HP-35s Calculator Program Closure 6A

Crandall's Adjustment for a Closed Traverse

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Date: March, 2008. Version: 1,0 Mnemonic: **K** for '**K**randall' (sorry)

Line	Instruction	Display	User Instructions
K001	LBL K		↱ LBL K
K002	CLSTK		↱ CLEAR 5
K003	FS? 10		↰ FLAGS 3 .0
K004	GTO K008		
K005	SF 1		↰ FLAGS 1 1
K006	SF 10		↰ FLAGS 1 .0
K007	GTO K009		
K008	CF 1		↰ FLAGS 2 1
K009	CLΣ		↱ CLEAR 4
K010	CRANDALL ADJ		(Key in using EQN RCL C, RCL R, etc.)
K011	PSE		↱ PSE
K012	100		
K013	STO I		↱ STO I
K014	STO (I)		↱ STO (I) [(I) is on the 0 key]
K015	ENTER FIX SIDES		(Key in using EQN RCL E, RCL N, etc.)
K016	PSE		↱ PSE
K017	ENTER FIX AZ		(Key in using EQN RCL E, RCL N, etc.)
K018	PSE		↱ PSE
K019	INPUT Q	Q?	↰ INPUT Q
K020	RCL Q		
K021	x < 0?		↱ x?0 3
K022	GTO K036		
K023	HMS→		↰ HMS→
K024	STO Q		↱ STO Q
K025	ENTER FIX DIST		(Key in using EQN RCL E, RCL N, etc.)
K026	PSE		↱ PSE
K027	INPUT D	D?	↰ INPUT D
K028	RCL Q		
K029	SIN		
K030	RCL× D		
K031	RCL Q		
K032	COS		
K033	RCL× D		
K034	Σ+		
K035	GTO K017		
K036	−30		
K037	STO I		↱ STO I
K038	0		
K039	STO (I)		↱ STO (I) [(I) is on the 0 key]

Crandall's Adjustment for a Closed Traverse

Line	Instruction	Display	User Instructions
K040	—31		
K041	STO I		STO I
K042	0		
K043	STO (I)		STO (I)
K044	—32		
K045	STO I		STO I
K046	0		
K047	STO (I)		STO (I)
K048	STO K		STO K
K049	20		
K050	STO I		STO I
K051	21		
K052	STO J		STO J
K053	ENTER VAR SIDES		(Key in using EQN RCL E, RCL N, etc.)
K054	PSE		PSE
K055	ENTER VAR AZ		(Key in using EQN RCL E, RCL N, etc.)
K056	PSE		PSE
K057	INPUT Q	Q?	INPUT Q
K058	RCL Q		
K059	x < 0?		x?0 3
K060	GTO K082		
K061	HMS→		HMS→
K062	STO Q		STO Q
K063	STO (I)		STO (I)
K064	ENTER VAR DIST		(Key in using EQN RCL E, RCL N, etc.)
K065	PSE		PSE
K066	INPUT D	D?	INPUT D
K067	RCL D		
K068	STO (J)		STO (J) [(J) is on the . key]
K069	RCL Q		
K070	SIN		
K071	×		
K072	RCL Q		
K073	COS		
K074	RCL× D		
K075	Σ+		
K076	1		
K077	STO+ K		STO + K
K078	2		
K079	STO+ I		STO + I
K080	STO+ J		STO + J
K081	GTO K055		
K082	Σx^2		SUMS Σx^2
K083	Σy^2		SUMS Σy^2
K084	×		
K085	Σxy		SUMS Σxy

Crandall's Adjustment for a Closed Traverse

Line	Instruction	Display	User Instructions
K086	x^2		↱ x^2
K087	–		
K088	STO D		↱ STO D
K089	Σy		↱ SUMS Σy
K090	Σxy		↱ SUMS Σxy
K091	×		
K092	Σx		↱ SUMS Σx
K093	Σy^2		↱ SUMS Σy^2
K094	×		
K095	–		
K096	RCL÷ D		
K097	STO A		↱ STO A
K098	Σx		↱ SUMS Σx
K099	Σxy		↱ SUMS Σxy
K100	×		
K101	Σy		↱ SUMS Σy
K102	Σx^2		↱ SUMS Σx^2)
K103	×		
K104	–		
K105	RCL÷ D		
K106	STO B		↱ STO B
K107	0		
K108	STO V		↱ STO V
K109	STO L		↱ STO L
K110	MISCLOSURE		(Key in using EQN RCL M, RCL I, etc.)
K111	PSE		↱ PSE
K112	LAT—NORTH		(Key in using EQN RCL L, RCL A, etc.)
K113	PSE		↱ PSE
K114	Σx		↱ SUMS Σx
K115	STO N		↱ STO N
K116	VIEW N		↰ VIEW N
K117	DEP—EAST		(Key in using EQN RCL D, RCL E, etc.)
K118	PSE		↱ PSE
K119	Σy		↱ SUMS Σy
K120	STO E		↱ STO E
K121	VIEW E		↰ VIEW E
K122	Σx		↱ SUMS Σx
K123	x^2		↱ x^2
K124	Σy		↱ SUMS Σy
K125	x^2		↱ x^2
K126	+		
K127	√x		
K128	STO D		↱ STO D
K129	MISC DIST		(Key in using EQN RCL M, RCL I, etc.)
K130	PSE		↱ PSE
K131	VIEW D		↰ VIEW D

Crandall's Adjustment for a Closed Traverse

Line	Instruction	Display	User Instructions
K132	Σy		↱ SUMS Σy
K133	Σx		↱ SUMS Σx
K134	÷		
K135	ATAN		↱ ATAN
K136	x ≥ 0?		↱ x?0 5
K137	GTO K140		
K138	360		
K139	+		
K140	→HMS		↱ →HMS
K141	STO Q		↱ STO Q
K142	MISC AZ		(Key in using EQN RCL M, RCL I, etc.)
K143	PSE		↱ PSE
K144	VIEW Q		↰ VIEW Q
K145	ADJUSTED TRAV		(Key in using EQN RCL A, RCL D, etc.)
K146	PSE		↱ PSE
K147	20		
K148	STO I		↱ STO I
K149	21		
K150	STO J		↱ STO J
K151	RCL (I)		
K152	STO Q		↱ STO Q
K153	RCL (J)		
K154	STO D		↱ STO D
K155	x < > y		
K156	SIN		
K157	×		
K158	RCL Q		
K159	COS		
K160	RCL× D		
K161	RCL× D		
K162	RCL× A		
K163	x < > y		
K164	RCL× D		
K165	RCL× B		
K166	+		
K167	STO C		↱ STO C
K168	STO+ V		↱ STO + V
K169	SIDE AZ		(Key in using EQN RCL S, RCL I, etc.)
K170	PSE		↱ PSE
K171	RCL Q		
K172	→HMS		↱ →HMS
K173	STO Q		↱ STO Q
K174	VIEW Q		↰ VIEW Q
K175	DIST CORRN		(Key in using EQN RCL D, RCL I, etc.)
K176	PSE		↱ PSE
K177	VIEW C		↰ VIEW C

Crandall's Adjustment for a Closed Traverse

Line	Instruction	Display	User Instructions
K178	RCL C		
K179	STO+ D		STO + D
K180	CORRECTED DIST		(Key in using EQN RCL C, RCL O, etc.)
K181	PSE		PSE
K182	VIEW D		VIEW D
K183	RCL Q		
K184	HMS→		HMS→
K185	STO Q		STO Q
K186	SIN		
K187	RCL× C		
K188	RCL Q		
K189	COS		
K190	RCL× C		
K191	Σ+		
K192	1		
K193	STO+ L		STO + L
K194	RCL K		
K195	RCL L		
K196	x ≥ y?		x?y 5
K197	GTO K202		
K198	2		
K199	STO+ I		STO + I
K200	STO+ J		STO + J
K201	GTO K151		
K202	SUM OF CORRNS		(Key in using EQN RCL S, RCL U, etc.)
K203	PSE		PSE
K204	VIEW V		VIEW V
K205	ADJ MISCLOSURE		(Key in using EQN RCL A, RCL D, etc.)
K206	PSE		PSE
K207	LAT—NORTH		(Key in using EQN RCL L, RCL A, etc.)
K208	PSE		PSE
K209	Σx		SUMS Σx
K210	STO N		STO N
K211	VIEW N		VIEW N
K212	DEP—EAST		(Key in using EQN RCL D, RCL E, etc.)
K213	PSE		PSE
K214	Σy		SUMS Σy
K215	STO E		STO E
K216	VIEW E		VIEW E
K217	Σx		SUMS Σx
K218	x^2		x^2
K219	Σy		SUMS Σy
K220	x^2		x^2
K221	+		
K222	$\sqrt{x}$		
K223	STO D		STO D

Crandall's Adjustment for a Closed Traverse

Line	Instruction	Display	User Instructions
K224	MISC DIST		(Key in using EQN RCL M, RCL I, etc.)
K225	PSE		PSE
K226	VIEW D		VIEW D
K227	Σy		SUMS Σy
K228	Σx		SUMS Σx
K229	÷		
K230	ATAN		ATAN
K231	x ≥ 0?		x?0 5
K232	GTO K235		
K233	360		
K234	+		
K235	→HMS		→HMS
K236	STO Q		STO Q
K237	MISC AZ		(Key in using EQN RCL M, RCL I, etc.)
K238	PSE		PSE
K239	VIEW Q		VIEW Q
K240	100		
K241	STO I		STO I
K242	0		
K243	STO (I)		STO (I)
K244	20		
K245	RCL I		
K246	x < y?		x?y 3
K247	GTO K251		
K248	1		
K249	STO— I		STO — (I)
K250	GTO K242		
K251	PROGRAM END		(Key in using EQN RCL P, RCL R, etc.)
K252	PSE		PSE
K253	FS? 1		FLAGS 3 1
K254	CF 10		FLAGS 2 .0
K255	RTN		RTN

Notes

(1) The program is designed to run in RPN mode. Its performance in ALG mode is unknown and may produce erroneous results.

(2) The program can work with traverses where all the sides are to be adjusted, where some of the sides are considered 'fixed' (not to be adjusted), and traverses between known points with co-ordinates. The last need the azimuth and distance between the fixed points derived from the co-ordinates, and treated as a fixed side.

(3) The sequence of operations is to enter the fixed sides (those not to be adjusted), and then the variable sides (those to be adjusted). The calculator stores the variable sides and retrieves them from memory to compute the adjusted lengths, and also re-computes the traverse misclosure. The memory limits the traverse to no more than 390 variable sides. If you want to run Crandall's Adjustment on a

traverse of more than 390 variable sides: (a) use a different computational device; (b) be aware that the errors in such a traverse may be too difficult to predict and work with in a meaningful way; (c) use a full least squares adjustment, plus use cross-ties on the ground; and (d) put your analyst on danger money!

(4) Provided that all the fixed sides are entered first, and then all the variable sides, it does not matter in which order the sides within each group are entered.

(5) Azimuths are entered in HP notation, i.e., DDD.MMSS

(6) The misclosure components of the adjusted traverse in X (or E or departure) and Y (or N or latitude) can be displayed by recalling Σy and Σx using the SUMS menu. (Note these are back-to-front.)

(7) This program was inspired by the program developed by the one-and-only Neil H. Bradbury, LS, in January, 1977, for the HP-25 calculator.

(8) The program assumes that the error in the length of each side is proportional to the length of the side, which is the situation with EDM. It will produce somewhat different results to a Crandall's adjustment based on the error increasing as the square root of the distance, which is the more traditional method based on error propagation using a tape.

(9) To indicate the end of the groups of sides of the traverse to be entered at any point, enter a negative value for the azimuth, –1 being easiest.

(10) At the end of the program, Flag 10 is reset to its value before the program started, and the 'indirect' memory is cleared and so de-allocated. This saves memory space and is simply good practice. If you quit before the program comes to the very end, you may leave quite a lot of memory used (from location 20 up to 100).

(11) This program does not use vectors or complex numbers for the misclosure calculation, because the components are required for the adjustment calculations. Consequently, the components are calculated and the vector sum is accumulated through the statistical registers, together with the various data items for the adjustment calculation.

(12) To avoid a problem with storing an azimuth (or distance) of zero, which may cause a memory error in the 'indirect' registers, an arbitrary value is stored in register 100. This should allow a 40-sided traverse. If you want to try a bigger traverse that may have an azimuth of zero in it, change the value of 100 at lines K012 and K240 to a value that is a little larger than twice the number of sides in the traverse plus 20. And make yourself some strong coffee! This will allocate enough 'indirect' memory at the start of the program, and clear and de-allocate it when the program ends. This particular issue came up in discussion with Mr. James Watson of RMIT, and brought to light the potential for a very subtle error in memory allocation, which this addition to the program should allow the user to avoid.

Theory

Crandall's Adjustment was developed by Charles Crandall, and published in 1914. It was the first serious rival to Bowditch's Method of Adjustment. The fundamental concepts were that angle measurement was far better than distance measurement, and that the small random errors in the angles of a traverse could be properly adjusted by simple distribution of the angular misclosure among the traverse's angles. This meant that all the remaining misclosure in the traverse, i.e., all the random errors, could be accounted for by the distances alone, so these were all that was adjusted by Crandall's Adjustment.

Crandall used least squares adjustment by condition equations for the adjustment. By avoiding having to adjust the angles as part of the adjustment proper, the number of conditions was reduced to two, which greatly simplified the calculations.

Angle Adjustment

The angular misclosure of the traverse can be adjusted by any reasonable means. The misclosure can be distributed evenly among all the angles, or larger amounts may be apportioned to angles that can be assumed to be less reliable, perhaps because of short lines or poor lines of sight. However the angles are adjusted, they should be adjusted to bring the misclosure to zero, and then the azimuths of each line calculated.

It is a good idea to run the traverse through one of the closure programs to make sure that there are no gross or systematic errors in the traverse, prior to adjustment. This is because the adjustment process assumes that only random errors are present in the data. ***If this assumption is not correct, the adjustment will produce erroneous results.***

Distance Adjustment

With the angular misclosure adjusted to zero, there are now only two conditions that must be met to have a consistent traverse. (The third condition, that the angular misclosure is zero, has been met by adjusting the angle ahead of this point.) Solution of a 2×2 matrix is straightforward, so a full least squares adjustment by condition equations can be performed. This adjustment changes only the lengths of the sides of the traverse. The angles are already adjusted and so held fixed.

If the length of each line in the traverse is M_i, while θ_i is its azimuth, then d_i will be the adjusted length of each line in the traverse, and v_i will be the correction to the measured length of each line to obtain the adjusted length:

$$d_i = M_i + v_i \qquad [1]$$

The conditions to be met can be expressed as:

$$d_1 \cos\theta_1 + d_2 \cos\theta_2 + d_3 \cos\theta_3 + \ldots = 0 \qquad \text{[Sum of latitudes equals zero]}$$

$$d_1 \sin\theta_1 + d_2 \sin\theta_2 + d_3 \sin\theta_3 + \ldots = 0 \qquad \text{[Sum of departures equals zero]}$$

Substituting Equation [1] into the above equations gives:

$$(M_1 + v_1)\cos\theta_1 + (M_2 + v_2)\cos\theta_2 + (M_3 + v_3)\cos\theta_3 + \ldots = 0$$

$$(M_1 + v_1)\sin\theta_1 + (M_2 + v_2)\sin\theta_2 + (M_3 + v_3)\sin\theta_3 + \ldots = 0$$

Re-arranging and gathering terms produces:

$$v_1 \cos\theta_1 + v_2 \cos\theta_2 + v_3 \cos\theta_3 + \ldots + q_1 = 0$$

$$v_1 \sin\theta_1 + v_2 \sin\theta_2 + v_3 \sin\theta_3 + \ldots + q_2 = 0 \qquad [2]$$

where $q_1 = M_1 \cos\theta_1 + M_2 \cos\theta_2 + M_3 \cos\theta_3 + \ldots =$ misclosure in latitude

$q_2 = M_1 \sin\theta_1 + M_2 \sin\theta_2 + M_3 \sin\theta_3 + \ldots =$ misclosure in departure

Crandall's Adjustment for a Closed Traverse

So q_1 and q_2 are obtained directly from the closure check of the traverse, done after the angles are adjusted and azimuths computed. Representing the departure of each line by D_i, and the latitude of each line by L_i, Equations [2] can be rewritten as:

$$v_1 \cos \frac{L_1}{d_1} + v_2 \cos \frac{L_2}{d_2} + v_3 \cos \frac{L_3}{d_3} + \ldots + q_1 = 0$$

$$v_1 \sin \frac{D_1}{d_1} + v_2 \sin \frac{D_2}{d_2} + v_3 \sin \frac{D_3}{d_3} + \ldots + q_2 = 0 \qquad [3]$$

The theory of least squares now allows the development of what are termed the normal equations (named after the normal distribution, which describes the distribution characteristics of the random errors). The details can be found elsewhere, but basically they are a combination of all the measured data, the precision values of the measurements, and the models that describe how they all fit together, i.e., the model of the conditions to be met (e.g., Equations [2] and [3]).

There are two cases that Crandall considered. The first is the situation where the error in the length of the sides increases in proportion to the square root of the length of the line, i.e., $\sqrt{d}$, which is a good assumption for taped distances. The second case is where the error in distance increases in proportion to the length of the line, which is more the case with short distances measured with rods, but also the case with EDM. This program is based on the second case, as it is more probable that EDM traverses will be used with this program.

If the error in the lengths of the sides of the traverse increases in proportion to the length of each side, then the normal equations for the adjustment are as follows:

$$A\sum_i L_i^2 + B\sum_i L_i D_i + q_1 = 0$$

$$A\sum_i L_i D_i + B\sum_i D_i^2 + q_2 = 0 \qquad [4]$$

Solving for A and B, which are called the correlatives:

$$\mathrm{A} = \frac{q_2\sum_i L_i D_i - q_1\sum_i D_i^2}{\sum_i D_i^2 \sum_i L_i^2 - \left(\sum_i L_i D_i\right)^2}$$

$$\mathrm{B} = \frac{q_1\sum_i L_i D_i - q_2\sum_i L_i^2}{\sum_i D_i^2 \sum_i L_i^2 - \left(\sum_i L_i D_i\right)^2} \qquad [5]$$

the corrections to the line lengths can be calculated using:

$$v_i = L_i \; d_i \; \mathrm{A} + D_i \; d_i \; \mathrm{B} \qquad [6]$$

Crandall's Adjustment for a Closed Traverse

As an aside, the corrections should all sum to zero if the traverse has no fixed sides, but that can be affected by rounding during the calculations, especially if the sums of the various components are large, so the result may be not quite zero. If the traverse has fixed sides, the sum of the corrections will be significantly different from zero, depending upon the length of the fixed side.

Including Fixed Sides and Points

In the event that the traverse includes more than one 'fixed' point (usually the starting point in calculations), Crandall's Method can still be used. A 'fixed' point means a point that has known co-ordinates, usually from a more precise prior survey, and will not be subject to adjustment in this program. This situation arises when a traverse connects to more than one known point.

If there are two fixed points, and these form the end points of one line of the traverse, then the traverse calculations are done in the normal way, except that the L_i, D_i, and L_iD_i values for the fixed line are not calculated and not included in the summations to solve the correlatives. This is the case in this program.

If there are more than two fixed points, or the fixed points are not adjacent, the traverse must be split into sections between fixed points, and the sections adjusted independently. This is not the ideal solution, as a full least squares adjustment should be used in this situation.

If the traverse runs between two known points, then the line (vector) between the two known points (computed from the co-ordinates of the two points) can be considered another side in the traverse. Computing around the traverse, the misclosure will reflect how well the traverse agrees with this computed vector. To adjust the traverse, don't include the L_i, D_i, and L_iD_i values for this line in the summations, and all the corrections will occur in the measured traverse lines.

For this program, any fixed lines should be worked out ahead of time, including the line between known end-points of the traverse (if applicable). The first part of the program allows the user to enter these sides, and they do not add to the data that sets up the adjustment. The second part of the program allows the user to enter the sides that do add to the adjustment. The final part of the program produces the results.

Sample Computations and Running the Program

1. All sides to be adjusted

The traverse to be adjusted is as follows:

Azimuth	Distance
0° 12'	156.41
90° 00'	211.65
165° 49'	173.82
250° 55'	176.60
308° 30'	112.26

Crandall's Adjustment for a Closed Traverse

The initial misclosure is:	DE	=	0.036
	DN	=	0.033
	Misclosure Length	=	0.049
	Misclosure Azimuth	=	47° 24' 15"

Running the Program

Press XEQ K and then ENTER to start the program.

The program briefly displays CRANDALL ADJ, then briefly displays ENTER FIX SIDE to indicate that the fixed sides should be entered first.

The program then prompts ENTER FIX AZ, to indicate that the azimuth of a fixed side should be entered in DDD.MMSS (HP) notation. The prompt is to enter Q?.

As there are no fixed sides in this case, key in 1 then press the +/– key, and press R/S.

The calculator shows ENTER VAR SIDE to indicate that the sides to be varied (adjusted) should be entered now.

The calculator then prompts ENTER VAR AZ to indicate that the azimuth of a variable sides should be entered in DDD.MMSS (HP) notation. The prompts to enter is Q?.

Key in the azimuth of the first side, 0.12, then press R/S.

The calculator prompts with ENTER VAR DIST, to indicate that the length of that variable side should be entered. The prompt is to enter D?.

Key in the distance 156.41, then press R/S.

The calculator prompts with ENTER VAR AZ, then the Q? prompt.

Key in the next azimuth, 90.0, and press R/S.

The calculator prompts with ENTER VAR DIST, then the D? prompt.

Key in the distance, 211.65, and press R/S.

The calculator prompts with ENTER VAR AZ, then the Q? prompt.

Key in the next azimuth, 165.49, and press R/S.

The calculator prompts with ENTER VAR DIST, then the D? prompt.

Key in the distance, 173.82, and press R/S.

The calculator prompts with ENTER VAR AZ, then the Q? prompt.

Key in the next azimuth, 250.55, and press R/S.

The calculator prompts with ENTER VAR DIST, then the D? prompt.

Key in the distance, 176.6, and press R/S.

The calculator prompts with ENTER VAR AZ, then the Q? prompt.

Key in the next azimuth, 308.3, and press R/S.

The calculator prompts with ENTER VAR DIST, then the D? prompt.

Key in the distance, 112.26, and press R/S.

The calculator prompts with ENTER VAR AZ, then the Q? prompt.

Crandall's Adjustment for a Closed Traverse

As this is the last variable side, key in a negative azimuth, –1, and press R/S.

[Note that the Q and D prompts contain the previous entries, albeit the Q value is in decimal degrees, which can help you keep track of where you are when entering sides.]

The calculator briefly displays MISCLOSURE, then briefly displays LAT–NORTH, then stops and displays:

N=
0.0330

which is the misclosure component in the latitude, or in the north-south direction. Press R/S to continue. The calculator briefly displays DEP–EAST, then stops and displays:

E=
0.0359

which is the misclosure in the departure or east-west direction. Press R/S to continue. The calculator briefly MISC DIST, then stops and displays:

D=
0.0488

which is the length of the misclosure vector. Press R/S to continue. The calculator briefly displays MISC AZ, then stops and displays:

Q=
47.2415

which is the azimuth of the misclosure vector, in HP notation (DDD.MMSS). Press R/S to continue.

The calculator briefly displays ADJUSTED TRAV and then proceeds around a loop displaying, in turn, the azimuth of the side, the correction to that side's distance, and the corrected distance for the side. The prompts before each value are SIDE AZ and Q= for the traverse side's azimuth (which is displayed in HP notation, DDD.MMSS), DIST CORRN and C= for the correction to the distance, and CORRECTED DIST and D= for the corrected side distance.

Pressing R/S after each value is displayed will cause the calculator to move on to the next value. The results are tabulated below. The sequence is moving along the rows from left-to-right, and then down. Note that the azimuth of the sides are unchanged: only the side lengths have been adjusted.

Side Azimuth	Distance Correction	Corrected Distance
0° 12' 00"	–0.0139	156.3961
90° 00' 00"	–0.0207	211.6293
165° 49' 00"	0.0132	173.8332
250° 55' 00"	0.0194	176.6194
308° 30' 00"	0.0001	112.2601

Crandall's Adjustment for a Closed Traverse

After the last corrected side distance has been displayed, the calculator then briefly displays SUM OF CORRNS, which is for the total of the corrections. The calculator stops and displays:

V=
–0.0019

which is the sum of all the distance corrections. This is pretty close to zero. Press R/S to continue. The calculator briefly displays ADJ MISCLOSURE, then LAT–NORTH briefly, then stops and displays:

N=
–9.0000E –16

which indicates that the misclosure of the adjusted traverse in the north-south direction, or in the latitudes, is exceedingly small. Press R/S to continue, and the calculator briefly displays DEP–EAST, then stops and displays:

E=
–1.1030E –13

which is the misclosure adjusted traverse in the east-west or departure direction, and is also very, very small. Press R/S to continue and the calculator displays MISC DIST briefly, then stops and displays:

D=
1.1030E –13

which is the length of the misclosure vector of the adjusted traverse which is also exceedingly tiny. Press R/S to continue, and the calculator briefly displays MISC AZ, then stops and displays:

Q=
89.3157

which is the azimuth of the misclosure vector of the adjusted traverse, in HP notation (DDD.MMSS). Press R/S to continue.

The calculator then shows RUNNING for several seconds as it clears the indirect memory, and then briefly displays PROGRAM END, and terminates.

You can see that it is handy to have the traverse data nicely tabulated, to make getting it into and out of the calculator quick, simple and error free.

2. One fixed side, a traverse between known points

For this traverse, one side is considered fixed, because the traverse is between two fixed points. The azimuth and distance between the two points are deduced from co-ordinates (using a different program), and are 59° 04' 33" for 1995.78. The angular misclosure is adjusted out of the traverse angles, and the azimuths of the sides calculated, on the same azimuth datum as the fixed side, i.e., the same co-ordinate system.

The program is started and the fixed side entered: 59.0433 and 1995.78.

Crandall's Adjustment for a Closed Traverse

As this is the only fixed side, the next azimuth is entered as –1, and the calculator moves to collect the data for the variable sides. These are as follows:

Azimuth	Distance
349° 47' 19"	429.20
109° 22' 12"	476.00
202° 58' 13"	1362.00
271° 07' 59"	210.10
259° 42' 45"	164.00
295° 34' 53"	319.80
237° 45' 39"	499.95
283° 57' 32"	482.10

The initial misclosure is: DE = 2.910

DN = –1.290

Misclosure Length = 3.184

Misclosure Azimuth = 293° 54' 23"

These are entered into the calculator as prompted. Once they have all been entered, an azimuth of –1 is entered, and the calculator shows the above misclosure data. Once this part is done, the calculator works through the adjustment of the sides, presenting the adjusted sides. The adjusted side values are:

Azimuth	Distance Correction	Distance
349° 47' 19"	0.4683	429.668
109° 22' 12"	–0.9666	475.033
202° 58' 13"	–0.4317	1361.568
271° 07' 59"	0.1719	210.272
259° 42' 45"	0.0930	164.093
295° 34' 53"	0.4393	320.239
237° 45' 39"	0.5639	500.514
283° 57' 32"	0.9761	483.076

Pressing R/S again, the calculator displays 1.314 as the sum of the corrections.

The final adjusted misclosure is: DE = 1.600E –11

DN = 2.500E –11

Misclosure Length = 2.968E –11

Misclosure Azimuth = 132° 37' 09"

The misclosure is now very much smaller than the finest level of distance measurement.

Crandall's Adjustment for a Closed Traverse

Comments

An important point to note about Crandall's Adjustment is that because all the corrections are placed in the distances, any non-random errors (e.g., gross errors) in the angles will produce very large corrections in the distances. This is an indication that there may be gross errors in the angles, and this should be checked. Similarly, gross errors in the distances will also produce some large corrections.

In the second example, the original lengths were in many cases almost approximate in their apparent precision, while the misclosure was quite large, being about 1: 1,900. This led to the large corrections in the distances seen in the results.

Note also that in the second example, with the fixed side, the sum of the corrections was 1.314, well away from the zero. This is characteristic of adjusting traverses with fixed sides.

Storage Registers Used

A Correlative A

B Correlative B

C Correction to side length

D Current side length, intermediate result in adjustment calculation, adjusted length, misclosure length

E Misclosure in departure, or the east-west direction.

I Used to address the indirect registers, via (I)

J Used to address the indirect registers, via (J)

K Counter for the number of sides

L Counter for the number of sides

N Misclosure in latitude or the north-south direction

Q Current side azimuth, azimuth of misclosure

V Sum of corrections to the lengths

Statistical Registers:

Σx = Sum of the latitudes

Σy = Sum of the departures

Σx^2 = Sum of the squares of the latitudes of the sides to be adjusted

Σy^2 = Sum of the squares of the departures of the sides to be adjusted

Σxy = Sum of the products of the latitudes and departures of the sides to be adjusted

Labels Used

Label **K** Length = 1058 Checksum = 3D86

Use the length (LN=) and Checksum (CK=) values to check if program was entered correctly. Use the sample computations to check proper operation after entry.

Crandall's Adjustment for a Closed Traverse

Flags Used

Flags 1 and 10 are used by this program. Flag 10 is set for this program, so that equations can be shown as prompts. Flag 1 is used to record the setting of Flag 10 before the program begins. At the end of the program, Flag 10 is reset to its original value, based on the value in Flag 1.

Reference

CRANDALL, Charles L., 1914. *Geodesy and Least Squares*. New York : John Wiley and Sons.