City Surveying

PART 3

By

A. DeGROOT

Fellow, American Society of Civil Engineers
Former Director, Civil Engineering School
International Correspondence Schools

International Correspondence Schools, Scranton, Pennsylvania

What This Text Covers . . .

City Surveying

PART 3

Adjustment of Level Net

Methods for Adjustment

1. After the collimation correction, the correction for curvature and refraction, the several rod corrections, and the orthometric correction have been applied to each section of a net of levels, it is still necessary to balance, or adjust, the differences of elevation so as to obtain exact closures throughout the entire net. Where the lines of levels form a net, it is not possible to adjust the closures merely by distributing them in direct proportion to the lengths of lines. There are four methods in common use for adjusting level nets: 1) the condition-equation method of least squares, 2) the observation-equation method of least squares, 3) the junction-point method, and 4) the polygon method. The first method is similar to the method explained in *City Surveying*, Part 1, for a triangulation net, and the second method is similar to the method explained in *City Surveying*, Part 2, for a traverse net. Either least-squares method is considered rigorous and scientific, and identical results are obtained by both methods. The best method for any particular level net depends on the circumstances.

Perhaps the most logical method of adjustment for a level net that contains either one or several fixed bench marks is one of the methods of least squares. The adjustment of a level net by the condition-equation method of least squares is much less tedious than is the adjustment of a triangulation survey by the same method. In fact, the time required for the adjustment of a level net by either method of least squares is only slightly greater than that required for an adjustment by one of the less rigorous methods.

If the net contains several bench marks whose elevations have been fixed by a previous survey, the adjustment of the closures may be made by the junction-point method. However, where the net contains only one bench mark whose elevation is fixed, a method known as the polygon method may be more advantageous for adjusting the closures. In city surveying, the junction-point method is generally used for adjusting a network of first-order levels. For second-order levels it is permissible to use either the junction-point method or the polygon method. Both the junction-point method and the polygon method will be described here by means of typical examples.

Data for Junction-Point Method

2. In Fig. 1 is shown a diagrammatic layout of a network consisting of several lines of levels. The four bench marks that are designated by the letters *A*, *B*, *C*,

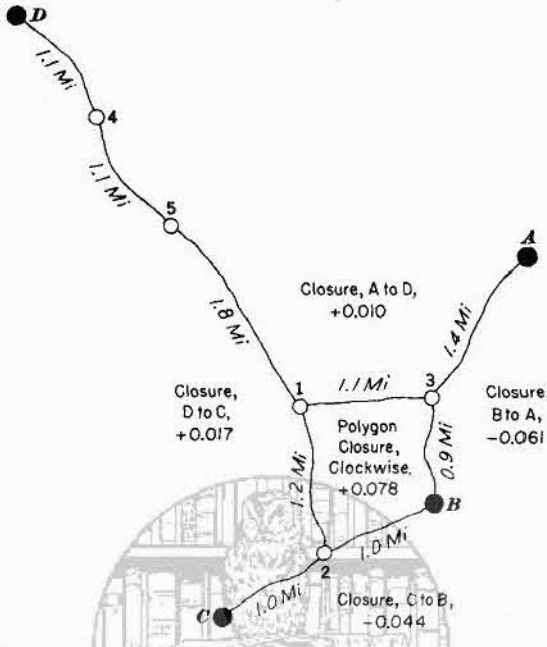

FIG. 1. LEVEL NET FOR JUNCTION-POINT METHOD

TABLE 1

Adjusted Elevations of Bench Marks by Junction-Point Method

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Section		Length of Section, in Miles	Field-Measured Difference of Elevation	Correction From Adjustment	Adjusted Difference of Elevation	Adjusted Elevation	B. M.
From B. M.	To B. M.						
						762.402	*A*
A	3	1.4	−21.504	−0.031	−21.535	740.867	3
3	*B*	0.9	−32.316	−0.030	−32.346	708.521	*B*
B	2	1.0	−15.340	−0.026	−15.366	693.155	2
2	*C*	1.0	+29.678	−0.018	+29.660	722.815	*C*
						693.155	2
2	1	1.2	+26.980	−0.009	+26.971	720.126	1
1	3	1.1	+20.754	−0.013	+20.741	740.867	3
						748.736	*D*
D	4	1.1	−20.862	−0.002	−20.864	727.872	4
4	5	1.1	−19.118	−0.002	−19.120	708.752	5
5	1	1.8	+11.378	−0.004	+11.374	720.126	1
D to 1		4.0	−28.602	−0.008	−28.610		

and *D*, respectively, have the following fixed elevations, in feet: *A*, 762.402; *B*, 708.521; *C*, 722.815; and *D*, 748.736. It is required to determine the elevations of the five bench marks that are designated by the numbers 1, 2, 3, 4, and 5 from the results of lines of levels run from the bench marks *A*, *B*, *C*, and *D*. The adjustments in the elevations will here be made by the junction-point method. In the first two columns of Table 1 are listed the designations of the bench marks at the extremities of the various lines, or sections; in the third column are given the lengths of the respective sections, in miles; and in the fourth column are shown the differences in elevation between the extremities of the respective stations, as determined from the observed rod readings and the corrections for temperature, absolute length of rod, and other known errors.

Preliminary Elevations of Junction Points

3. The basic calculations for establishing the adjusted elevations of bench marks 1, 2, and 3 at junction points in Fig. 1 are indicated in Table 2. In order to determine the required adjusted elevations, it is necessary to consider all possible routes from the various bench marks with fixed elevations to the other bench marks. For example, in the preliminary calculations, the elevation of bench mark 1 is determined by considering each of the following five routes that end at bench mark 1: from *A* through 3, from *B* through 3, from *B* through 2, from *C* through 2, and from *D* through 4 and 5. Similarly, the elevation of bench mark 2 is computed from *B*, from *C*, and from 1; and the elevation of bench mark 3 is calculated from *A*, from *B*, and from 1. Since there are no intersecting lines between *D* and 1, the corrections to the elevations of bench marks 4 and 5 are determined by direct proportion after the adjusted elevation of bench mark 1 has been established. Therefore, at first, the entire section from *D* to 1 is treated as a unit, and the parts of that section are disregarded.

In the first column of Table 2 is entered the number of the bench mark whose elevation is desired. In the second column is given the designation for the originating bench mark, or the bench mark at the beginning of the route under consideration. In the third column are entered the number or the numbers of the intervening bench marks. The fourth column contains the elevation of the originating bench mark for each route. Before the proper value can be entered for the fixed elevation of bench mark 1 in the establishment of elevations for bench marks 2 and 3, certain preliminary calculations must be performed.

The fifth column is for the difference in elevation between the ends of each route, as obtained from the values given in column 4 of Table 1. In order to obtain these differences in elevation, consideration must be given to the direction in which each line was run in the field and to the direction in which the line between a fixed bench mark and a junction point was taken in the adjustment. Thus, in Table 1, the difference in elevation between bench marks *A* and 3 is recorded as −21.504 ft (feet), and the difference between bench marks 1 and 3 is

TABLE 2

Computations for Establishing Adjusted Elevations of Bench Marks by Junction-Point Method

(1) Junction Point B. M.	(2) Originating B. M.	(3) Intermediate B. M.'s	(4) Fixed Elevation of Originating B. M.	(5) Unadjusted Difference of Elevation	(6) Preliminary Elevation of Junction Point, or Column 4 + Column 5	(7) Length of Route, in Miles = M	(8) Weight $= 1 \div M$	(9) Weighted Elevation of Junction Point, or Column 8 × Column 6	(10) Remarks
1	*A*	3	762.402	−42.258	720.144	2.5	0.4	.058	
1	*B*	3	708.521	+11.562	720.083	2.0	0.5	.042	
1	*B*	2	708.521	+11.640	720.161	2.2	0.5	.080	
1	*C*	2	722.815	− 2.698	720.117	2.2	0.5	.058	
1	*D*	4+5	748.736	−28.602	720.134	4.0	0.2	.027	
							2.1	.265	
								720.126	Weighted Mean Elev. of B. M. 1
2	*B*		708.521	−15.340	693.181	1.0	1.0	.181	
2	*C*		722.815	−29.678	693.137	1.0	1.0	.137	
2	1		720.126	−26.980	693.146	1.2	0.8	.117	
							2.8	.435	
								693.155	Weighted Mean Elev. of B. M. 2
3	*A*		762.402	−21.504	740.898	1.4	0.7	.629	
3	*B*		708.521	+32.316	740.837	0.9	1.1	.921	
3	1		720.126	+20.754	740.880	1.1	0.9	.792	
							2.7	2.342	
								740.867	Weighted Mean Elev. of B. M. 3

+20.754 ft. Since the direction in which the line of levels from 1 to 3 was run is opposite to that considered in proceeding from *A* to 1 through 3, the difference in elevation between bench marks 3 and 1 must be taken as −20.754 ft. The total difference in elevation between *A* and 1, which is entered in column 5 of Table 2, is −21.504 + (−20.754) = −42.258 ft. The values in that column for the other routes terminating at bench mark 1 are obtained as follows: For the route from *B* through 3, the total is +32.316 + (−20.754) = +11.562 ft. For the route from *B* through 2, it is −15.340 + (+26.980) = +11.640 ft. For the route from *C* through 2, it is −29.678 + (+26.980) = −2.698 ft. For the route from *D* through 4 and 5, it is −20.862 + (−19.118) + (+11.378) = −28.602 ft. The preliminary elevations of the various bench marks, as given in the sixth column of Table 2, are obtained by taking the algebraic sum of the values in columns 4 and 5 for the respective routes.

Weighted Elevations

4. In column 7 of Table 2 are listed the respective lengths of the various routes between the bench marks designated in columns 1 and 2. Thus, for the route from *A* to 1 through 3, the length is 1.4 + 1.1 = 2.5 miles. It is here assumed that, for the purpose of adjustment, the several preliminary elevations of the same bench mark should be weighted in inverse proportion to the lengths of the routes covered in establishing those elevations. In column 8 are entered the weights, or the reciprocals of the lengths in column 7. Sometimes, the reciprocals of the square roots of the lengths are used.

Column 9 contains the weighted elevations. The value for each route is the product of the weight in column 8 and the preliminary elevation in column 6. For simplification in multiplication, only the decimal parts of the preliminary elevations are multiplied by the weights, as it is obvious that the number of whole feet will be the same in the final elevation as in the preliminary elevation. Thus, the value 0.058 in the first line is the product of 0.144 and 0.4. In case the number preceding the decimal point is not the same for all the preliminary elevations for a certain bench mark, it is necessary to multiply both the decimal and the first number preceding the decimal point by the weight.

To determine the decimal part of the weighted mean elevation of any bench mark in Table 2, the sum of the decimal parts of all the weighted elevations of that bench mark is divided by the sum of the corresponding weights in column 8. For bench mark 1, the sum in column 9 is 0.058 + 0.042 + 0.080 + 0.058 + 0.027 = 0.265; the sum in column 8 is 0.4 + 0.5 + 0.5 + 0.5 + 0.2 = 2.1; and the quotient is 0.265 ÷ 2.1 = 0.126. Since the number of feet in the elevation of bench mark 1 is obviously 720, the required weighted mean elevation of that bench mark is 720.126 ft. This value is considered to be the fixed elevation of bench mark 1 and can be entered in the proper places in column 4 for determining the preliminary elevations of bench marks 2 and 3. The weighted mean, or fixed,