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GEOSCIENCES DEPARTMENT

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INCORPORATED

SCIENCE SERVICES DIVISION

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STATUS REPORT
AUTOMATED BULLETIN AND
SEISMIC DATA RETRIEVAL SYSTEM

AFTAC Project No. VT/1124
ARPA Order No. 104-60
ARPA Proj. Code 8100

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Contractor: Texas Instruments Incorporated
Science Services Division
Date of Contract: 10 January 1962
Amount of Contract: $1,951,969
Contract Number: AF 33(600)-43486
Contract Expiration Date: 30 June 1963
Project Manager: H. M. Rackets

1 November 1963

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STATUS REPORT

AUTOMATED BULLETIN AND SEISMIC DATA RETRIEVAL SYSTEM

I. INTRODUCTION

The Automated Bulletin Program was developed to reduce errors caused by manual copying and recopying of data, to reduce the cost of bulletin preparation, to provide a means of handling increasing amounts of seismic data without heavy demands on skilled personnel, and to provide rapid access to large amounts of seismic data stored on magnetic tape. The "program" is actually a system of programs which can be run in sequence on a "system" oriented computer with a minimum of magnetic tape changes. The IBM 7074 of Texas Instruments is run on the "FAST" Monitor System which has the ability to run a sequence of related programs; its main virtue is extremely fast FORTRAN compile time which should reduce the computer run time required to make program modifications.

The system was oriented to obtain a maximum of valid information for research as well as to efficiently provide a seismic bulletin. The concept of operations consists of first picking the arrivals and then checking them against predicted arrivals generated by the computer from USC&GS hypocenter information and travel time curves. Manual bulletins are frequently prepared only after USC&GS information is available to assist in picking arrivals.

This latter procedure provides a more complete bulletin, particularly when data analysts are not highly experienced, but introduces a weighting in favor of existing travel time curves. If re-analysis of film strips with aid of PDE data is not performed, scatter in picked arrival times will increase, but should be more closely centered about the actual arrival times.

The automated bulletin system will identify phases and collate events analyzed with PDE data more economically than can be done manually, but by operating on raw station data still greater economy can be effected.

II. DESCRIPTION OF THE PROGRAM

A. SUMMARY

The Automated Bulletin System is comprised of four principal 7074 programs written in FORTRAN:

1. PDE Data Generation - The USC&GS Hypocentral Data, station location and travel time tables for 35 phases and branches of phases stored in the program are operated upon to generate an output tape containing the expected arrival times at each station of all stored phases. This tape may be printed through an autocoder 1401 program to provide a "PDE list" of expected arrivals for each station. See Figure 3.

2. Preliminary Association - Ground motion is generated from period, amplitude, and stored magnification curves. Time correction and gain changes are accounted for, possible associations and overlapping events are flagged.

3. Association Routine - The expected arrivals are compared with actual arrivals, PDE association made, and phases identified.

4. Pass I Unassociated - Events not associated are examined to determine if the station analyst identified as P wave and S wave and provided an azimuth of approach. The S-P interval yields a distance estimate which, combined with the station location and azimuth, provides an epicentral location estimate.

A fifth basic program, the Unassociated Pass II is still in the research stage, so events routed to its input tape are presently reviewed and manually inserted into the bulletin in chronological sequence. Very few events presently fall into this category because of expansion of the USC&GS net.

In addition, several 7074 stock sort routines and several 1401 programs written in autocoder are used. The data inputs to the program are made on key punch IBM cards. These cards are prepared from raw data report forms prepared by the data analyst, observatory technician, and the USC&GS PDE reports. Samples of the data forms used by the observatory personnel are reflected in Figures 1 and 2. The Form 10 contains event analysis information, Form 11 reports the changes in instrumentation which would affect the data.

Figure 4 is a simplified data flow; Figures 5-7 and 9-12 are more detailed data flow diagrams. Although several tapes are indicated, only a few need be physically transferred from the 7074 during the run if the program is run on "system." Normally, 1401 tapes are physically removed and transferred although they may also be tied to the system and electronically switched from the 7074 to the 1401.

Data flow and description of each of the four programs follows. The flow diagrams are for basic flow only and do not show fine details of mathematical operations. The Preliminary Association flow is presented in somewhat more detail than other routines but is not indicative of relative complexity.

B. PRELIMINARY ASSOCIATION

The following are performed by the preliminary association program:

1. Ground motion is obtained from trace motion.
2. Instrument parameters are compensated (see Figure 5):

BULLETIN-ANALYSIS WORK SHEET

________________ Seismological Observatory .

Record Period No ____

			Date-Time-Group								Short Period		Intermediate		Broad		Long							Comments				
Station	Event Number	Phase No.	Year	Mo.	Day	Hr	Min	Sec.	Comp	C or D	Amp $_o$	T $_o$	Amp $_o$	T $_o$	Amp $_o$	T $_o$	Amp $_o$	T $_o$	I or E	Phase	LNRT	Azim.	Day Code	1	2	3	4	5

S. O. FORM 10 (29 NOV 62)

Analyst __________ Checked by __________ Page ____

Figure 1. S. O. Form 10

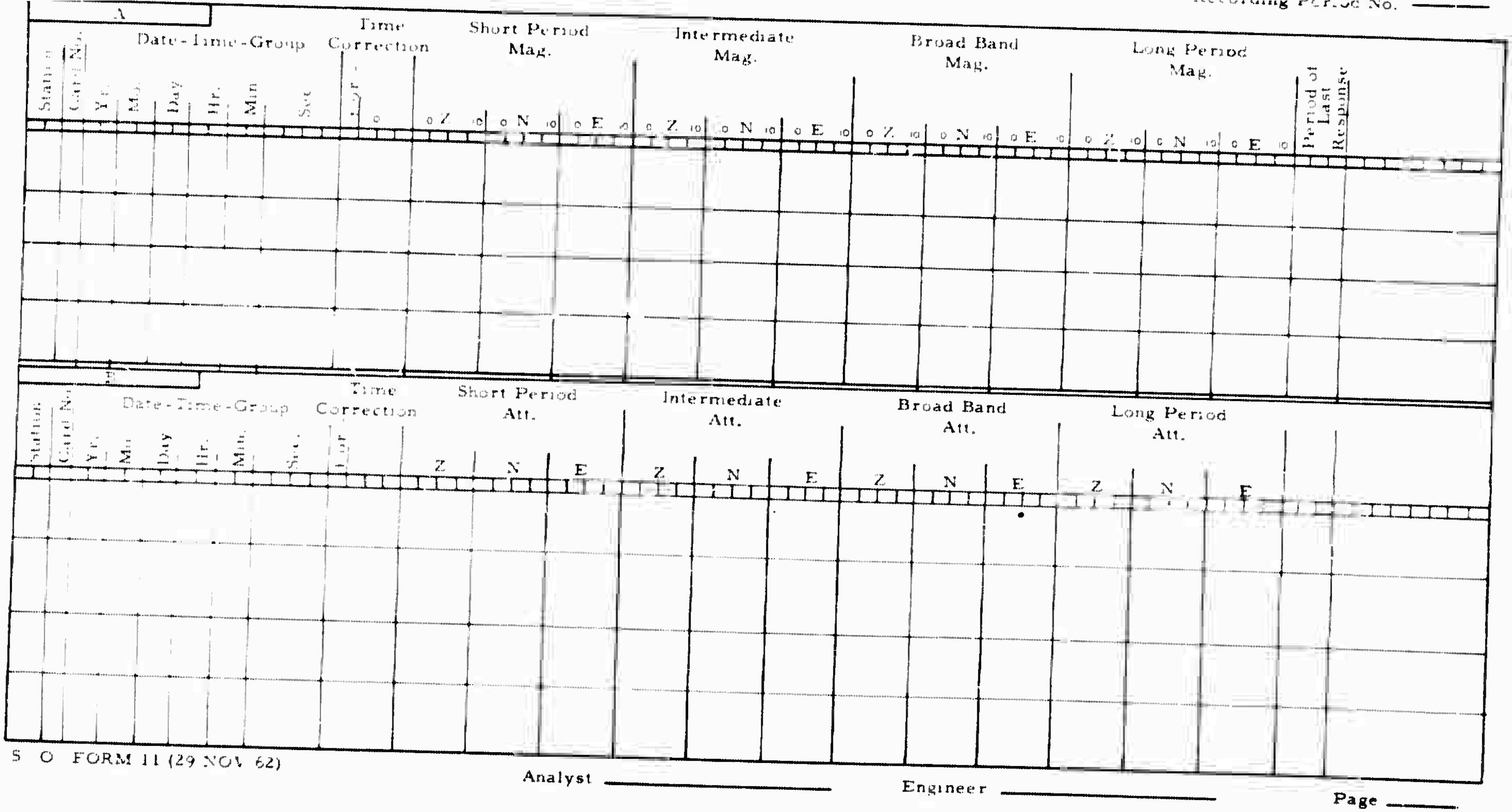


Figure 2. S. O. Form 11

STATION	EVENT	ARRIVAL TIME	ORIGIN TIME	LAT.	LONG.	DEPTH	MAG.	AZ.	DELTA	PHASE	ALPHA	BETA
UBSO	143	63/01/17/21/16/07.97	63/01/17/20/41/14.80	25.60	125.20	140		312.0	98.97	SSS	0.101E-03	-0.194E 00
UBSO	143	63/01/17/21/18/04.49	63/01/17/20/41/14.80	25.60	125.20	140		312.0	98.97	SKKSDF	0.456E-04	-0.232E 00
UBSO	143	63/01/17/21/21/25.79	63/01/17/20/41/14.80	25.60	125.20	140		312.0	98.97	G	0.000E 00	0.000E 00
UBSO	143	63/01/17/21/27/13.70	63/01/17/20/41/14.80	25.60	125.20	140		312.0	98.97	L	0.000E 00	0.000E 00
UBSO	143	63/01/17/21/31/40.39	63/01/17/20/41/14.80	25.60	125.20	140		312.0	98.97	R	0.000E 00	0.000E 00
UBSO	144	63/01/18/03/23/56.86	63/01/18/03/12/05.70	33.10	135.80	425		310.0	85.25	P	0.260E-04	-0.121E 00
UBSO	144	63/31/18/03/25/34.09	63/01/18/03/12/05.70	33.10	135.80	425		310.0	85.25	PX	-0.960E-04	0.175E 00
UBSO	144	63/01/18/03/27/24.12	63/01/18/03/12/05.70	33.10	135.80	425		310.0	85.25	PP	-0.105E-04	-0.768E-01
UBSO	144	63/01/18/03/29/22.48	63/01/18/03/12/05.70	33.10	135.80	425		310.0	85.25	PPP	0.210E-04	-0.868E-01
UBSO	144	63/01/18/03/33/38.58	63/01/18/03/12/05.70	33.10	135.80	425		310.0	85.25	SKSAB	0.528E-04	-0.252E 00
UBSO	144	63/01/18/03/33/43.98	63/01/18/03/12/05.70	33.10	135.80	425		310.0	85.25	SKKSAC	0.547E-04	-0.230E 00
UBSO	144	63/01/18/03/33/50.04	63/01/18/03/12/05.70	33.10	135.80	425		310.0	85.25	S	0.676E-04	-0.231E 00
UBSO	144	63/01/18/03/34/52.36	63/01/18/03/12/05.70	33.10	135.80	425		310.0	85.25	SP	0.290E-04	-0.185E 00
UBSO	144	63/01/18/03/35/18.22	63/01/18/03/12/05.70	33.10	135.80	425		310.0	85.25	SPP	0.148E-03	-0.270E 00
UBSO	144	63/01/18/03/35/50.58	63/01/18/03/12/05.70	33.10	135.80	425		310.0	85.25	PS	0.103E-04	-0.342E-01
UBSO	144	63/01/18/03/39/39.39	63/01/18/03/12/05.70	33.10	135.80	425		310.0	85.25	SS	0.458E-04	-0.178E 00
UBSO	144	63/01/18/03/41/47.71	63/01/18/03/12/05.70	33.10	135.80	425		310.0	85.25	PKKPDF	0.159E-04	-0.122E 00
UBSO	144	63/01/18/03/43/11.74	63/01/18/03/12/05.70	33.10	135.80	425		310.0	85.25	SSS	0.909E-04	-0.205E 00
UBSO	144	63/01/18/03/48/14.34	63/01/18/03/12/05.70	33.10	135.80	425		310.0	85.25	SKKSDF	0.409E-04	-0.232E 00
UBSO	145	63/01/18/05/55/43.64	63/01/18/05/42/31.60	-14.90	167.60	66		254.1	94.15	P	0.440E-03	-0.177E 00
UBSO	145	63/01/18/05/55/54.09	63/01/18/05/42/31.60	-14.90	167.60	66		254.1	94.15	PCP	0.000E 00	0.000E 00
UBSO	145	63/01/18/05/56/03.72	63/01/18/05/42/31.60	-14.90	167.60	66		254.1	94.15	PX	-0.495E-03	0.189E 00
UBSO	145	63/01/18/05/59/33.68	63/01/18/05/42/31.60	-14.90	167.60	66		254.1	94.15	PP	0.424E-03	-0.163E 00
UBSO	145	63/01/18/06/01/37.25	63/01/18/05/42/31.60	-14.90	167.60	66		254.1	94.15	PPP	0.556E-03	-0.170E 00
UBSO	145	63/01/18/06/06/11.06	63/01/18/05/42/31.60	-14.90	167.60	66		254.1	94.15	SKSAC	0.566E-03	-0.295E 00
UBSO	145	63/01/18/06/06/26.61	63/01/18/05/42/31.60	-14.90	167.60	66		254.1	94.15	SKKSAC	0.609E-03	-0.296E 00
UBSO	145	63/01/18/06/06/45.70	63/01/18/05/42/31.60	-14.90	167.60	66		254.1	94.15	S	0.586E-03	-0.291E 00

Figure 3. Computer Output Tape

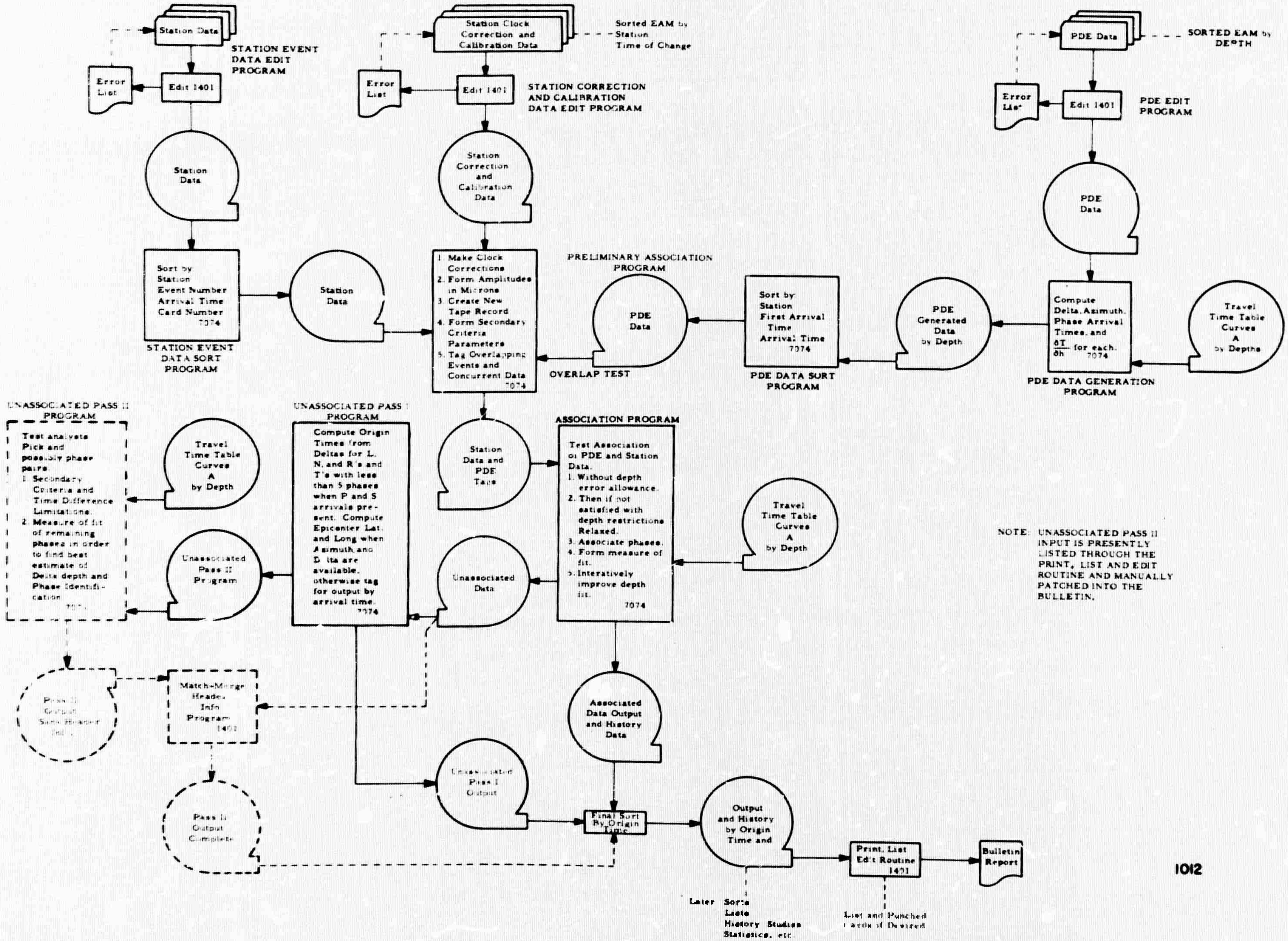


Figure 4. Seismic Bulletin System, Block Diagram

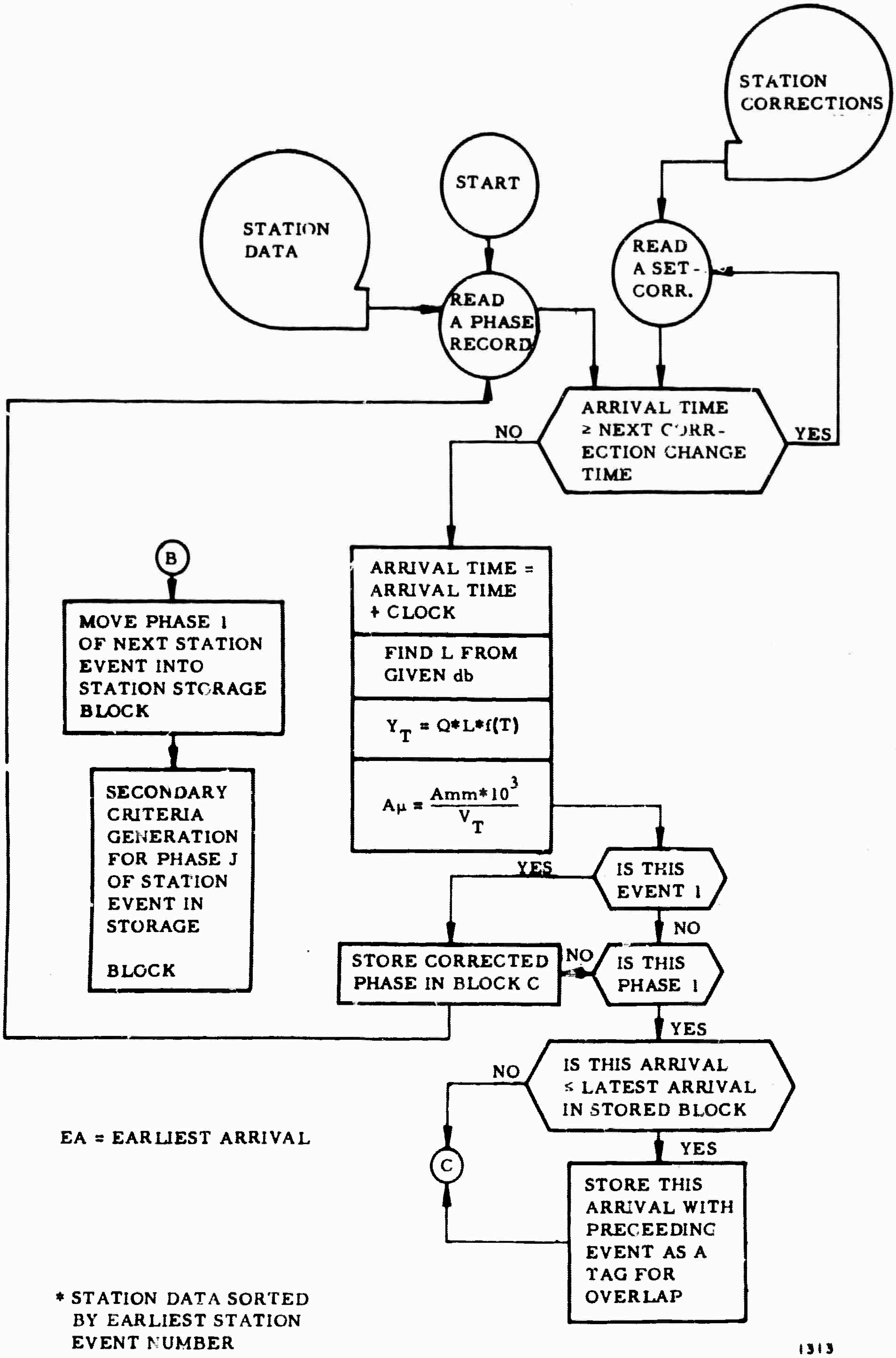


Figure 5. Preliminary Association Program - Correction Routine

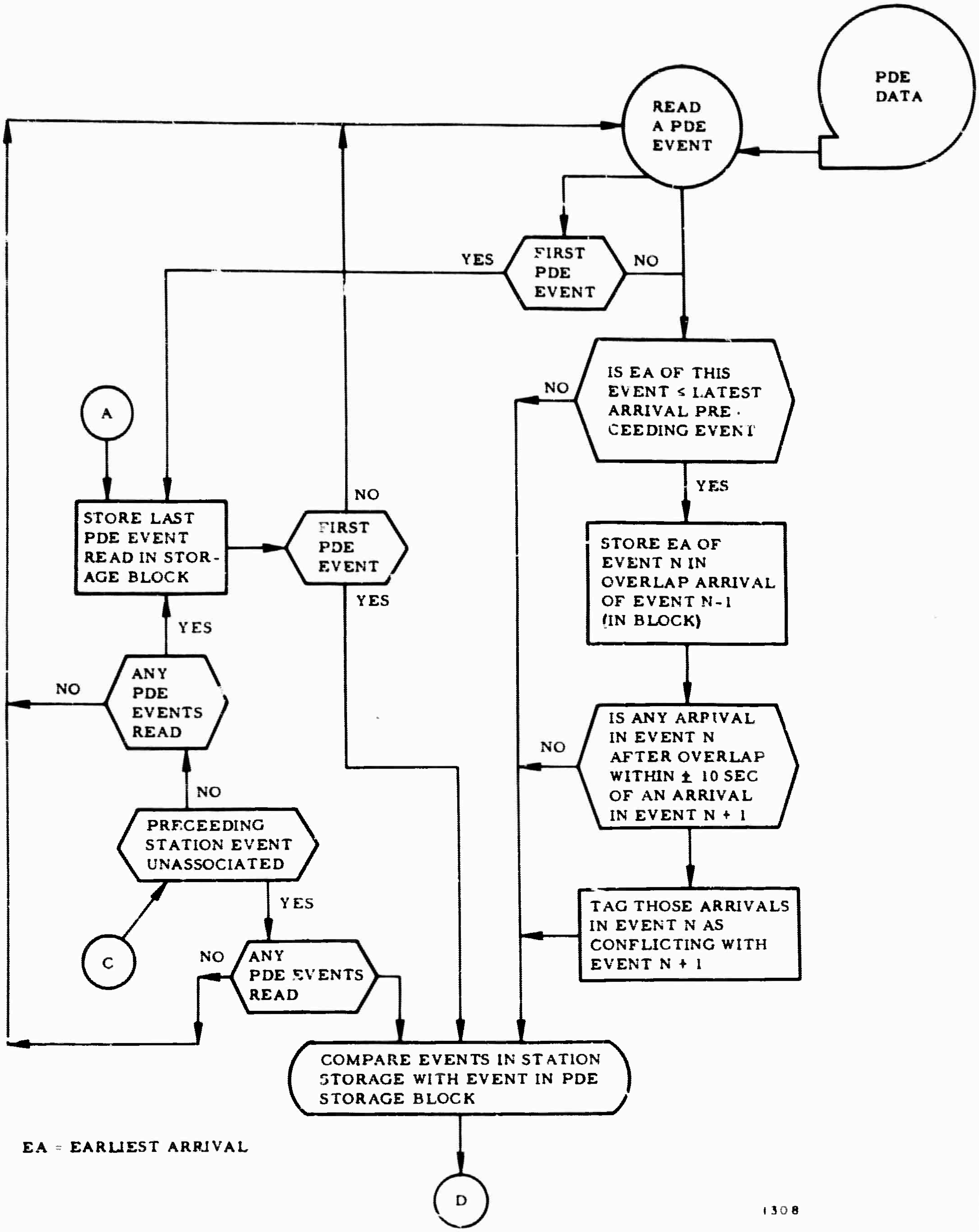
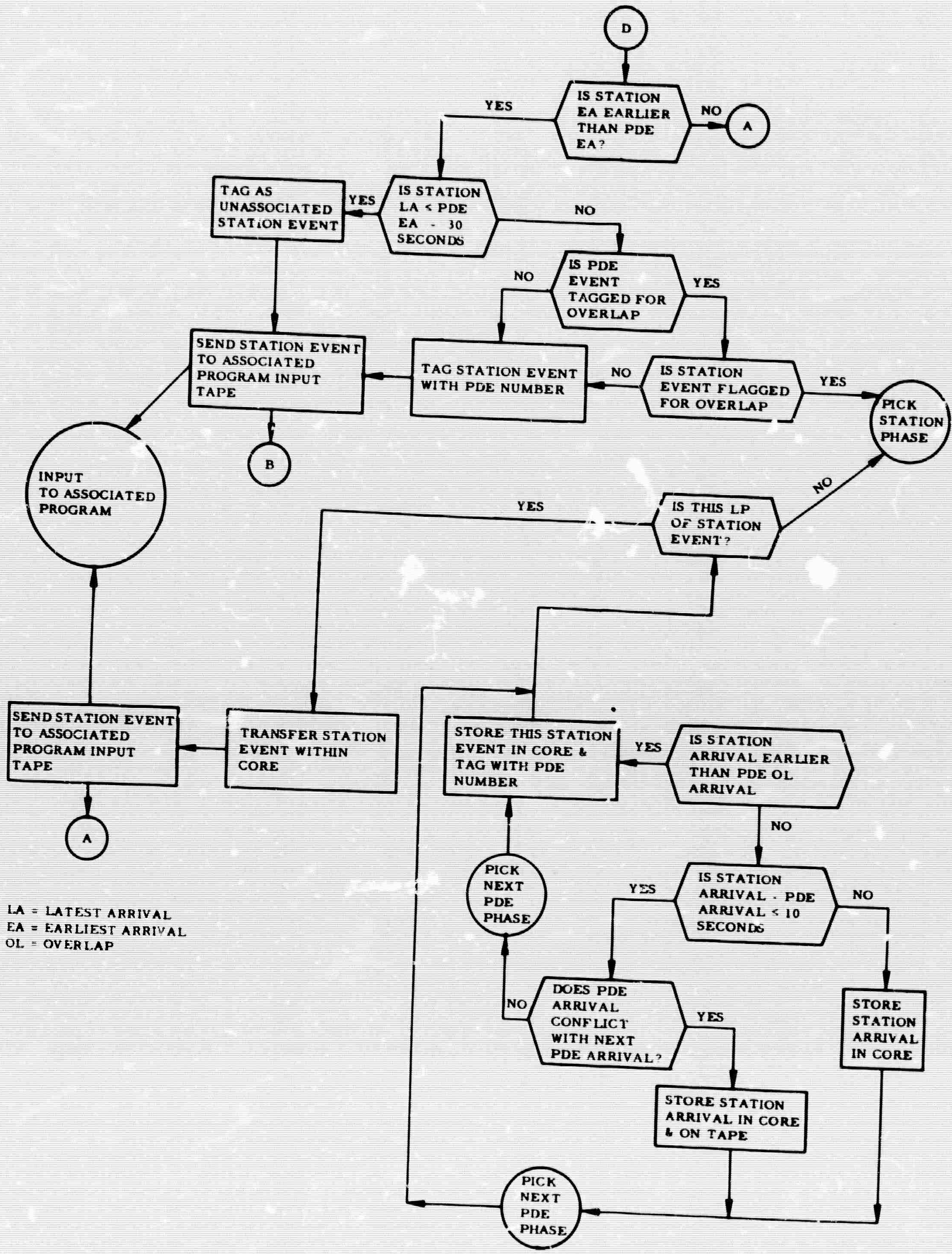


Figure 6. Preliminary Association Program - Preliminary Overlap and Compare Routine



LA = LATEST ARRIVAL
EA = EARLIEST ARRIVAL
OL = OVERLAP

Figure 7. Preliminary Association Program - Overlap, Tag, and Transfer Routine

a. Changes in magnification

b. Changes in timing (clock correction)

3. Three-symbol secondary criteria codes are formed (see Figure 5):

a. Is trace amplitude higher on short- or long-period instruments?

1 = short period, 2 = long period, 3 - same.

b. Is ground motion greater on vertical or horizontal components?

1 = horizontal 2 = vertical, 3 = same.

c. Does component which is most nearly inline or most nearly transverse indicate greatest ground motions?

1 = inline, 2 = transverse, 3 = undefined.

Each phase has a secondary criteria word consisting of the codes a, b and c; e.g., 121 which means: best on short period, best on vertical and best inline. This is typical for a P wave. An arriving SS might be 212.

4. 4. First and last phase arrival times for each PDE event predicted for a given station are used as a gate. Any station phase between these predicted arrivals trigger the application of association criteria words which are placed on the magnetic tape in a reserved location for each event. Several overlap situations are distinguished with different identification words. (see Figures 6 and 7).

a. Station event has a phase or phases that fall between predicted arrival times generated by the PDE data program for a particular event.

b. Two-station events have phases between the same earliest and latest predicted arrivals.

c. The event has a phase or phases that fall between predicted limits for two different PDE events.

C. ASSOCIATION PROGRAM

Events flagged as "possibly associable" by the prelimi-nary association program are stored in core memory with the corresponding PDE expected arrival times. The first phase of the station event is compared to each PDE expected arrival. If a PDE expected arrival corresponds within ten seconds, this arrival is flagged as the first station arrival and the event is flagged as associated. All PDE data concerning the event (PDE header) is made a part of this event's record. The first phase misstie (difference between computed arrival time using PDE and the observed arrival time).

is applied to all subsequent phase arrival time predictions to compensate for differences in path, source asymmetry, etc. in the phase identification routines. The first phase travel time curve (usually P or PKP) is thought to be more accurately known because it is preceded only by noise and not by waves generated by the event. See Figures 9, 10, and 11for data flow.

The travel time curves (see Figure 8) are stored as a series of "prime" points. Each group of three points is fitted with a parabola by the computer. The points are stored as functions of time and distance for a given depth. If distance can be determined from PDE data, new prime points are generated which are functions of depth and time for a given distance. Parabolas are fitted through these points and the derivative of the parabolic equation for each phase, taken at the given point of depth and arrival time at a given distance, is determined for each phase with a stored window width of ± 5 seconds or less. The derivatives provide the rate of change of arrival time as a function of depth. For example: Given the parabolic equation $T = ah^2 + bh + C$, the derivative of T with respect to h is $\frac{\partial T}{\partial h} = 2ah + b$.

$\frac{\partial T}{\partial h}$ may be approximated by $\frac{\Delta T}{\Delta h}$ where ΔT is the misstie and Δh the change in depth necessary to account for the misstie. Thus, $\Delta h \approx \Delta T \times \frac{1}{2ah + b}$. The coefficients a and b have already been determined by the PDE data program and are stored on the PDE output tape for each predicted phase of each PDE event at each station. The average of all the depth differences so determined is added to the given depth. This new depth is stored on the output tape as part of the record for this event. The phase missties for those phases which are identified are now given for the new depth. These depths seldom differ from recent USC&GS depths by more than a few kilometers.

If the first phase of the station event introduced into the association program ties to a PDE expected arrival within sixty seconds, but not within ten seconds, the event is treated somewhat differently. It is first tested to determine the epicentral distance; if less than 16 degrees all the data is sent to the output tape as "associated." The PDE header information is included but the phases are not identified. Because of the high variability and numerous types of local to regional arrivals, accurate phase identification must be dependent upon travel time curves developed for a particular station. These curves are not available at this time so are not incorporated in the program. If the event is at a distance greater than 16° the preliminary association program has already indicated that this event must have a misstie between ten and sixty seconds. Again, the partial differential equation is solved to determine if there is a depth for which this misstie is zero. If there is no such depth, the event is considered unassociated and is sent to the Unassociated Pass 1 input tape. If a depth for which the misstie is zero exists, the event is sent back to the part one phase identification program except that the window widths are now enlarged to three times the basic window

Code No.	Phase	2X Basic Window ±Second	Secondary Criteria: System	Secondary Criteria: Inline or Transverse	Secondary Criteria: V or H	Max. Δ Range Degrees	Depth Range Km.
1	P	3	SP	I	V	0-140	0-797.5
2	PKPAB	3				143-180	
3	BC	3				143-147	
4	DE	3				110-145	
5	EF	3				145-180	
6	PX	3				10-105	
7	PKKPAB	3				126-104	
8	BC	3				126- 94	
9	DF	3				162- 0	
10	PcP	4				0-100	
11	SKPAB	5				130-148	
12	BC	5				130-140	
13	DF	5	SP			104-180	
14	PP	4	None			0-210	
15	PPP	10	None			1-220	0-797.5
16	R	300	LP			35-180	0-60
17	SP	9				44-147	0-797.5
18	SPP	10				44-180	
19	SSP	10	LP		V	90-220	
20	SKSAC	15	None		H	62-133	
21	DE	15				99-133	
22	EF	15				133-180	
23	SKKSAC	10				85-243	
24	DF	10				173- 0	
25	PKSAB	6				130-148	
26	BC	6				130-140	
27	DF	6	None	I		104-180	
28	S	4	None	Either		0-107	
29	PS	15	LP	I		50-140	
30	PPS	6				44-180	
31	PSS	15		I		90-220	0-797.5
32	SS	15		Either		1-214	
33	SSS	20		Either		0-220	0-797.5
34	L	300		T		35-180	0-60
35	G						

Note: Window set to minimum because of conflict with L and R. Suggested Program Modifications would allow a more realistic window width.

Figure 8. Travel Time Curves Stored In Bulletin Program

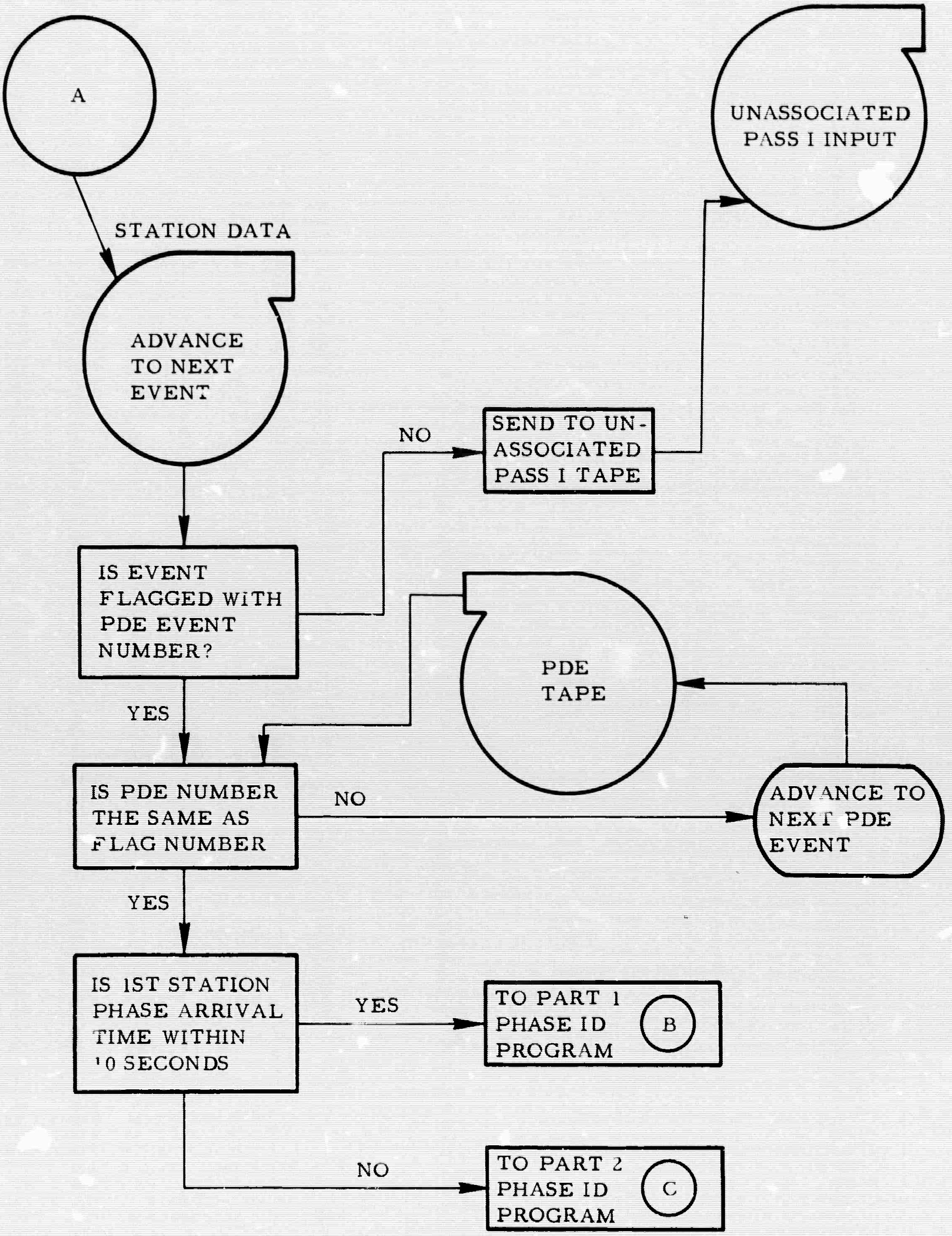


Figure 9. Association Program - Event Advance and 10-Second Misstic Separation Routine

1314

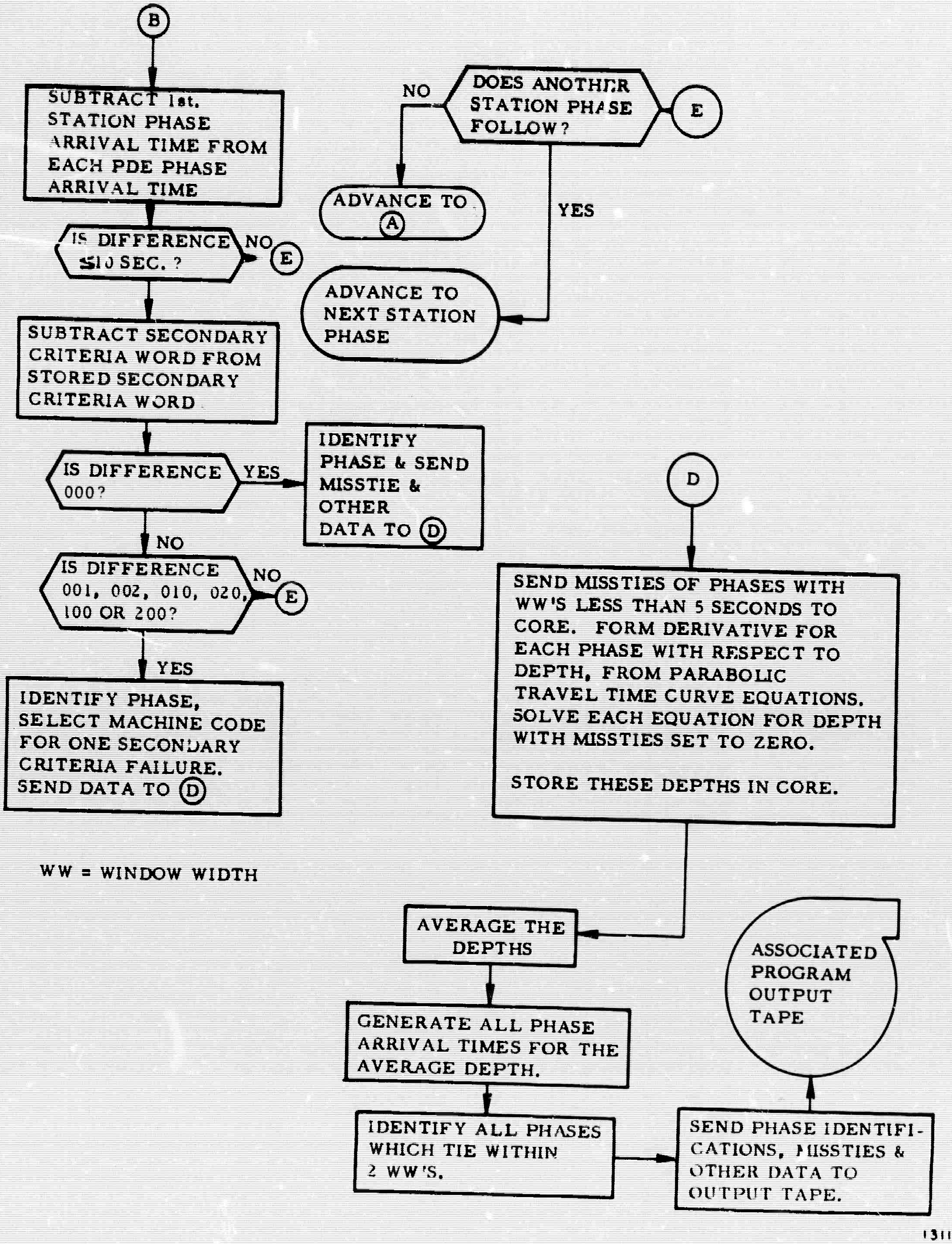


Figure 10. Association Program - Part I Phase Identification Routine

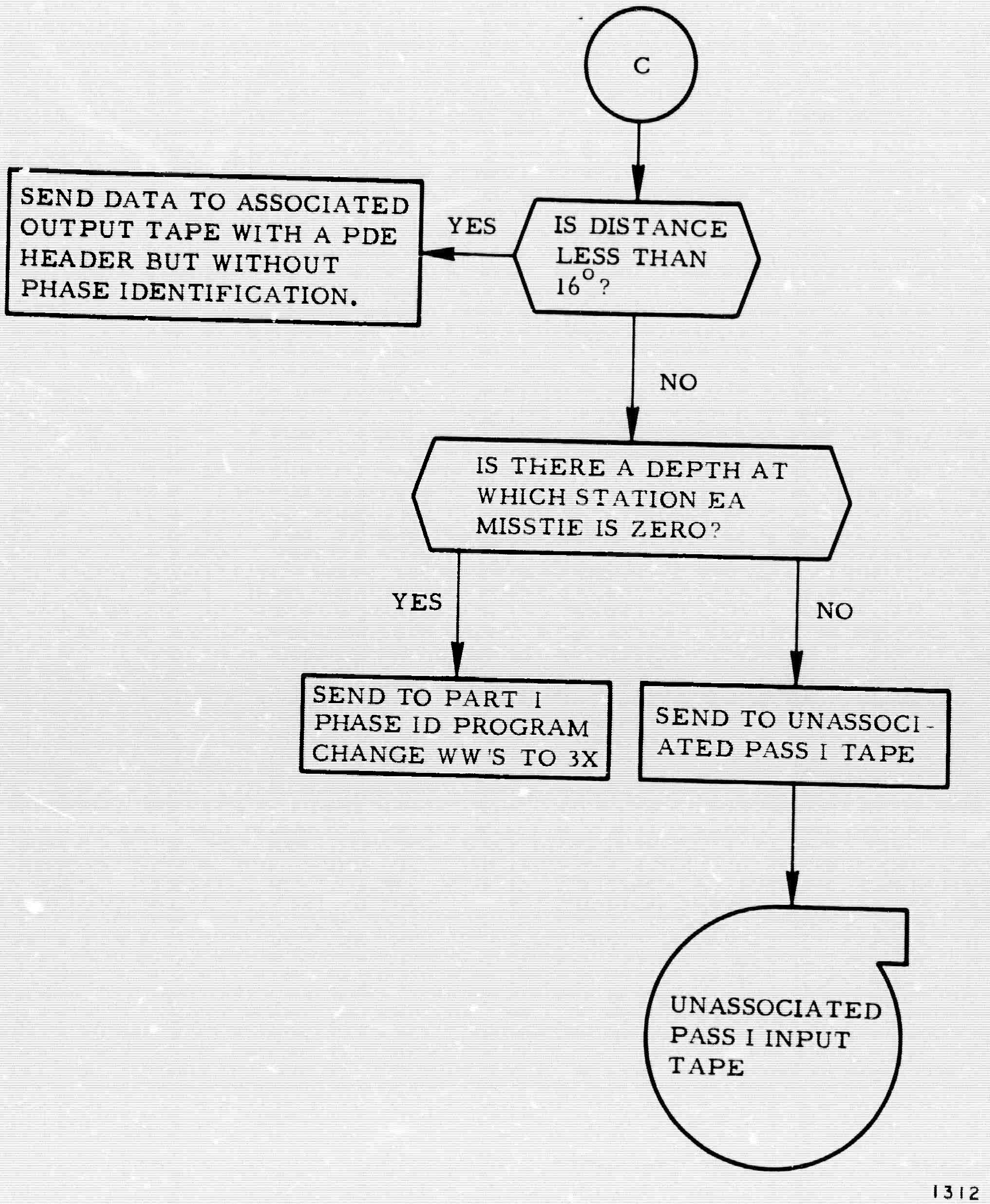


Figure 11. Association Program - Part 2 Phase Identification Routine

width and the depth is changed to that depth for which the misstic is zero. Phases are then identified in the normal manner and all information is sent to the output tape along with a machine code indicating that it went through this routine.

D. UNASSOCIATED DATA PROGRAM - PASS I

This program treats all unassociated phases except for teleseisms with more than five phases. The station analyst's phase identifications are searched for P and S. If they are found, the arrival times are subtracted from each other and the distance looked up on a stored S-P versus distance arrival time curve for normal depth. If the station analyst also estimated an azimuth of approach, the program will, in addition, estimate a latitude and longitude for the event. See Figure 12 for data flow.

E. UNASSOCIATED DATA PROGRAM - PASS II

This program is still in the research stage. It is designed to solve teleseisms having more than five phases when no PDE information is given. It divides the incoming events into one of three categories:

1. All phases are of compressional type.
2. All phases are of shear type.
3. There are both compressional and shear phases.

Statistically selected pairs of first and second arriving phases for the all-compressional or all-shear type categories are listed in stored tables. For the combination type event, a list of the most likely first compressional and first shear type arrivals are stored in tables. In the all-compressional category, the program tests each pair assuming that the first phase is properly identified but that the second most likely phase may not be the second station phase but may be the third, fourth, or fifth. The reason is that many high-amplitude spurious phases are often observed between P and PP or between P-diffracted and PKP.

The program first selects a station phase pair then tests the entire three dimensional travel time curves to determine if there is any area within these pairs of travel time curves in which the event can exist. If the event passes this test, the travel time tables are then searched as a function of both distance and depth to determine if there is one or more distances and depths for which the event can exist. Once the range of existence is bracketed, the arrival times for other phases are generated. Each time a fit is found this solution is stored in memory until the entire table of pairs has been searched. The solutions are then tested and the best solution chosen. If no fit can be found, the data are sent on as unassociated.

The immediate problem in continuing development of the Pass II Program is primarily one of locating obvious programming errors. Some events have successfully gone through this program provided they fit

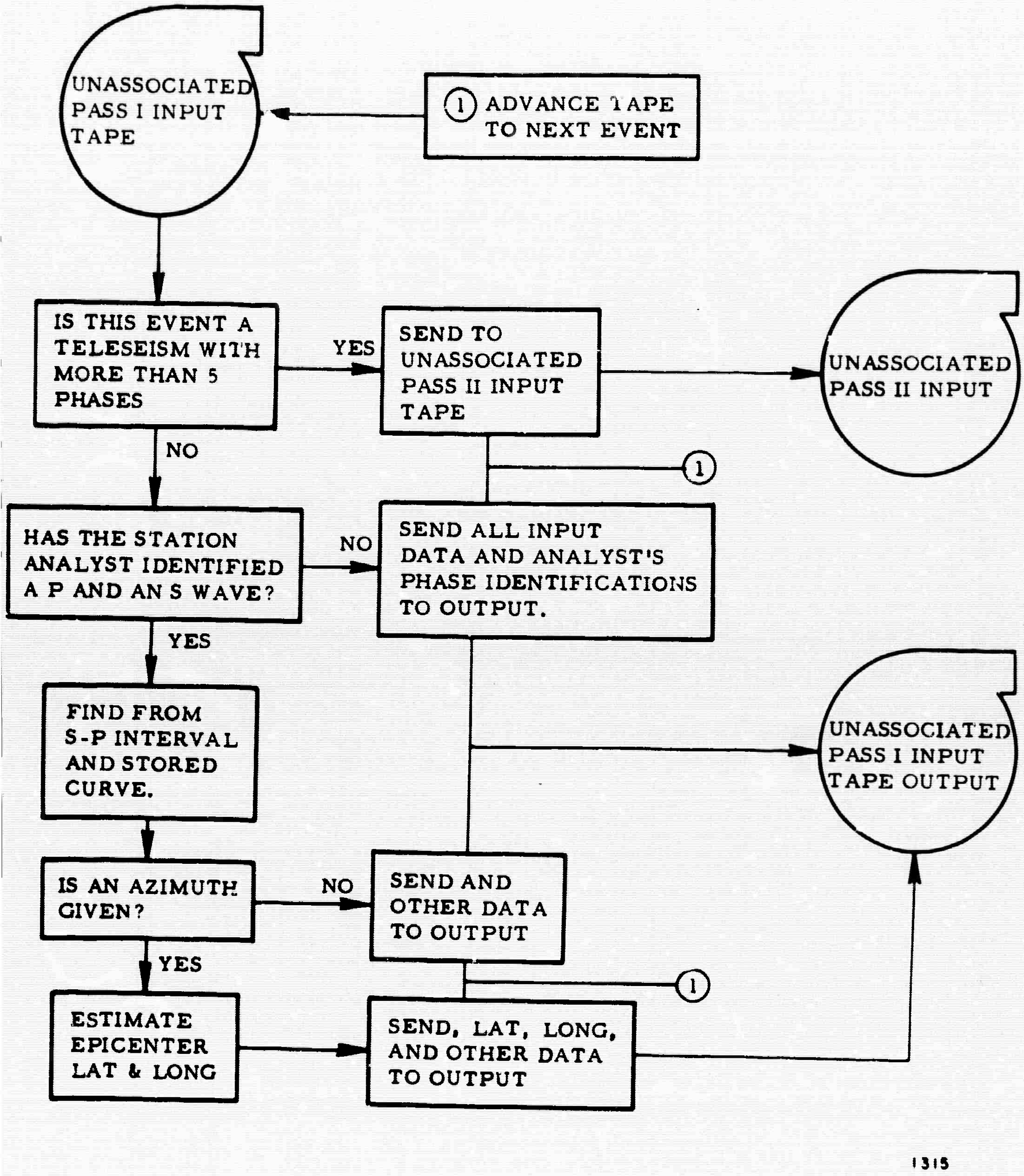


Figure 12. Unassociated Program - Pass I

	I E	PHASE NAME	TIME DAY	H M S.	C D	INST	AMPMAX MMICRNS	PERIOD IN SEC	LN RT	COMM
CPO	D	AZ			M		KM			
	E	R	4	6 41 .		Z			T	87
						LPZ				
BMO	D	96.58 AZ 229.8	4	6 43 42.3	M		44KM	32.60S	178.60E	
	E	P	4	6 57 8.1		Z	4.2	1.0	T	61
	E	L	4	7 27 40.0		LPN	192.8	16.0		
						LPZ				
						LPE				
UBO	D	AZ			M		KM			
	E	R	4	7 28 40.0		LPZ	96.9	36.0	T	
UBO	D	AZ			M		KM			
	E	S	4	7 50 59.6		N	.9	.4	N	
						E				
UBO	D	AZ			M		KM			
	E	P	4	8 30 10.3	C	Z	1.2	.4	T	
						N				
BMO	D	58.65 AZ 305.7	4	8 47 25.2	M		33KM	46.30N	154.30E	
	E	P	4	8 57 23.7		Z	3.0	1.0	T	
	E	L	4	9 17 52.0		LPE	258.7	12.0		
						LPN				
						LPZ				
UBO	D	65.93 AZ 310.9	4	8 47 25.2						
	E	P	4	8 58 12.4	D	N	1.8	.7	T	
						Z				
CPO	D	82.30 AZ 322.7	4	8 47 25.2						
	E	P	4	8 59 46.1		Z	1.6	.6	T	
BMO	D	91.74 AZ 245.1	4	8 50 13.4	M		243KM	18.80S	169.50E	
	E	P	4	9 2 55.8		Z	1.0	.8	T	

Figure 13. A Sample Page From Automated Bulletin

certain peculiar criteria. The problem seems to lie in acquisition of travel time prime points. The theory the program is built upon cannot be tested until programming problems are solved and some real data (as opposed to test data) are processed.

Data flow in this program is complicated and the routine is seldom required with USC&GS information from an enlarged and improved network. This program would be valuable in preparing preliminary bulletins when PDE information is not available but it is not essential to the automated bulletin system as it is now used. The five or ten events per month, which would normally be routed to this program, are not large (from January data) and can be reviewed by manual methods and listed in chronological sequence in the bulletin, or the Unassociated Pass I program can be reprogrammed to accept these events and process them in the same manner as smaller unassociated events.

III. COMPARISON OF AUTOMATED & MANUAL BULLETIN EFFORTS

A. INTRODUCTION

A bulletin of January 1963 data for Project VT/1124 observatories was produced using the automation program. A sample page of this publication is presented in Figure 13. A second bulletin for this same data was produced by manual methods. Data analysis input to the automated method was obtained from observatory personnel without use of PDE information. PDE information was used by a central analysis group to review the film strip records for manual preparation of the January bulletin.

Comparison of the manual and automated bulletins has been completed. Results of this study are discussed below and are summarized in Table I.

B. COMPARISON OF EVENT ASSOCIATIONS

PDE reports listed 251 events for January. If each of the three observatories had recorded each of these events, a total of 753 events would have been reported and associated in the January bulletin.

A count of the number of all types of events listed in each of the two bulletins reflected approximately 2570 in the automated version and 1120 in the manual. This difference is attributed to the number of locals, near regional and regional types which were discarded after the final review of records in the latter method.

Of the 753 possible associations to PDE data, only 515 were considered as probable associations using the criteria that body waves would be the first arrival from the event. The automated bulletin actually associated 454 of these probables while 497 were correlated using the manual technique. As a result of this comparison, re-analysis of the automated program revealed two errors in the programming logic. These have been corrected, and would

TABLE I

Line	Subject	Automated	Manual
1.	Number of events listed in bulletin	2570	1120
2.	Number of events listed in PDE reports (X3)	753	753
3.	Number of observatory reported events which should have associated with PDE events	515	515
4.	Number of bulletin listed events associated with PDE events	454	497
5.	Additional bulletin listed events which would associate after programming corrections	50	-
6.	Total number of bulletin listed events which should have been associated with PDE events (i. e., line 4 + 5)	504	497
7.	Number of reported phases for events associated with PDE events	1773	2098
8.	Number of reported phases associated with PDE events and identified	837	1473
9.	Number of identified phases not reported in raw data - New picks after record review using PDE data	-	325
10.	Number of identified phases not stored in computer	-	105
11.	Additional phases identifiable after programming corrections	93	-
12.	Additional phases identifiable with increased window widths	230	-
13.	Resultant totals of identifiable phases using raw data analysis i. e. - Auto - line 8 + 11 + 12 Manual - line 8 - 9 - 10	1160	1043

now permit an additional 50 events to associate with PDE information. Of the remaining 21 events reported by the observatory, which should have been associated with PDE data, several causes for improper solution by the program have been advanced. These are discussed in more detail in the section of this report covering recommended modifications to the program. It should be noted that the manual bulletin also failed to include approximately the same number of non-associations.

From this review, it is concluded that the capability for associating reported events with PDE events is nearly equal using either the manual or automated technique. The equality of the two systems in this respect should speak highly of the caliber of analysis performed by the observatory personnel, since their reports were prepared prior to the availability of PDE data.

C. COMPARISON OF PHASE IDENTIFICATION

The automated bulletin input, as reported by the observatories, contained 1,773 phase picks, for the 515 events that should have associated. The automated program actually identified 837 phases of events which associated. With present corrections to the program, an additional 50 or more events should also associate. This would result in an increase of about 93 identified phases. The number of phase identifications could be further increased by about 25% with some loss of accuracy by widening phase-time windows to those used for normal manual analysis. This would have produced about 230 additional identifications.

The manual bulletin contains 2,098 phase picks, after reanalysis using PDE data, of which 1,473 were identified. 325 new phases were picked and arrival times changed for most of the remaining phase picks. Presumably, the 325 new picks represent phases which were located after consultation with PDE data and so represent new identifications. These phase times were, therefore, not available to the computer input.

Tables II and III itemize phases identified by both methods. Table II reflects those phases for which travel times were stored in the computer memory. Table III contains other phases identified by manual methods which were not stored in the computer. These, therefore, could not be identified in the automated bulletin at that time.

In summary, when the additional data used in the manual bulletin and the overlap programming error in the automated bulletin are considered, the performance of the automated bulletin program appears presently adequate and extremely promising in terms of further refinements. The computer logic seems as adequate as the human logic presently used in manual preparation. It appears to be somewhat better in association and identification of lonesome phases. Secondary criteria does not seem to be a major problem in phase identification although improvement would result from program refinement in this area.

TABLE II

COMPARISON OF NUMBER OF PHASES IDENTIFIED

Phase	Automated Total	Automated Lonesome	Manual with reanalysis Total	Manual with reanalysis Lonesome
P	348	102	436	87
PP	28	1	105	4
pP	53	4	70	
PKPAB) BC) DE) EF)	42	13	63	14
PcP	42	2	35	
PPP	7	1	8	
S	15	1	63	
SP	18	1	23	
PS	21		31	
SS	29		49	
SKPAB) BC) DF)	7		9	
PKSAB) BC) DF)	2		1	
SKSAC) DE) EF)	15		34	
SKKSAC) DF)	9		9	
SPP	4		8	
PPS	6		24	
PSP (from PPS)	2		0	
SSP	7		1	
PSS	0		2	
SPS (from SSP)	0		0	
SSS	16		22	
PKKPAB) BC) DF)	16	1	43	
G	2		0	
L	68		91	2
R	80	2	241	21
	837	128	1368	128

TABLE III

COMPARISON OF NUMBER OF PHASES IDENTIFIED

Additional Phases Not Presently Stored in Computer Memory

SUR	8
Lg	16
P'P'	23
ScP	14
PKKS	11
ScS	10
P'PKS	5
SKKP	4
pP'	4
PcS	2
S'P	3
ScSP	2
S'S'	1
P'S'	1
PcPP'	1
	105

IV. RECOMMENDED PROGRAM MODIFICATIONS TO IMPROVE PERFORMANCE

Some minor corrections to the program have already been accomplished, based on the processing of January data. However, a re-test of the entire program has not been performed. Normally several test runs are desirable in a program of this complexity to ensure that modifications have been perfected.

These corrections and other possible improvements are discussed in this section. Some of the proposed improvements can be accomplished to different degrees and by more than one method. Some of them are interdependent; that is, one particular change cannot be made without also making another. Consequently, in some cases, estimates are for various combinations of changes which can be performed most efficiently together.

A. TO IMPROVE ASSOCIATIONS

1. To Correct for PDE Overlap Rejection

If the expected arrival time from two PDE events overlap, the station events may or may not be associated correctly. The revision creates new station records in core with those phases, which are in the overlapping time zone for both PDE events at a given station, listed with both the station events in the bulletin. These phases will then be identified for one or both of the events if they fit the necessary criteria, or they may not be identified for either event if they do not pass the travel time and other criteria for either event. The most common situation arising from the error is failure to test a station against the second of an overlapping PDE event pair when the station did not record the first PDE event.

Modifications to correct this have been made. Re-test of portions of the program is still necessary and would require an estimated 3 man days and approximately 6 hours of machine time.

2. Correct for Secondary Criteria Holdover

One event was not associated because of a programming error which rejected the first phase on the basis of secondary criteria which had remained in memory from a previous event. Five other events did not associate for unknown reasons, although they may also have been caused by this problem. This error is more troublesome for phase identification (although it occurred infrequently) than for event association. It usually can be noticed by an obviously erroneous print out. For example: On some events a component period and amplitude will be listed which is not present on the original analysis sheets, or a component may be listed with no period and amplitude given. See the first entry of Figure 13.

The program had failed to erase data from a previous event only when the last phase of the previous event was larger and best recorded on a longer period instrument than the first phase of the following event. The non-erased data included the secondary criteria code for each station phase so an erroneous code could be associated with an event's first arrival. The program would then reject a tentative phase identification based on travel time because it will have failed to meet more than two of the secondary criteria. Under these circumstances the event would not have been associated although the travel time error may be very small.

This problem has been corrected and required check out can be accomplished simultaneously with the previously listed item.

3. Delete the Requirement for First Phase Identification:

The program is very sensitive to identification of the first station phase of an event. If the first phase in a station event cannot be associated with any phase predicted for a PDE event, the balance of the phases in the station event will not be tested.

There are two basic causes for first phase misstie.

a. Very high-gain short-period instruments sometimes record arrivals earlier than those predicted by the standard travel time tables. It is not often that the event is early by more than ten seconds, which is the association window-width limit. In some cases, a very late emergent P phase may be more than ten seconds later than the predicted arrival.

b. P diffracted and later phases which are the first arriving phase of an event, for example, PKP or PKIKP or PKJKP, have arrival times either unknown or insufficiently known. When unusual first phases are seen (usually on larger events) their arrival time is often displaced more than ten seconds from the PKP or PKKP curve. In this situation, the commonly seen branches of PKP, PKKP or other well-known phases will be the second phase of the event.

Three fairly large events failed to associate in the January Bulletin because of first phase misstie.

Natural variations in observed phase arrival times cannot be modified but the association routine can be revised to reduce its dependency on the first phase being within 10 seconds of its predicted arrival time. One solution is to widen the window width for the first phase. However, this problem is more often seen on large than small events and later phases often are well within the window widths. A better solution is to investigate both the first and other phases.

The revision would allow testing of all phases and the best fit, for time and secondary criteria, chosen. The static misstie procedure (see part B) must also be deleted to accomplish this change, resulting in a generally improved time fit for later phases. This will allow an equal number of phase identifications, with more narrow time windows.

This change will require more memory than is available in the 7074; therefore, the depth iteration part of first phase, 60-second misstie routine will be deleted. The 60-second misstie routine served a genuine purpose when the program was first designed, but subsequent improvement in the USC&GS hypocenter program has practically eliminated gross errors in depth. Consequently the only purpose the routine serves at present is to allow association of some badly timed first phases by assuming the epicenter at a different depth. The proposed revision will check all phases, not just the first, so the 60-second misstie routine will no longer be required. Approximately 6 man-weeks of reprogramming effort will be needed to accomplish this modification. Several test operations through the machine would be anticipated, using approximately 10 hours of machine time.

4. <u>Additional Pre-Edit of 1401 Program</u>

This addition would eliminate date-time-group errors in the input data. It would theoretically increase monthly operating costs about 0.1%

but reduce or eliminate the probability for expensive 7074 reruns caused by analyst errors in transcribing input data. At least five additional associations would have been made for January if date time group mistakes had been found.

Several procedures would also reduce occurences of this problem, e.g.

a. A central analysis facility could analyze all records for a given period of time and automatically designate year, month and properly sequenced event numbers.

b. A key punch operator assigned exclusively to this task would notice and correct errors of this type.

Potential human error is not eliminated, however, so a separate edit program would still be required. Elimination of this serious problem is strongly recommended.

Approximately 65 man hours of programming effort would be required, plus an estimated 3 hours of machine time for program check out.

5. Retain Data, Presently Sent To the Unassociated Pass II Program, In the Unassociated Pass I Program

Teleseisms with more than five phases, which do not associate with a PDE event are presently routed to a special magnetic tape. This is the input to the Unassociated Pass II Program. Until the Pass II Program is completed, the contents of this tape must be listed and manually inserted in the bulletin. The Pass I Program can be altered to accept and order the data so that it will be properly displayed in the bulletin. Rewriting can be accomplished with approximately 15 man-hours of programming and 2 of machine time for check out.

6. Shift Rayleigh and Love Travel Time Curves so that more of the lonesome surface wave associations are possible. (See discussion under following section on improvements for phase identification.)

B. TO IMPROVE PHASE IDENTIFICATIONS

1. Increase Window Widths of Several Phases.

These phases have travel times which are not sufficiently well known or have branches in addition to those which have been published in existing travel time tables--or they are more variable as a function of horizontal inhomogeneities of earth structure than are other phases. PP and PKKP appear to require a widening of their basic window widths to about five seconds. The computer presently uses two times the basic window for computation so that, effectively, these windows would be ± 10 seconds. Identification of PKP would also be improved by increasing its window width.

2. Store Rayleigh and Love Wave Travel-Time Curves In the Same Manner As Body Phases and Reduce Their Window Width.

Presently, R and L are stored with their arrival times several minutes later than the first possible R and L arrival. The time window extends to the earliest expected arrival but not earlier. This method of storage allows the same phase identification logic as applied to body waves to be used with the more variable dispersive surface waves. However, for association, any phase must tie within 10 seconds. Thus, only very late arriving lonesome L and R waves could associate with the purposely displaced basic travel time curves. A study of the January data indicates that most L and R waves arrive within a few seconds of the earliest possible arrival time so that few phase identifications would be lost and more lonesome surface waves would associate if their travel time curves were treated in the normal manner. Reducing the window to a few tens of seconds will prevent some misidentifications because of phase window overlap (although few are seen in the January bulletin). Early test runs indicated considerable overlapping window interference from G, so its window was reduced to a minimum. Consequently few G waves are identified. The change in L and R travel times and deletion of G for surface and 33 km depths, but increasing the window width, should all but eliminate the problem. The prime point interpolation would still allow L, R, and G phases at depths exceeding 33 km to about 60 km.

Modifications B-1 and 2 can be accomplished simultaneously. Approximately 20 man-hours of programming and 2 hours machine time are estimated.

3. Delete Allowance For Failure of One Secondary Criteria

On the average, about ten per cent of most phase types will fail one of the secondary criteria. However, the January data indicates that those phases which are most often recorded, especially surface phases, rarely fail any of the secondary criteria. Thus the requirement that all but one criteria be passed allows at least as many phases to be mis-identified as it allows identification of common phases which do not fit the usual secondary criteria pattern.

About 20 body phases failed one secondary criteria in January. Ten are correctly identified. Five are probably not "recognized" phases but have been identified as common phases. The remaining are classified as SSP but should be PKKP.

If the program is changed so that all secondary criteria must be passed, those phases for which certain criteria are valid for less than 90% of the time should have that criteria removed or qualified. Examples are: SS, SSS, PS, PPS, PSS. The secondary criteria requirement for largest motion in the horizontal plane would be deleted for these phases.

The January data shows that SS and SSS pass the requirement about 75% of the time. Figures have not been compiled on PS, PPS, and PSS, but results should be similar.

This change also requires deletion of the static misstie procedure. Man hour and machine requirements for accomplishment are listed as part of B5, below.

4. Add Ability To Test Several Phases At a Time and Make a Best Choice For Identification.

This will prevent misidentification when the reported phase is within more than one phase window stored in memory; e.g., where travel time curves cross.

The earliest stored travel time curve whose window width is wide enough to include the station phase arrival time is the first tested when identifying station phases. Because the program allows failure of one of the three secondary criteria so that if the station phase is near a travel time curve crossing, the later curve may represent the correct phase, but the earlier phase window will encounter the station phase first and all except one secondary criteria will be passed. Thus, the program will associate the station phase with the first phase and not test the later one. In the January data seven phases have been identified as SSP. Three of these have machine comments indicating that the station recorded the event better on short-period instruments than long-period ones and the time fits better for PKKP. The phase is undoubtedly PKKP.

The best way to correct this misidentification is to test two stored travel time curves if the curves are within 20 seconds of each other and compare the number of criteria passed for both of the stored phases. Application of B3 will considerably reduce the problem, however.

5. Delete Application of Static Misstie To Later Phases.

A frequent practice in manually identifying later phases is to assume that the first phase, usually P or PKP, has arrived at exactly the correct arrival time. Then, later arrivals can be compared relative to the first phase on the travel time curve. This procedure helps correct for differences in velocity as a function of path, for non-symmetry of the source, and possible errors in origin time caused by the inclusion of poorly timed phases in the origin time calculation. This procedure is carried in the computer program. The misstie of the first arriving phase, to that predicted from the origin time and location given by the USC&GS, is called the static misstie. This misstie is applied to all the later phases for the purpose of phase identification.

Analysis of the January data indicates that this procedure more often increases than reduces later phase missties, resulting in some phases no longer arriving within their respective window widths. This procedure should be deleted from the program. The reason that this procedure does not perform as well as expected can probably be attributed to the high-gain instrumentation which records first phases which would not normally be seen. The later phases, however, must rise from the background noise which includes activity on the trace brought on by earlier arrivals so that probably the time of the later phases, when they are seen, will be about the same as would have been recorded by lower gain instruments.

This suggested change and the two preceding ones are necessarily interrelated. A total of 160 man hours of programming effort and about 5 hours of machine time would be anticipated for these last three modifications.

6. <u>Increase the Quantity of Secondary Criteria.</u>

The additional secondary criteria would constitute new information which would have to be punched into cards and handled in the program. An indication of whether the phase is dispersive or non-dispersive would limit misidentifications in areas where Love and Rayleigh travel time curves cross body wave travel time curves. The phase relationship of the three components would insure proper identification and association of Love and Rayleigh waves, because Love waves should show transverse motion in the direction of propagation and Rayleigh waves should show retrograde elliptical motion in the direction of propagation. PKS, SKS, PKKS, SKKS, etc., must exhibit vertically polarized S motion so that these phases can be distinguished much of the time from S, SS, etc. P'P' and certain other core phases have reverse step out across an array, which distinguishes them from intersecting phases. All programs of the system must be modified to take the new data. Several station analyst coded comments would be eliminated to make space available on the input cards for new secondary criteria.

This is a continuing item which should be studied and modified as later data is processed and reviewed. The two examples listed above are suggested at this time and would require an estimated 150 man hours of programming and 25 hours of machine time.

C. SUMMARY

The association improvement package is recommended at this time. All the suggested revisions can be accomplished with about 4 man months for programming and about 15 hours of computer time. Bulletin processing could proceed while improvements were accomplished.

V. CONCLUSIONS

January data from the three S. O. stations has been processed through the automated bulletin computer system. Comparison of figures with the manual bulletin indicate that the automated process is as efficient at making associations with PDE events as the manual process and about 63% as efficient in identifying phases even though the film strips were re-analyzed with PDE data to aid in phase picking. If the additional phases picked but not available to the computer and the 105 individual phases (7.1% of the total) which were of types not in the computer memory, are considered, the automated bulletin's capability for identifying phases from raw data is 89% of the manual method which used arrival times adjusted by re-analysis.

Several suggestions for logic changes and the checkout of two corrections made since processing the January data are recommended. Improvement anticipated from new logic changes is not great (i. e., an increase from 89% to 95% for phase identifications and from 98% to 100% for event associations exclusive of lonesome Rayleigh waves). The changes, however, are definitely worth the effort if large amounts of data are to be processed.