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UNITED STATES DEPARTMENT OF INTERIOR  
GEOLOGICAL SURVEY

Texas Instruments Model 59 Hand-Calculator Program  
for Interpretation of Refraction Seismic Data  
over up to Four Dipping Layers

by

David L. Campbell

U.S. Geological Survey, Denver, Colorado 80225

Open-File Report 79-1662

1979

Citation of particular manufacturers and model numbers does not constitute endorsement by the U.S. Geological Survey.

Although this program has been extensively tested, the U.S. Geological Survey cannot guarantee that it will give correct results in any or all particular applications.

**PROGRAM DESCRIPTION**

A number  $N \leq 4$  of seismic refractors of velocities  $v_i$  dip with dips  $\delta_i$  under an overburden of velocity  $v_1$ . Shots are fired at both ends, A and B, of an in-line array of geophones, and apparent velocities  $V_{Ai}$ ,  $V_{Bi}$  and zero-intersect times  $T_{Ai}$  are measured on the resulting travel time graph. Using this data, this program finds true velocities  $v_i$  and dips  $\delta_i$ , and depths  $D_{Ai}$  to layer below shot point A, for successive layers  $i$ . (See figure on next page.)

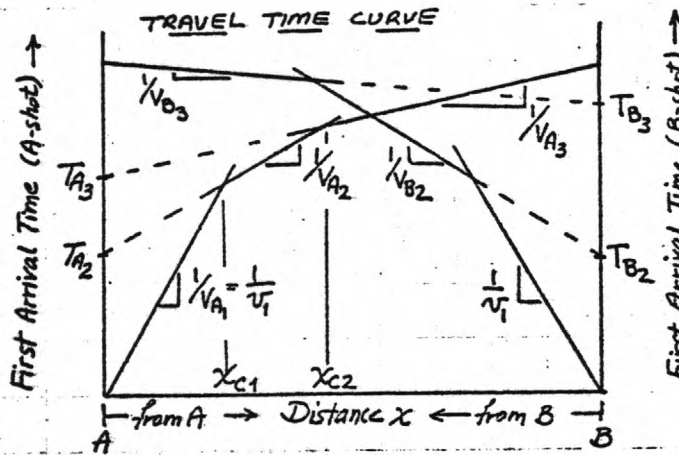
**USER INSTRUCTIONS**

STEP	PROCEDURE	ENTER	PRESS	DISPLAY
1	Load side 1 and side 2 of card.			
2	For surface layer	$v_1$	XST	
		$v_1$	C	$v_1$
	Flashing display means the 2 values of $v_1$ were not equal.			
3	For subsequent layers, working shallow to deep...	$V_A$	XST	
		$V_B$	C	$v$
		$T_A(0)$	XST	$\delta$
			D	$D_A$
4	For next deeper layer, go to step 3. Interpretation can proceed for up to 4 dipping layers, not counting surface layer. If more than 4 layers are used, flashing display "5.00" results.			
5	For next case, press "2nd CMs" and go to Step 2. Units: Units must be compatible; that is, if $v$ 's are in ft/sec, say, then all times $T$ must be in sec and all depths $D$ will be in ft.			

USER DEFINED KEYS	DATA REGISTERS (INV   INT)				LABELS (Op 08)				
A	0	$V_{An}, \alpha$	10	$\Sigma T$	20	$\Sigma h$	<input type="checkbox"/> INV <input type="checkbox"/> Inv <input type="checkbox"/> CE <input type="checkbox"/> CLR <input type="checkbox"/> $\Sigma 1$ <input type="checkbox"/> $\Sigma 2$		
B	1	$V_{Bn}, \beta$	11	$v_1$	21	$\delta_1$	<input type="checkbox"/> $\sqrt{x}$ <input type="checkbox"/> $\sqrt{y}$ <input type="checkbox"/> STO <input type="checkbox"/> RCL <input type="checkbox"/> SUM <input type="checkbox"/> $y^x$		
C	2	$v_n$	12	$v_2$	22	$\delta_2$	<input type="checkbox"/> EE <input type="checkbox"/> ( ) <input type="checkbox"/> + <input type="checkbox"/> - <input type="checkbox"/> GTO <input type="checkbox"/> X		
D	3	$\delta_n$	13	$v_3$	23	$\delta_3$	<input type="checkbox"/> SBR <input type="checkbox"/> - <input type="checkbox"/> RST <input type="checkbox"/> + <input type="checkbox"/> R/S <input type="checkbox"/> .		
E	4	$N = \text{no. layers}$	14	$v_4$	24	$\delta_4$	<input type="checkbox"/> $\sqrt{\square}$ <input type="checkbox"/> $\square$ <input type="checkbox"/> CLR <input type="checkbox"/> INV <input type="checkbox"/> ME <input type="checkbox"/> CP		
A'	5	$i = \text{this layer}$	15	$v_5$	25	$a$	<input type="checkbox"/> Tan <input type="checkbox"/> Perm <input type="checkbox"/> P=R <input type="checkbox"/> Sm <input type="checkbox"/> Cos <input type="checkbox"/> CMs		
B'	6	$v$ index	16	$h_1$	26	$b$	<input type="checkbox"/> Exc <input type="checkbox"/> P/d <input type="checkbox"/> I=1 <input type="checkbox"/> Exp <input type="checkbox"/> Fix <input type="checkbox"/> Int		
C'	7	$h$ index	17	$h_2$	27	$P$	<input type="checkbox"/> On <input type="checkbox"/> Pause <input type="checkbox"/> $\Sigma 1$ <input type="checkbox"/> $\Sigma 2$ <input type="checkbox"/> Mod <input type="checkbox"/> $\Sigma 3$ <input type="checkbox"/> $\Sigma 4$ <input type="checkbox"/> $\Sigma 5$ <input type="checkbox"/> $\Sigma 6$ <input type="checkbox"/> $\Sigma 7$ <input type="checkbox"/> $\Sigma 8$ <input type="checkbox"/> $\Sigma 9$		
D'	8	$\delta$ index	18	$h_3$	28	$Q$	<input type="checkbox"/> M/Pr <input type="checkbox"/> B MS <input type="checkbox"/> $\Sigma 7$ <input type="checkbox"/> $\Sigma 8$ <input type="checkbox"/> $\Sigma 9$ <input type="checkbox"/> $\Sigma 0$ <input type="checkbox"/> $\Sigma 1$ <input type="checkbox"/> $\Sigma 2$		
E'	9	Used	19	$h_4$	29	$\cos \alpha + \cos \beta$	<input type="checkbox"/> Adv <input type="checkbox"/> Pit <input type="checkbox"/> $\Sigma$		
FLAGS	No flags	used. <sup>2</sup>	3	4	5	6	7	8	9

# Program Description (CONTINUATION SHEET)

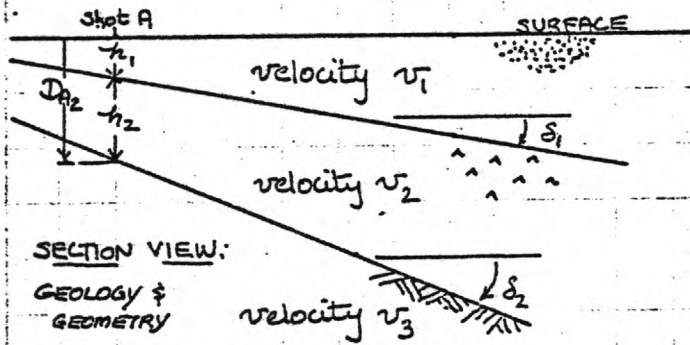
p. 2



nomenclature:

Branch 1 of travel time curve has slope  $1/v_1$  and zero intercept,  $T_{A1}=0$ .  
 Branch 2 has slope  $1/v_{A2}$  (or  $1/v_{B2}$ ) and zero-intercept  $T_{A2}$  ( $T_{B2}$ ).  
 Branch 3 has slope  $1/v_{A3}$  (or  $1/v_{B3}$ ) and intercept  $T_{A3}$  ( $T_{B3}$ )... and so on.  
 Crossover distances  $x_{c1}$ ,  $x_{c2}$  are those at which first arrivals begin to occur on a new branch.

- Convention: dips  $\delta$  are regarded positive down from horizontal.



Snell's law relations:

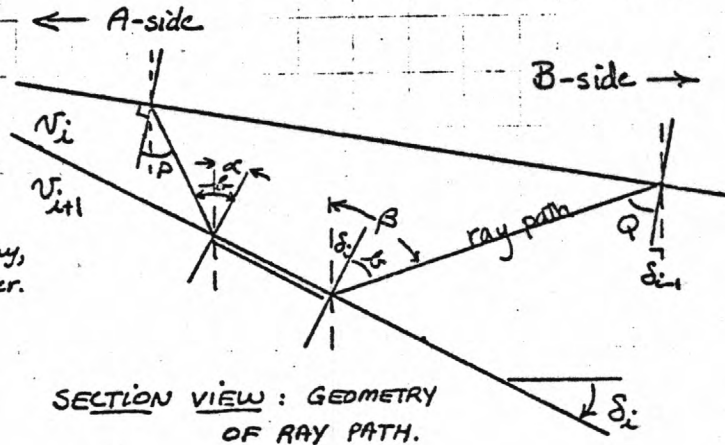
$n^{\text{th}}$  layer:  $\sin \alpha_n = \sin \beta_n = \frac{v_n}{v_{n+1}}$   
 elsewhere:  $v_i \sin \beta_{i-1} = v_{i-1} \sin \alpha_i$   
 $v_i \sin \alpha_{i+1} = v_{i-1} \sin \beta_i$   
 at surface:  $v_B = v_1 / \sin \alpha_1$   
 $v_A = v_1 / \sin \beta_1$

Thicknesses:  $h_i = S_i (T_{Ai} - \Sigma T)$   
 where  $S_i = v_i / (\cos \alpha_i + \cos \beta_i)$   
 and  $\Sigma T = \sum_{i=1}^n h_i / v_i$

Indexes:  $i$  = summation index  
 $n$  = layer index, this calculation.  
 $N$  = total no. of layers.

angles:  
 $a, b$  = angles, layer normal to ray  
 $\alpha, \beta$  = angles, vertical to ray  
 $P, Q$  = angles, layer normal to ray,  $i-1^{\text{st}}$  layer.

geometry:  
 $\alpha_i = a_i - \delta_i = P_i - \delta_{i-1}$   
 $\beta_i = b_i + \delta_i = Q_i + \delta_{i-1}$







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LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS					
000	76	LBL	Sub C:	055	21	21		110	54	)						
001	13	C		056	95	=		111	42	STO						
002	58	FIX		057	42	STO		112	09	09						
003	02	02		058	25	25		113	95	=						
004	42	STO		059	43	RCL		114	42	STO	$b = Q - \Delta S$					
005	01	01		060	00	00		115	26	26						
006	32	XIT		061	75	-		116	43	RCL						
007	42	STO		062	43	RCL		117	27	27						
008	00	00		063	21	21		118	85	+						
009	43	RCL		064	95	=	$b = \beta - \delta$	119	43	RCL						
010	04	04		065	42	STO		120	09	09	$a = P + \Delta S$					
011	69	OP		066	26	26		121	95	=						
012	24	24		067	71	SBR		122	42	STO						
013	32	XIT		068	68	NOP		123	25	25						
014	00	0		069	71	SBR		124	73	RC*						
015	77	GE		070	79	X	$\Sigma T$	125	08	08						
016	67	EQ		071	71	SBR		126	42	STO						
017	42	STO		072	68	NOP	$i = 2$	127	03	03	$\delta_i$					
018	05	05		073	76	LBL		128	71	SBR						
019	43	RCL		074	97	DSZ	$DSZ:$	129	78	$\Sigma +$						
020	11	11		075	43	RCL	loop entry	130	71	SBR						
021	55	÷		076	26	26	$b$	131	79	X						
022	43	RCL		077	71	SBR		132	71	SBR						
023	00	00		078	88	DMS		133	68	NOP	Increment $i$					
024	95	=		079	42	STO		134	61	GTO						
025	22	INV		080	28	28	$Q$	135	97	DSZ						
026	38	SIN		081	43	RCL		136	76	LBL	$IFF:$					
027	42	STO		082	25	25	$a$	137	87	IFF	loop exit					
028	00	00		083	71	SBR		138	43	RCL						
029	43	RCL		084	88	DMS		139	27	27						
030	11	11		085	42	STO		140	85	+						
031	55	÷		086	27	27	$P$	141	43	RCL						
032	43	RCL		087	43	RCL		142	28	28						
033	01	01		088	04	04	End loop?	143	95	=						
034	95	=		089	75	-		144	55	÷						
035	22	INV		090	01	1		145	02	2						
036	38	SIN		091	95	=	if $(i \geq m)$	146	95	=						
037	42	STO		092	32	XIT	GTO iff	147	42	STO						
038	01	01	$\alpha_i$	093	43	RCL		148	25	25	$a = \frac{P+Q}{2}$					
039	03	3		094	05	05		149	42	STO						
040	32	XIT	Check	095	77	GE		150	26	26	$b$					
041	43	RCL	for	096	87	IFF		151	43	RCL						
042	04	04	single-	097	43	RCL		152	28	28						
043	22	INV	layer	098	28	28	$Q$	153	75	-						
044	77	GE	case	099	75	-		154	43	RCL						
045	89	$\pi$		100	53	<		155	27	27						
046	32	XIT		101	73	RC*		156	95	=						
047	05	5	Too	102	08	08		157	55	÷						
048	22	INV	many	103	69	OP		158	02	2	$\frac{P-Q}{2}$					
049	77	GE	layers?	104	38	38		159	95	=						
050	10	E'		105	75	-		MERGED CODES								
051	43	RCL		106	73	RC*		62	Pgm	Ind	72	STO	Ind	83	GTO	Ind
052	01	01		107	08	08		63	TRC	Ind	73	RCL	Ind	84	OP	Ind
053	85	+	$a = \alpha + \delta$	108	69	OP		64	PRD	Ind	74	SUM	Ind	92	INV	SBR
054	43	RCL		109	28	28		TEXAS INSTRUMENTS INCORPORATED								



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LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
160	69	OP		215	21	21		270	26	26	
161	38	38		216	32	X↑T		271	95	=	
162	85	+		217	43	RCL		272	22	INV	
163	73	RC*		218	11	11		273	38	SIN	
164	08	08		219	55	+		274	92	RTN	
165	69	OP		220	53	(		275	76	LBL	Fun $\Sigma^+$ :
166	28	28		221	53	(		276	78	$\Sigma^+$	
167	95	=		222	53	(		277	43	RCL	
168	42	STO	$\delta_i = \delta_{i-1} \times \frac{P-Q}{2}$	223	43	RCL		278	25	25	
169	03	03		224	01	01		279	75	-	
170	71	SBR		225	85	+		280	43	RCL	
171	78	$\Sigma^+$		226	43	RCL		281	03	03	
172	71	SBR		227	00	00		282	95	=	
173	77	GE		228	54	)		283	42	STO	
174	43	RCL		229	55	+		284	01	01	
175	03	03		230	02	2		285	43	RCL	
176	72	ST*		231	54	)		286	03	03	
177	08	08	New $S_i$	232	38	SIN		287	85	+	
178	32	X↑T		233	54	)		288	43	RCL	
179	43	RCL		234	95	=		289	26	26	
180	02	02		235	42	STO		290	95	=	
181	55	+		236	02	02		291	42	STO	
182	43	RCL		237	42	STO		292	00	00	
183	25	25		238	12	12		293	92	RTN	
184	38	SIN		239	61	GTO		294	76	LBL	Fun $\bar{X}$ :
185	95	=		240	99	PRT		295	79	$\bar{X}$	
186	42	STO	$v_i$	241	76	LBL	Fun $\bar{GE}$ :	296	71	SBR	
187	02	02		242	77	GE		297	77	GE	
188	69	OP		243	43	RCL		298	05	*	
189	26	26		244	01	01		299	73	RC*	
190	72	ST*		245	39	COB		300	07	07	
191	06	06		246	85	+		301	95	=	
192	69	OP		247	43	RCL		302	44	SUM	
193	36	36		248	00	00		303	10	10	
194	61	GTO		249	39	COB		304	92	RTN	
195	99	PRT		250	95	=		305	76	LBL	Sub $\bar{D}$ :
196	76	LBL	Sub $\bar{\pi}$ :	251	55	+		306	14	D	
197	89	$\bar{\pi}$		252	73	RC*		307	75	-	
198	00	0		253	06	06		308	43	RCL	TAN → DAN
199	42	STO	Calc. for	254	95	=		309	10	10	
200	10	10	single	255	42	STO		310	95	=	
201	71	SBR	refractor	256	29	29		311	55	+	
202	77	GE		257	92	RTN		312	43	RCL	
203	43	RCL		258	76	LBL	Fun $\bar{Dms}$ :	313	29	29	
204	00	00		259	88	DMS		314	95	=	
205	75	-		260	38	SIN		315	44	SUM	
206	43	RCL		261	65	*		316	20	20	
207	01	01		262	73	RC*		317	72	ST*	
208	95	=		263	06	06		318	07	07	
209	55	+		264	69	OP		319	43	RCL	
210	02	2		265	36	36					
211	95	=		266	55	+					
212	42	STO	$\delta_i = \frac{\alpha_i - \beta_i}{2}$	267	73	RC*					
213	03	03		268	06	06					
214	42	STO		269	69	OP					

$$v_2 = \frac{v_1}{\sin^{-1}(\frac{v_1 \sin \theta}{v_2})}$$

Get  $\frac{\cos \alpha_i + \cos \beta_i}{v_i}$  and store in Reg 29.

Input a or b, Calc P or Q =  $\sin^{-1}[\frac{P \sin a, b}{Q}]$

MERGED CODES

62	Per	Ind	72	STO	Ind	83	GTO	Ind
63	Exc	Ind	73	RCL	Ind	84	GO	Ind
64	Prd	Ind	74	SUM	Ind	92	INV	SBR

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LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
320	20	20		375	09	09		430	69	OP	
321	61	GTO		376	22	INV	Printout	431	00	00	
322	98	ADV		377	58	FIX		432	43	RCL	
323	76	LBL	<i>Fcn EQ:</i>	378	98	ADV		433	09	09	
324	67	EQ		379	69	OP		434	92	RTN	
325	43	RCL		380	00	00		435	76	LBL	<i>Fcn Adv:</i>
326	01	01		381	02	2		436	98	ADV	
327	32	X:T		382	07	7	"LAYER"	437	42	STO	
328	43	RCL		383	01	1		438	09	09	
329	00	00		384	03	3		439	22	INV	Print-out
330	22	INV		385	04	4		440	58	FIX	
331	67	EQ		386	05	5		441	01	1	"DPTH"
332	10	E'		387	01	1		442	06	6	
333	42	STO		388	07	7		443	03	3	
334	11	11		389	03	3		444	03	3	
335	42	STO		390	05	5		445	03	3	
336	09	09		391	69	OP		446	07	7	
337	00	0		392	01	01		447	02	2	
338	32	X:T		393	43	RCL		448	03	3	
339	71	SBR		394	04	04		449	69	OP	
340	99	PRT		395	85	+		450	04	04	
341	76	LBL		396	01	1		451	58	FIX	
342	68	NOP	<i>Nop:</i>	397	95	=		452	02	02	
343	69	OP		398	69	OP		453	43	RCL	
344	25	25		399	02	02		454	09	09	
345	43	RCL		400	69	OP		455	69	OP	
346	05	05	<i>Increment</i>	401	05	05		456	06	06	
347	85	+		402	04	4		457	92	RTN	
348	01	1		403	02	2					
349	00	0		404	02	2	"VLOC"				
350	95	=		405	07	7					
351	42	STO		406	03	3					
352	06	06		407	02	2					
353	85	+		408	01	1					
354	05	5		409	05	5					
355	95	=		410	69	OP					
356	42	STO		411	04	04					
357	07	07		412	58	FIX					
358	85	+		413	02	02					
359	05	5		414	43	RCL					
360	95	=		415	09	09					
361	42	STO		416	69	OP					
362	08	08		417	06	06					
363	43	RCL		418	01	1					
364	11	11		419	06	6					
365	92	RTN		420	02	2	"DIP"				
366	76	LBL	<i>E':</i>	421	04	4					
367	10	E'		422	03	3					
368	33	X <sup>2</sup>		423	03	3					
369	94	+/-		424	69	OP					
370	34	FX		425	04	04					
371	91	R/S		426	32	X:T					
372	76	LBL	<i>Fcn Prt:</i>	427	69	OP					
373	99	PRT		428	06	06					
374	42	STO		429	32	X:T					

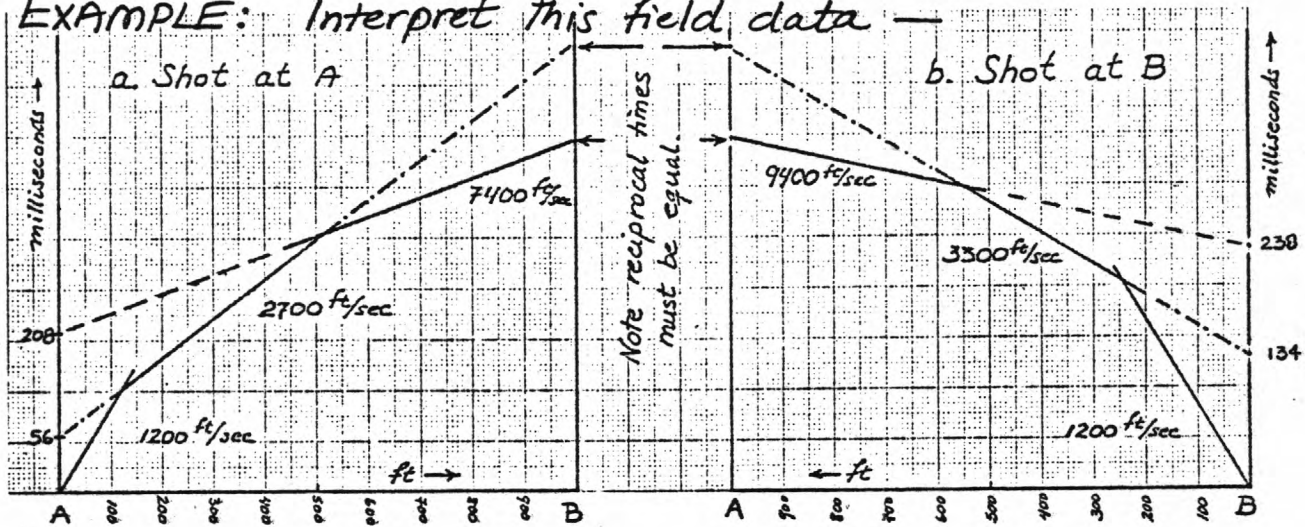
MERGED CODES

62	Form	Ind	72	STO	Ind	83	GTO	Ind
63	Exc	Ind	73	RCL	Ind	84	Op	Ind
64	Prd	Ind	74	SUM	Ind	92	INV	SBR

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EXAMPLE: Interpret this field data



VARIABLE	KEY	DISPLAY
$v_1 = V_{A1} = 1200 \text{ ft/sec}$	x+t	(0.00)
$v_1 = V_{B1} = 1200 \text{ ft/sec}$	C	$v_1 = 1200.00 \text{ ft/sec}$
$V_{A2} = 2700 \text{ ft/sec}$	x+t	(0.00)
$V_{B2} = 3300 \text{ ft/sec}$	C	$v_2 = 2967.10 \text{ ft/sec}$
	x+t	$\delta_1 = 2.53 \text{ deg}$
$T_{A2} = 0.056 \text{ sec}$	D	$D_{A1} = 36.77 \text{ ft}$
$V_{A3} = 7400 \text{ ft/sec}$	x+t	(2967.10)
$V_{B3} = 9400 \text{ ft/sec}$	C	$v_3 = 8262.27 \text{ ft/sec}$
	x+t	$\delta_2 = -1.49 \text{ deg}$
$T_{A3} = 0.208 \text{ sec}$	D	$D_{A2} = 271.10 \text{ ft}$

Print-out:

LAYER 1	1200.00	VLOC
	0.00	DIP
LAYER 2	2967.10	VLOC
	2.53	DIP
	36.77	DPTH
LAYER 3	8262.27	VLOC
	-1.49	DIP
	271.10	DPTH

Calculation for B side (optional) —

2nd CMS

$v_1 = 1200$	x+t	(8262.27)
1200	C	1200.00
$V_{B2} = 3300$	x+t	(0.00)
$V_{A2} = 2700$	C	2967.10
	x+t	-2.53
$T_{B2} = 0.134 \text{ sec}$	D	$D_{B1} = 88.00 \text{ ft}$
$V_{B3} = 9400$	x+t	(2967.10)
$V_{A3} = 7400$	C	8262.27
	x+t	1.49
$T_{B3} = 0.238 \text{ sec}$	D	$D_{B2} = 235.73 \text{ ft}$

LAYER 1	1200.00	VLOC
	0.00	DIP
LAYER 2	2967.10	VLOC
	-2.53	DIP
	88.00	DPTH
LAYER 3	8262.27	VLOC
	1.49	DIP
	235.73	DPTH