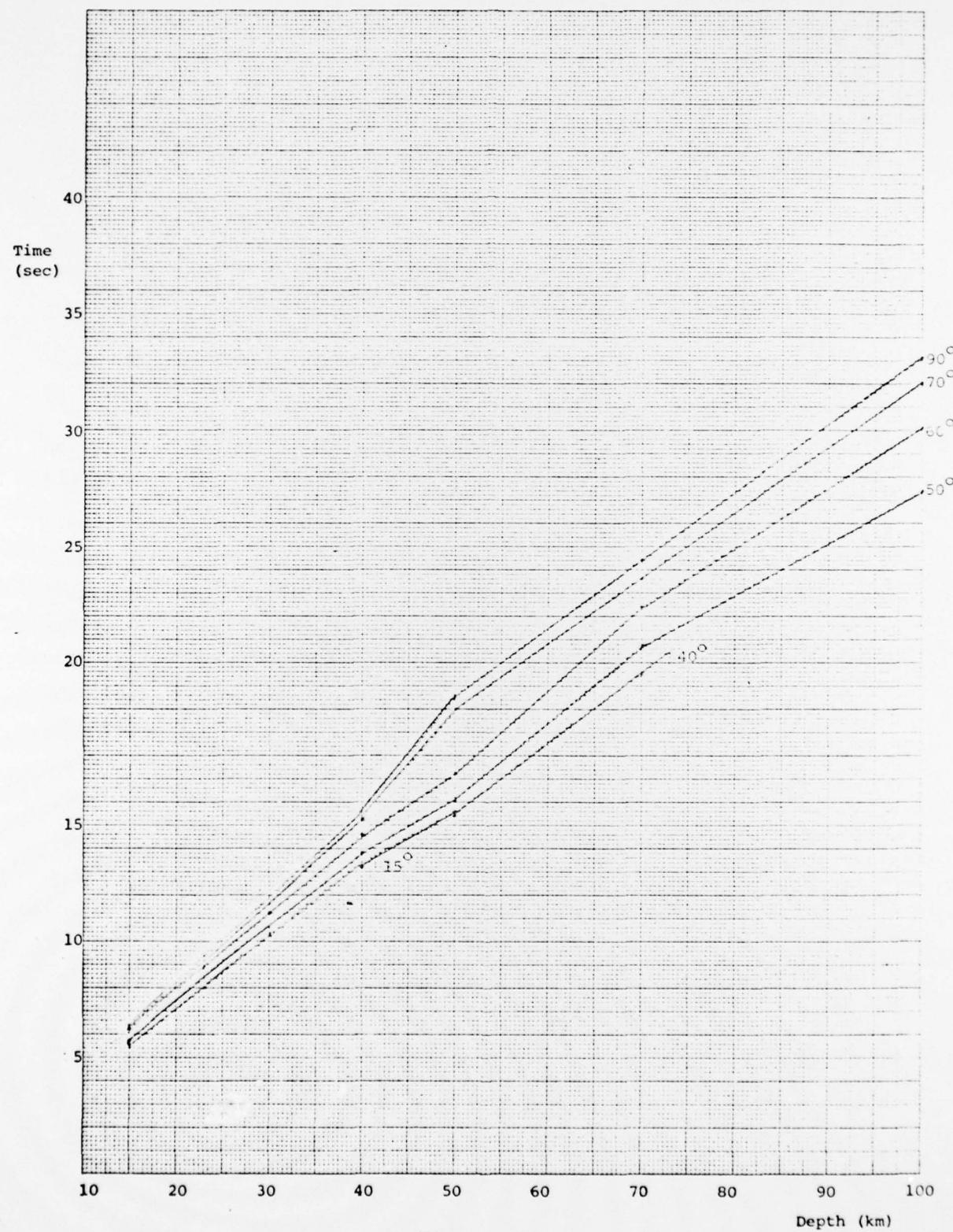


Figure 3b

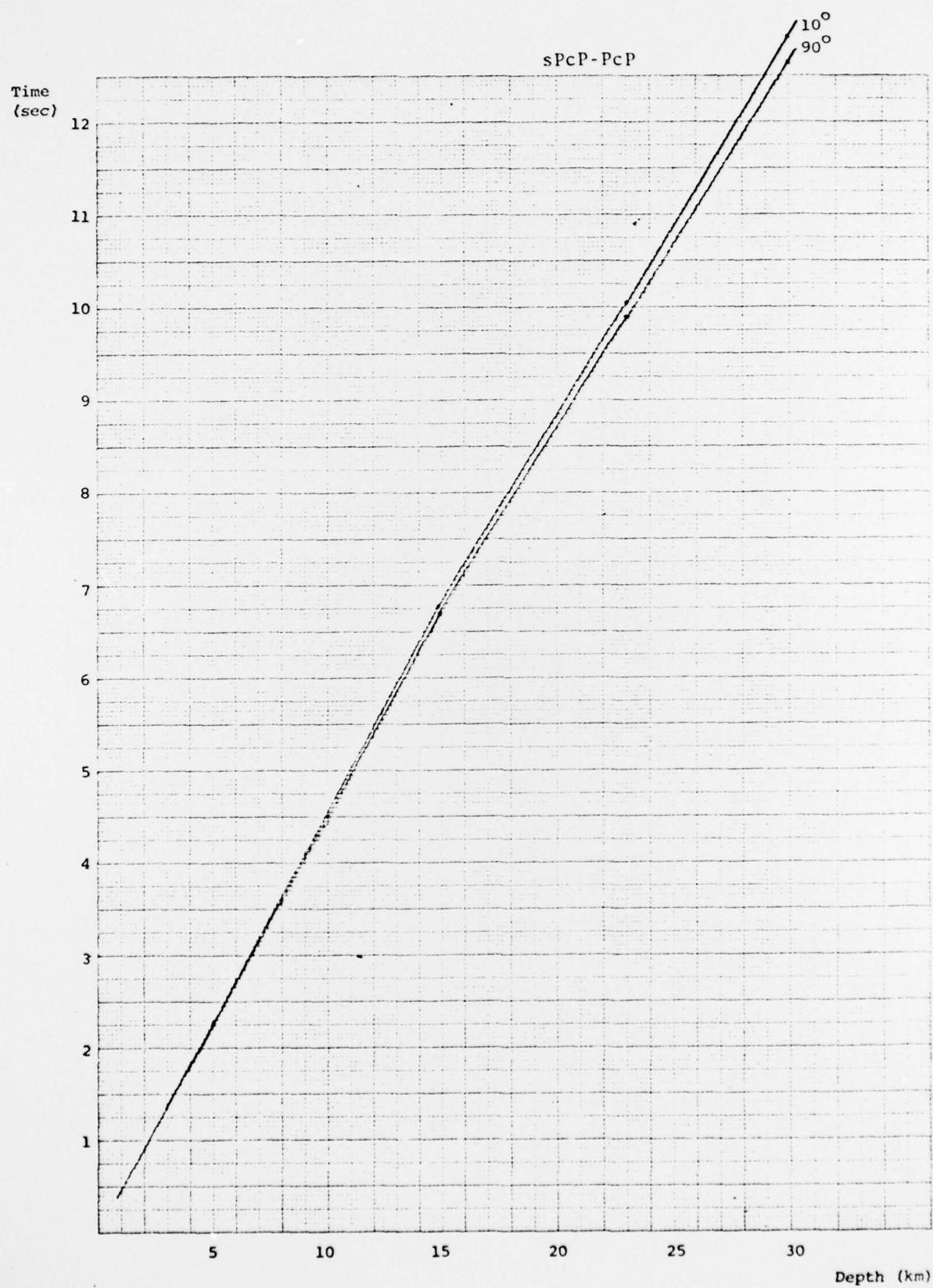


Figure 4a

sPcP-PcP

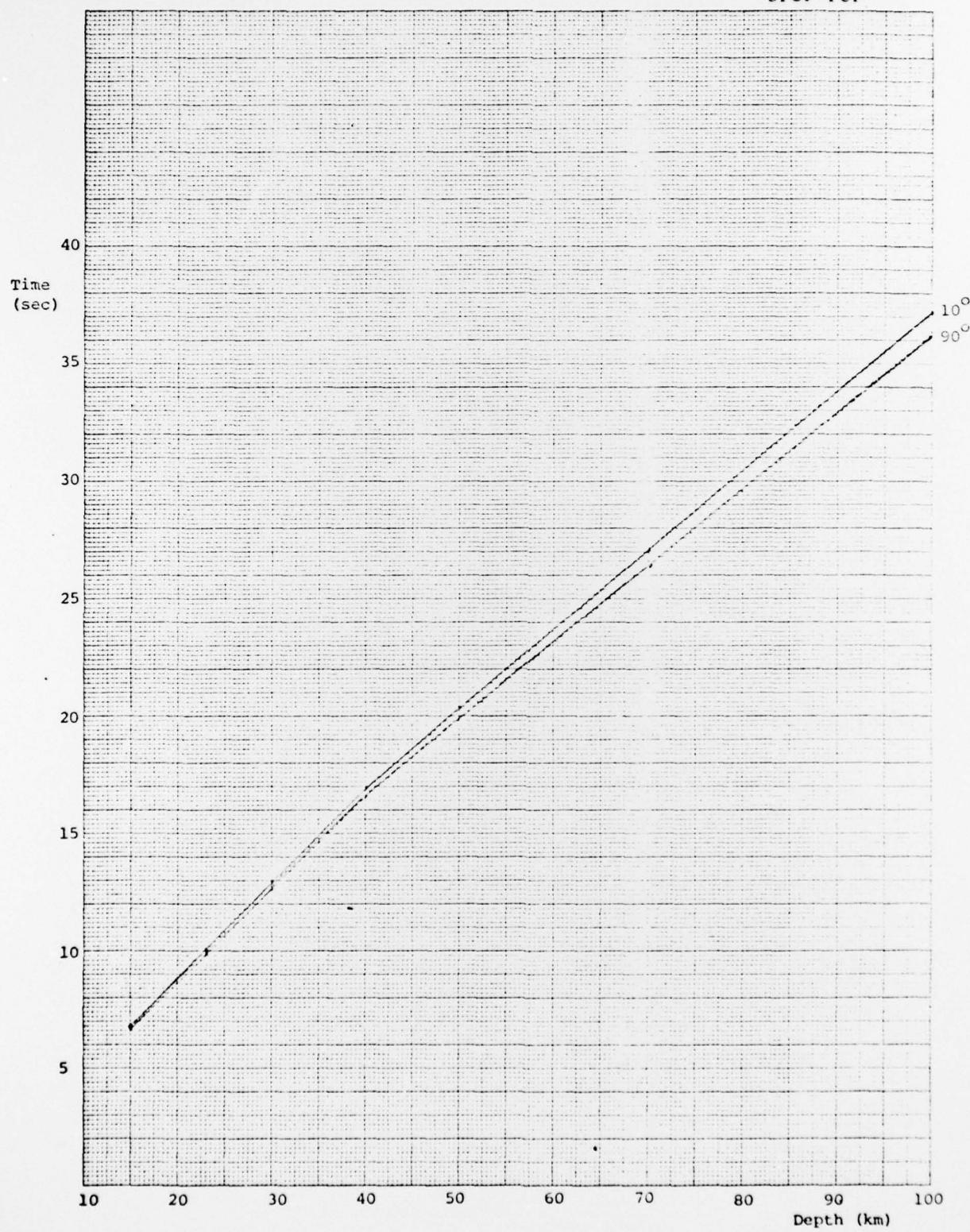


Figure 4b

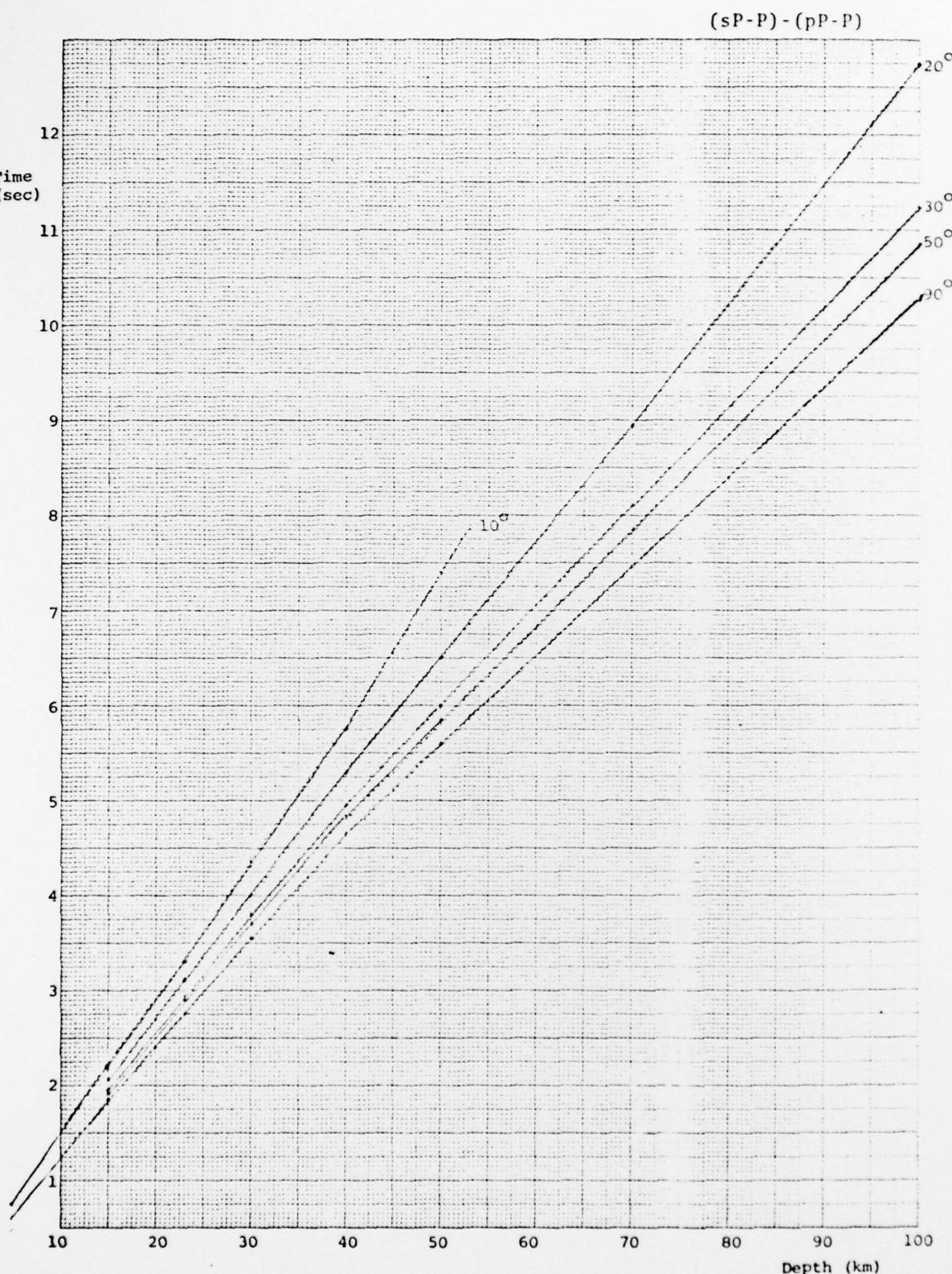


Figure 5

TRAVEL TIME DIFF (SEC) VS DEPTH (KM) AND DISTANCE DELTA (DEG)

DOUBLE POWER SERIES COEFFICIENTS FOR CALCULATING TRAVEL TIME DIFFERENCE

	TAU SUB 1J	TAU SUB 2J	TAU SUB 3J
J = 0	* 94255761E+00	- 55572891E-02	- 22859618E-04
J = 1	- 1721955E+00	* 24415032E-02	- 12823485E-04
J = 2	* 20157839E-01	- * 36968760E-03	* 27281394E-05
J = 3	- 12017345E-02	* 25614554E-04	- 20722974E-06
J = 4	* 42236115E-04	- * 99470331E-06	* 83545479E-08
J = 5	- 92821287E-06	* 23459771E-07	- 20059357E-09
J = 6	* 12923121E-07	- * 34397382E-09	* 29679735E-11
J = 7	- 11085379E-09	* 30672552E-11	- 26585638E-13
J = 8	* 53483940E-12	- * 15241345E-13	* 13235732E-15
J = 9	- 11106700E-14	* 32361308E-16	- 28128183E-18

CALCULATED TRAVEL TIME DIFFERENCE TABLE (***) MEANS UNALLOWED DEPTH FOR GIVEN DELTA

DELTA *	10.000	15.000	20.000	30.000	40.000	50.000	60.000	70.000	80.000	90.000
DEPTH \$	1.866	1.968	2.111	2.229	2.252	2.270	2.291	2.302	2.316	
5.000	5.444	5.622	5.927	6.302	6.370	6.438	6.500	6.561	6.601	6.645
10.000	8.151	8.369	8.864	9.397	9.517	9.622	9.725	9.822	9.889	9.960
15.000	10.362	10.565	11.269	11.911	12.063	12.221	12.364	12.491	12.585	12.680
20.000	13.112	13.388	14.251	15.251	15.503	15.689	15.893	16.067	16.201	16.331
25.000	15.347	15.924	17.100	18.446	18.785	19.024	19.293	19.519	19.696	19.864
30.000	**	19.904	22.177	24.351	24.857	25.223	25.622	25.969	26.228	26.475
35.000	**	29.116	32.958	33.635	34.274	34.841	35.424	35.773	36.146	

RESIDUALS BETWEEN TRAVEL TIME DIFFERENCE INPUT AND CALCULATED TRAVEL TIME DIFFERENCE

DELTA *	10.000	15.000	20.000	30.000	40.000	50.000	60.000	70.000	80.000	90.000
DEPTH \$	0.019	- 0.074	- 0.052	- 0.100	- 0.093	- 0.088	- 0.086	- 0.089	- 0.086	- 0.085
5.000	* 1.42	* 0.47	* 0.12	* 0.068	* 0.068	* 0.068	* 0.069	* 0.069	* 0.069	* 0.069
10.000	- 0.625	- 0.124	- 0.089	- 0.093	- 0.112	- 0.103	- 0.101	- 0.111	- 0.091	* 0.011
15.000	- 0.129	- 0.107	- 0.016	- 0.030	- 0.060	- 0.049	- 0.052	- 0.066	- 0.043	- 0.051
20.000	* 1.63	* 2.03	* 3.54	* 277	* 210	* 239	* 217	* 198	* 222	* 214
25.000	- 0.030	- 0.143	- 0.158	- 0.055	- 0.027	* 0.13	- 0.007	- 0.007	- 0.002	- 0.004
30.000	* 2.08	* 0.11	* 0.15	- 0.106	- 0.060	- 0.092	* 0.477	- 0.076	- 0.088	
35.000	* 1.57	* 0.31	* 0.32	* 0.32	* 0.32	* 0.32	- 0.099	* 0.019	* 0.006	

$(S+)^{BP-PP}$

TRAVEL TIME DIFF (SEC) VS DEPTH (NM) AND DISTANCE DELTA (DEG)

DOUBLE POWER SERIES COEFFICIENTS FOR CALCULATING TRAVEL TIME DIFFERENCE

	TAU SUB 1J	TAU SUB 2J	TAU SUB 3J
J = 0	• 99139961E+00	-• 39882993E-01	• 88693120E-03
J = 1	-• 14539561E+00	• 80307558E-02	-• 1975324E-03
J = 2	• 14753415E-01	-• 67171785E-03	• 17907379E-04
J = 3	-• 85573805E-03	• 31364853E-04	-• 90225685E-06
J = 4	• 31045998E-04	-• 93362993E-06	• 28400472E-07
J = 5	-• 72163911E-06	• 18663708E-07	-• 58237492E-09
J = 6	• 10634489E-07	-• 24774943E-09	• 77836964E-11
J = 7	-• 95965989E-10	• 21101808E-11	-• 65333857E-13
J = 8	• 48325852E-12	-• 10348369E-13	• 31231642E-15
J = 9	-• 10355417E-14	• 22134197E-16	-• 64780206E-18

CALCULATED TRAVEL TIME DIFFERENCE TABLE (* means unallowed depth for given delta)

DEPTH	DELTA *	10.000	15.000	20.000	30.000	40.000	50.000	60.000	70.000	80.000	90.000
5.000	1.0454	1.858	1.860	1.959	2.113	2.196	2.209	2.221	2.228	2.240	
14.900	5.438	5.426	5.438	5.595	5.995	6.258	6.305	6.339	6.365	6.402	
23.100	8.068	8.163	8.194	8.333	9.904	9.329	9.411	9.460	9.509	9.566	
30.000	10.413	10.339	10.397	10.527	11.248	11.824	11.938	12.902	12.070	12.146	
39.100	13.222	13.027	13.144	13.360	14.330	15.139	15.297	15.386	15.481	15.585	
50.000	*****	15.182	15.388	15.925	17.242	18.315	18.510	18.633	18.749	18.889	
70.000	*****	*****	20.045	22.532	24.207	24.431	24.662	24.787	25.009		
100.000	*****	*****	*****	30.078	32.890	32.949	33.500	33.491	33.886		

RESIDUALS BETWEEN TRAVEL TIME DIFFERENCE INPUT AND CALCULATED TRAVEL TIME DIFFERENCE

DEPTH	DELTA *	10.000	15.000	20.000	30.000	40.000	50.000	60.000	70.000	80.000	90.000
5.000	-• 049	• 095	• 028	-• 067	-• 094	-• 092	-• 102	-• 089	-• 092	-• 085	
14.900	• 026	• 142	• 152	• 070	• 062	• 003	• 002	• 006	• 011	• 003	
23.100	-• 020	-• 094	-• 094	-• 112	-• 109	-• 111	-• 110	-• 107	-• 094	-• 099	
30.000	-• 009	-• 111	-• 123	-• 092	-• 070	-• 054	-• 063	-• 059	-• 048	-• 053	
39.100	• 027	• 240	• 166	• 190	• 275	• 238	• 228	• 230	• 231	• 242	
50.000	*****	*****	*****	-• 057	-• 053	-• 016	-• 014	-• 012	-• 006	-• 009	
70.000	*****	*****	*****	• 051	-• 115	-• 161	-• 079	-• 124	-• 039	-• 059	
100.000	*****	*****	*****	• 091	-• 264	• 148	-• 142	• 172	• 110		

(S+)PPP-PFP TRAVEL TIME DIFF (SEC) VS+DSDPH (KM) AND DISTANCE DELTA (DEG)

DOUBLE POWER SERIES COEFFICIENTS FOR CALCULATING TRAVEL TIME DIFFERENCE

	TAU SUB 1J	TAU SUB 2J	TAU SUB 3J
J = 0	-• 5977079E+00	• 6742386E-01	-• 13310196E-02
J = 1	• 29276694E+00	-• 20371409E-01	• 37801578E-03
J = 2	-• 33915826E-01	• 23186443E-02	-• 41281689E-04
J = 3	-• 29771427E-02	-• 13821156E-03	• 23606905E-05
J = 4	-• 76939122E-04	• 49070703E-05	-• 80252808E-07
J = 5	• 17511067L-05	-• 10964565E-06	• 17146263E-08
J = 6	-• 25570498E-07	• 15568639E-08	-• 23303267E-10
J = 7	• 22951982E-09	-• 13688700E-10	• 19580996E-12
J = 8	-• 11545163E-11	• 67671726E-13	-• 92810797E-15
J = 9	• 24887750E-14	-• 14394943E-15	• 16982703E-17

CALCULATED TRAVEL TIME DIFFERENCE TABLE (** means unallowed depth for given delta)

DEPTH J	DELTA = 10.000	15.000	20.000	30.000	40.000	50.000	60.000	70.000	80.000	90.000
5.000	1.959	1.957	1.864	1.865	1.955	2.050	2.149	2.177	2.206	2.209
14.900	5.456	5.501	5.465	5.456	5.529	5.779	6.065	6.203	6.281	6.296
23.900	8.039	8.225	8.272	8.219	8.234	8.534	8.973	9.247	9.356	9.384
32.900	10.146	10.501	10.557	10.423	10.461	10.724	11.299	11.718	11.848	11.889
39.900	13.950	13.693	13.502	13.156	13.193	13.255	14.342	14.996	15.149	15.213
50.900	**	**	**	**	**	**	**	**	**	**
70.000	**	**	**	**	**	**	**	**	**	**
100.000	**	**	**	**	**	**	**	**	**	**

RESIDUALS BETWEEN TRAVEL TIME DIFFERENCE INPUT AND CALCULATED TRAVEL TIME DIFFERENCE

DEPTH J	DELTA = 10.000	15.000	20.000	30.000	40.000	50.000	60.000	70.000	80.000	90.000
5.000	-• 0.69	-• 0.77	• 0.96	• 0.27	-• 0.58	-• 1.29	-• 1.35	-• 0.90	-• 1.04	-• 1.04
14.900	• 1.04	• 0.46	• 0.74	• 1.37	• 0.66	• 0.12	• 0.23	• 0.10	• 0.13	• 0.14
23.900	• 0.19	-• 1.04	-• 2.15	-• 1.14	-• 1.06	-• 1.67	-• 0.59	-• 1.27	-• 0.85	-• 0.85
32.900	• 0.72	-• 3.01	-• 3.51	-• 1.51	-• 0.94	-• 0.78	-• 0.50	-• 0.48	-• 0.09	-• 0.15
39.900	• 1.45	-• 4.61	-• 2.51	-• 1.61	-• 1.69	-• 2.73	-• 2.37	-• 1.94	-• 3.16	-• 3.05
50.900	**	**	**	**	**	**	**	**	**	**
70.000	**	**	**	**	**	**	**	**	**	**
100.000	**	**	**	**	**	**	**	**	**	**

(S+D) APPROXIMATE TRAVEL TIME DIFF (SEC) VS DEPTH (KMI) AND DISTANCE DELTA (DEG)
 DOUBLE BOUND SERIES COEFFICIENTS FOR CALCULATING TRAVEL TIME DIFFERENCE

	TAU SUR 1J	TAU SUR 2J	TAU SUR 3J
0 = 0	-47927114E+00	-19464165E-02	-84976760E-05
0 = 1	-12076922E-03	-18634579E-04	-16407364E-06
0 = 2	-77373842E-06	-16349518E-05	-14444878E-07
0 = 3	-545523175E-06	-68472250E-07	-62791879E-09
0 = 4	-18952584E-07	-15726244E-08	-15024954E-10
0 = 5	-20217469E-09	-26023550E-10	-20038016E-12
0 = 6	-20008976E-11	-13305245E-12	-13946856E-14
0 = 7	-551933397E-14	-35763749E-15	-39361661E-17

CALCULATED TRAVEL TIME DIFFERENCE TABLE (***) MEANS UNALLOWED DEPTH FOR GIVEN DELTA)

DELTA & DEPTH	16,000	15,000	20,000	30,000	40,000	50,000	60,000	70,000	80,000	90,000
5000	2.352	2.355	2.354	2.347	2.340	2.335	2.331	2.329	2.328	2.329
14,000	6.765	6.765	6.765	6.740	6.719	6.702	6.699	6.681	6.677	6.678
23,000	16.150	16.150	16.141	16.109	16.075	16.047	16.026	16.012	16.005	16.005
30,000	12.354	12.354	12.921	12.921	12.833	12.795	12.766	12.746	12.736	12.733
39,000	16.669	16.679	16.659	16.661	16.559	16.466	16.444	16.416	16.401	16.393
50,000	20.313	20.311	20.266	20.266	20.209	20.129	20.060	20.065	19.967	19.933
70,000	27.133	27.124	27.056	26.975	26.859	26.757	26.673	26.613	26.582	26.558
100,000	37.136	37.121	37.054	36.962	36.817	36.567	36.449	36.344	35.304	35.275

DELTA & DEPTH	16,000	15,000	20,000	30,000	40,000	50,000	60,000	70,000	80,000	90,000
5000	-0.014	-0.010	-0.008	-0.006	-0.004	-0.003	-0.002	-0.001	-0.001	-0.001
10,000	-0.017	-0.015	-0.012	-0.009	-0.006	-0.004	-0.002	-0.001	-0.001	-0.001
15,000	-0.019	-0.017	-0.015	-0.012	-0.009	-0.006	-0.004	-0.002	-0.001	-0.001
20,000	-0.021	-0.019	-0.017	-0.014	-0.011	-0.008	-0.006	-0.004	-0.002	-0.001
25,000	-0.023	-0.021	-0.019	-0.016	-0.013	-0.010	-0.008	-0.006	-0.004	-0.002
30,000	-0.023	-0.021	-0.019	-0.017	-0.014	-0.011	-0.008	-0.006	-0.004	-0.002
35,000	-0.023	-0.021	-0.019	-0.017	-0.014	-0.011	-0.008	-0.006	-0.004	-0.002
40,000	-0.023	-0.021	-0.019	-0.017	-0.014	-0.011	-0.008	-0.006	-0.004	-0.002
45,000	-0.023	-0.021	-0.019	-0.017	-0.014	-0.011	-0.008	-0.006	-0.004	-0.002
50,000	-0.023	-0.021	-0.019	-0.017	-0.014	-0.011	-0.008	-0.006	-0.004	-0.002

Figure 9