SPECIAL PUBLICATION NO. 225

NOAA Reprint

Manual of Reconnaissance for Triangulation

BY WILLIAM MUSSETER

National Geodetic Survey
Rockville, Md.

September 1977

Reprinted December 1985

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Ocean Survey

NOAA Reprint

Manual of Reconnaissance for Triangulation

BY WILLIAM MUSSETER

National Geodetic Survey

Rockville, Md.

September 1977

For sale by the National Technical Information Service,
U.S. Department of Commerce, Springfield, Va. 22151.
Please refer to document accession no. PB2677457.

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Ocean Survey

First edition 1941

Second edition 1951

PREFACE TO REVISED (1959) EDITION

Since the last printing of this manual in 1951 the specifications for first- and second-order triangulation have been made more exacting. First-order work has been separated into three classes and second-order into two classes. Specifications under these classes appear on page 4 in the revised table which has been copied at reduced scale from Special Publication No. 247, "Manual of Geodetic Triangulation." The only other changes in this edition, due to the revision of the specifications, appear on pages 3 to 7.

CONTENTS

ILLUSTRATIONS

MANUAL OF RECONNAISSANCE FOR TRIANGULATION

GENERAL STATEMENT

During the past few years, such progress has been made in the methods of executing triangulation that it is desirable to revise somewhat the treatment of the subject of reconnaissance as given in Special Publication No. 93, "Reconnaissance and Signal Building" and Special Publication No. 120, "Manual of First Order Triangulation." It is with this in mind that the following outline of present practices is written.

This manual is primarily a guide to engineers of the United States Coast and Geodetic Survey, and, as such, presupposes some familiarity with triangulation methods of the Bureau. These methods are fully covered by various manuals published by the Coast and Geodetic Survey.

The changes introduced by the use of the portable steel tower signals and the multiple-unit observing parties, and by the closing in of the triangulation net, have made increasing demands upon the reconnaissance both in accuracy and in scope of information desired. At the same time, the use of new instruments, including the altimeter, has affected the methods employed.

The use of the steel tower signal, first introduced in 1927, has revolutionized control surveys in flat and timbered regions. It has enabled the reconnaissance engineer to specify signals of greater heights without involving undue expense, and has resulted in the use of triangulation, to the exclusion of traverse, for nearly all horizontal control. It has permitted triangulation to be carried into regions where this type of survey was considered impossible a few years ago. Since high signals are now readily available, the demand for signal height has rapidly increased and frequently the full height of the steel towers is necessary. In these regions, the clearance of lines over obstructions is about as small as formerly, and since the size and cost of steel-equipped triangulation parties are large, this makes accurate reconnaissance very desirable. Also the use of the steel towers requires that greater attention be paid to accessibility in the selection of stations to guard against hauling difficulties. The economy of the steel signal favors the establishment of many extra, or supplemental, points for local use and as ties to surveys of other organizations. The availability of steel towers and the low cost of additional stations make it possible to plan stronger figures than formerly, and this results in better control of the area.

Triangulation parties now consist of from two to nine observing units and the limit has by no means been reached. Monthly expenses of these parties run as high as $15,000, compared with $1,500 to $2,000 for single-unit parties of several years ago. Hence, delay caused by an obstructed line, or other failure of the reconnaissance, is more expensive than formerly. It is now imperative that reconnaissance parties reduce such failures to a minimum. The rapidity of progress of the triangulation parties requires that they be furnished with all information obtainable concerning roads and local conditions.

With the completion of the major loops of triangulation has come the process of breaking down the enclosed areas, first by arcs with 50-mile spacing, and then by arcs with 25-mile spacing. This spacing has reduced the latitude for departing from the ideal route to very meager limits. Formerly it was common practice to follow lines of least resistance by following valleys and keeping in contact with arteries of transportation. At present, triangulation must follow an almost straight course between termini, overcoming any obstacles it may encounter. On this account, it is often necessary to cover areas that are convex in profile, or otherwise difficult, for considerable distances. All of these factors combine to require a greater degree of accuracy and wider scope of information for the reconnaissance than was necessary a few years ago.

The problems of reconnaissance differ for almost every arc, and no general instructions can cover all the peculiar conditions found in the field. In the following paragraphs an attempt will be made to consider and explain the principles of reconnaissance and give some typical examples of the operations involved.

To some readers the methods outlined may appear unnecessarily elaborate and expensive for the proper requirements of the reconnaissance. However, a careful investigation of the records shows that when skill and energy are used in prosecuting the work, the costs are no higher than were those of earlier and less precise methods. For many years before the steel signals came into use, it was the custom of the reconnaissance engineer to rely more on his own experience and native ability than on instrumental work. Very good results were thus secured and they fully met the requirements of the time. However, only a small proportion of the triangulation executed during that period was in difficult timbered regions, and the few men engaged on reconnaissance were thoroughly experienced. Also, the reconnaissance engineer customarily had charge of the signal building, which was done well in advance of the observing, and therefore he had an opportunity to correct any errors that were found in the reconnaissance.

Chapter I.—FUNDAMENTALS OF RECONNAISSANCE

Reconnaissance is essentially the design of the triangulation. A proper reconnaissance should definitely select sites of main and supplemental stations; test and determine, with reasonable accuracy, the visibility of all lines; specify signal heights; collect information as to roads, climatic conditions, and any other knowledge which will expedite the work of the building and observing parties; and interview property owners, securing permission to enter on their premises and otherwise generally pave the way for the triangulation party, so that it may pursue its work with a minimum of friction and lost time. It is evident that the term "reconnaissance," which implies only a preliminary or general kind of information, is in reality a misnomer in this case.

CLASSIFICATION OF CONTROL SURVEYS

The basis of classification of control surveys is the accuracy with which the length and azimuth of a line of the triangulation or traverse are determined. Since it is impossible to ascertain the absolute error in the determination of the length or azimuth of each line of triangulation or traverse, indirect gages must be used. On triangulation the principal criterion is that the discrepancy between the measured length of a base line and its length as computed through the scheme from the next preceding base shall not, after the side and angle equations have been satisfied, be greater than 1 part in 25,000 of the length of the base for first-order work, 1 part in 10,000 for second order, and 1 part in 5,000 for third order. Similar ratios are prescribed for the error of closure in position of traverse of the corresponding orders of accuracy. Coupled with this gage of the length agreement between bases and almost coordinate in importance are the requirements limiting the error of angle measurements, for the limits imposed on angular errors serve to maintain a uniform accuracy along the chain of triangles.

The specifications for procuring a required accuracy make use of other criteria, such as the number and strength of the geometrical figures between adjacent bases, the observation of an astronomical azimuth at specified intervals, and the accuracy of measurement of base lines. All these tests are subsidiary to the controlling tests of

A comparison of the three orders of horizontal control ordinarily used by this bureau is readily obtained from the following table, which shows the limits for the principal items of the specifications for these orders:

Requirements for horizontal control

TRIANGULATION

Criterion for—	First order: Class I (Special)	First order: Class II (Optimum)	First order: Class III (Standard)	Second order: Class I	Second order: Class II	Third order
Principal uses	Urban surveys, scientific studies.	Basic network	All other	Area networks and supplemental cross arcs in national net.	Coastal areas, inland waterways and engineering surveys.	Topographic mapping.
Spacing of arcs or principal stations.	Stations: 1–5 miles or greater as required.	Arcs: 60 miles. Stations: 10–15 miles.	Stations: 10–15 miles.	Stations: 4–10 miles.	As required	As required.
Strength of figure:						
ΣR_1 between bases:						
Desirable limit	25	60	80	80	100	125.
Maximum limit	30	80	110	120	130	175.
Single figure:						
Desirable limit:						
R_1	5	10	15	15	25	25.
R_2	10	30	50	70	80	120.
Maximum limit:						
R_1	10	25	25	25	40	50.
R_2	15	60	80	100	120	170.
Base measurement:						
Actual error not to exceed	1 part in 300,000.	1 part in 300,000.	1 part in 300,000.	1 part in 300,000.	1 part in 150,000.	1 part in 75,000.
Probable error not to exceed.	1 part in 1,000,000.	1 part in 1,000,000.	1 part in 1,000,000.	1 part in 1,000,000.	1 part in 500,000.	1 part in 250,000
Triangle closure:						
Average not to exceed	1"	1"	1"	1".5	3"	5".
Maximum seldom to exceed	3"	3"	3"	5"	5"	10"
Side checks:						
Ratio of maximum difference of logs of sides to tab. diff. for 1" of log sine of smallest angle.	1.5	1.5–2	2	2–4	4	10–12.
Or in side equation test, average corr. to direction not to exceed.	0".3	0".4	0".4	0".6	0".8	2"
Astro. azimuths:						
Spacing-figures	6–8	6–10	8–10	8–10	10–12	12–15.
Probable error	0".3	0".3	0".3	0".3	0".5	2".0.
Closure in length (also position when applicable) after side and angle conditions have been satisfied, should not exceed.	1 part in 100,000.	1 part in 50,000.	1 part in 25,000.	1 part in 20,000.	1 part in 10,000.	1 part in 5,000.

TRAVERSE

	First order	Second order	Third order
Number of azimuth courses between azimuth checks not to exceed.	15	25	50.
Astronomical azimuth: Probable error of result.	0".5	2".0	5".0.
Azimuth closure at azimuth check points not to exceed.	2 sec. $\sqrt{N}$ or 1.0 sec. per station.	10 sec. $\sqrt{N}$ or 3.0 sec. per station.	30 sec. $\sqrt{N}$ or 8.0 sec. per station.
Distance measurements accurate within	1 in 35,000	1 in 15,000	1 in 7,500.
After azimuth adjustment, closing error in position not to exceed.	0.66 ft. $\sqrt{M}$ or 1 in 25,000	1.67 ft. $\sqrt{M}$ or 1 in 10,000	3.34 ft. $\sqrt{M}$ or 1 in 5,000.

It will be noticed that the standards of accuracy prescribed above apply mainly to the field observations. Other standards are used for the adjusted work. The process of adjusting observations by the method of least squares makes the results consistent throughout but does not remove all errors. If the observational errors are small and indiscriminately plus and minus, then the adjustment will probably distribute them so that there will be but a slight accumulation and systematic errors of varying signs are not distributed correctly by the adjustment process.

Under certain conditions the specified allowable error in the length of a line may be found to be exceeded even when the triangulation meets the other specifications for that particular grade of control. Where two points are close together, as compared with the size of the triangulation figure of which they are a part, the distance between those points may be in error in excess of that indicated by the class of triangulation of the scheme. The accuracy of the computed length of any line can be estimated by computing the ΣR_1 from the base to that line in accordance with the formula for the strength of figures as given on page 11.

Triangle closure and agreement in length are not the only standards for triangulation which should be applied. It is possible by a lucky balancing of errors to secure small triangle closures in a short scheme of triangulation even when the observations are below standard. It is also possible by omitting from the computations observations which differ greatly from the mean to reduce triangle closures greatly. It may also happen that a balancing of errors in computing a chain of triangles will result in a very small discrepancy in length on the next fixed line. The accuracy of triangulation is perhaps best indicated by the probable error of a direction, but since this gage of the work is not available until after the adjustment has been made, the triangle closure and the agreement in length, as given by the preliminary computations, are the best available field criteria. To insure that the requisite accuracy is maintained throughout the triangulation, it is essential to give careful considerations to the instrumental equipment and the methods of observing in order that the systematic and accidental errors may be kept within the prescribed limits and that no part of the triangulation will exhibit undue weakness.

SPECIFICATIONS FOR RECONNAISSANCE

The general instructions for reconnaissance as given in Special Publication No. 120, "Manual of First Order Triangulation," are still in force except as modified on account of the present short spans between fixed lines and the desirability of a more intensive control of the area covered. For convenience of reference, these instructions are repeated below.

1. **Character of figures.**—The chain of triangulation between base nets shall be made up of completed quadrilaterals and of central-point figures, with all stations occupied. It must not be allowed to degenerate even for a single figure to single triangles, except by specific permission by the Director. There

stations occupied. It must not be allowed to degenerate even for a single figure to single triangles, except by specific permission by the Director. There must be two ways of computing the lengths through each figure. On the other hand, there must be no overlapping of figures and no excess of observed lines beyond those necessary to secure a double determination of every length, except as follows: In a four-sided central-point figure one of the diagonals may be observed; a figure used in expanding from a base often requires the observation of additional lines; and a network of triangulation over a city or other wide area may very properly contain a few overlapping figures to meet special conditions.

2. Strength of figures.—In the chain of triangulation between base nets in the basic network the value of the quantity

$$R=\frac{D-C}{D}\Sigma\left[\delta_A^2+\delta_A\delta_B+\delta_B^2\right]$$

(see p. 11) for any one figure must not in the selected best chain (call it R_1) exceed 25, nor in the second best (call it R_2) exceed 60, in units of the sixth place of logarithms. These are extreme limits never to be exceeded. Keep the quantities R_1 and R_2 down to the limits 10 and 30 for the best and second-best chains, respectively, whenever the estimated total cost does not exceed that for a chain barely within the extreme limits by more than 25 percent. The values of R for a figure may be readily obtained by the use of the "table for determining relative strength of figures in triangulation" on page 10.

In the above formula the two terms

$$\frac{D-C}{D}\text{ and }\Sigma\left[\delta_A^2+\delta_A\delta_B+\delta_B^2\right]$$

depend entirely upon the figures chosen and are independent of the accuracy with which the angles are measured. The product of these two terms is therefore a measure of the strength of the figures with respect to length, insofar as the strength depends upon the selection of stations and of lines to be observed over. The method of computing the strength of figures is explained on page 10.

3. Lengths of lines.—It is best that no line of the first-order triangulation outside of the base nets be less than 5 kilometers in length, if it is to be used directly in carrying the length forward through the scheme; that is, if it is opposite a distance angle used in computing R_1. So far as accuracy of observations is concerned, there is little advantage in having the lines longer than this. Above this minimum length two main considerations affect the size of the scheme: First, the combined cost per mile of progress of reconnaissance, building, and observing; and second, the number and accessibility of the points determined. Since these two factors are opposed, the compromise scheme selected should have the stations close enough together to be used by engineers without special instruments and signal lamps.[1]

4. Frequency of bases.—If the character of the country is such that a base site can be found near any desired location, ΣR_1 between base lines should be made about 60. This will be found to correspond to a chain of from 10 to 25 triangles, according to the strength of the figures secured. With strong

[1] Long lines and high stations are no longer desirable in the triangulation net, although they were frequently used in the earlier work when the basic framework was being determined. High stations and long lines cannot be used conveniently by local engineers and therefore lines longer than 10 or 15 miles are now seldom determined. Of course, in high mountainous regions, longer lines are sometimes necessary to coordinate new work with that previously existing and to furnish adequate distribution of control as economically as possible.

to secure a base site at the desired location. ΣR_1 may be allowed to approach but not exceed 110. There will be danger when this larger limit is used that an intervening base may be necessary, for if the discrepancy between adjacent first-order bases is found in any case to exceed 1 part in 25,000 an intervening base must be measured.

5. **Base sites and base nets.**—In selecting base sites it should be kept in mind that a base can be measured with the required degree of accuracy on any site where the grade on any 50-meter tape length does not exceed 10 percent, and that narrow valleys or ravines less than 50 meters wide in the direction of the base are not insuperable obstacles to measurement. The length of each base is to be not less than 4 kilometers. In each base net great care should be taken to secure as good geometric conditions as possible. There should be no hesitancy in placing the base on rough ground, provided the roughness is not greater than that indicated above, if by doing so the geometric conditions in the base net are improved. Each base net should not be longer than two ordinary figures of the main chain between bases. The base net may also be strengthened by observing over as many lines between stations of the net as can be made intervisible without excessive cost for building or cutting. Caution is necessary in thus strengthening a base net by observing extra lines to avoid making the figure so complicated as to be excessively difficult and costly to adjust.

6. **Connections to existing triangulation.**—In starting from or connecting with either first- or second-order triangulation, it is essential that the connection be made to a line of proper strength, and also that observations be made from the two ends of that line upon a third point of the existing triangulation. If the new angles agree closely with the old observations the exact recovery of the old stations is assured. Even when connecting the triangulation of the third order it is better if possible to connect with a line rather than a point, for the comparison of the lengths of the line common to the two systems of triangulation may give information of great value in adjusting the weaker scheme. Connection in position alone, namely, to a single point, or in position and azimuth, namely, to a single point but with a direction observed from that point to another old station, may sometimes be advantageously made at intervals between the connections in length. If the line used for a connection is opposite a weak angle in the old triangulation the comparison in length will have little value.

CHANGES OF SPECIFICATIONS

The following modifications of the above specifications are mainly to permit use of single triangles because of the relatively short arcs of new triangulation now required between junctions with adjusted arcs and to allow for the fact that the desirable maximum length of line is now 15 miles, with average length and breadth of quadrilaterals about 10 miles.

While single triangles are now sometimes permissible, it must not be inferred that they may be used indiscriminately. A figure giving double determination of length must be employed whenever it is possible to do so without undue expense or delay. The limits of R_1 and R_2 of a figure have been reduced to 15 and 25, respectively, and their desirable limits to 10 and 15, respectively. The lengths of arcs between fixed lines are now so short that base lines are seldom needed, and as the triangulation net is extended the time is rapidly approaching when they may be dispensed with entirely. Practically all base lines are now measured on railroad tracks, and the base nets are usually less complicated than formerly. The special subjects of base lines and base nets will be taken up under those headings. (See pp. 76 and 79.)

Under paragraph 1 of the specifications, the use of overlapping figures, that is, figures requiring more than one side equation, is closely limited. However, such figures have always been used when necessary to cover a difficult area and to maintain the required figure strength. Such latitude does not mean that complex figures may be chosen at will, but that the judgment of the reconnaissance engineer is relied upon to select a superior scheme at the expense of a reasonable increase in office work.

For several years, a limited length of line has been specified in the instructions. This limit has varied somewhat with the character of the country and the purpose of the triangulation. Generally, the desired length of cross and side lines has been between 8 and 12 miles, with few diagonals exceeding 15 miles. This limitation is imposed for two reasons—to avoid hindrance to progress caused by conditions of low visibility, and to supply to other organizations lines they can readily use.

Azimuth marks, as now established at all occupied stations, have largely eliminated the second condition. As for the first, it is recognized that for different types of country there are different economical lengths of line. In order to obtain the proper intensity of control, supplemental stations may be established within the areas of the main scheme figures. Since the requirements for these supplemental stations are only that each shall form a part of at least one well formed triangle, more accessible and useful locations can be found for them than when all the conditions of carrying forward the scheme are imposed. Generally, instructions are issued authorizing the reconnaissance engineer to select the size of figures which he feels best suited to the area.

CLASSES OF TRIANGULATION

Regular reconnaissance parties are concerned with first- and second-order triangulation only. When the adjustment of the triangulation net is made, a number of the arcs are designated "second order," if that is the accuracy actually obtained for them. In practice, the angles for second-order triangulation are observed under the same instructions as for first-order triangulation, but under the criterion that a direction need not be reobserved unless it deviates by more than 5 seconds from the mean of the 16 positions and that stations are not to be reoccupied for closing errors if these do not exceed about 5 seconds. There is no difference in the requirements of the reconnaissance for the two classes except that for second-order arcs single triangles may be used somewhat more freely and figure strength may be reduced slightly for greater economy. The extent to which these are permissible has been allowed to rest with the officer in charge of the reconnaissance. For all practical purposes, the requirements of the two orders may be considered the same.

STRENGTH OF FIGURES

The strength of a figure depends on the amount of variation of the sines of the distance angles per unit of change in the angles themselves, multiplied by a factor, peculiar to the figure, which is a function of the number of observed directions and of conditions to be satisfied within the figure. In other words, with a given error in the observed angles, a strong figure is one in which the displacement of the loci of the intersections caused by this error will be relatively small.

Computation of strength of figure.—In the following table the values tabulated are for $[\delta_A^2+\delta_A\delta_B+\delta_B^2]$. The unit is one in the sixth place of logarithms. The two arguments of the table are the distance angles in degrees, the smaller distance angle being given at the top of the table. The distance angles are the angles in each triangle opposite the known side and the side required. δ_A and δ_B are the logarithmic differences corresponding to 1 second for the distance angles A and B of a triangle.

Table for determining relative strength of figures in triangulation

°	10°	12°	14°	16°	18°	20°	22°	24°	26°	28°	30°	35°	40°	45°	50°	55°	60°	65°	70°	75°	80°	85°	90°
10	428	359																					
12	359	295	253																				
14	315	253	214	187																			
16	284	225	187	162	143																		
18	262	204	168	143	126	113																	
20	245	189	153	130	113	100	91																
22	232	177	142	119	103	91	81	74															
24	221	167	134	111	95	83	74	67	61														
26	213	160	126	104	89	77	68	61	56	51													
28	206	153	120	99	83	72	63	57	51	47	43												
30	199	148	115	94	79	68	59	53	48	43	40	33											
35	188	137	106	85	71	60	52	46	41	37	33	27	23										
40	179	129	99	79	65	54	47	41	36	32	29	23	19	16									
45	172	124	93	74	60	50	43	37	32	28	25	20	16	13	11								
50	167	119	89	70	57	47	39	34	29	26	23	18	14	11	9	8							
55	162	115	86	67	54	44	37	32	27	24	21	16	12	10	8	7	5						
60	159	112	83	64	51	42	35	30	25	22	19	14	11	9	7	5	4	4					
65	155	109	80	62	49	40	33	28	24	21	18	13	10	7	6	5	4	3	2				
70	152	106	78	60	48	38	32	27	23	19	17	12	9	7	5	4	3	2	2	1			
75	150	104	76	58	46	37	30	25	21	18	16	11	8	6	4	3	2	2	1	1	1		
80	147	102	74	57	45	36	29	24	20	17	15	10	7	5	4	3	2	1	1	1	0	0	
85	145	100	73	55	43	34	28	23	19	16	14	10	7	5	3	2	2	1	1	0	0	0	0
90	143	98	71	54	42	33	27	22	19	16	13	9	6	4	3	2	1	1	1	0	0	0	0
95	140	96	70	53	41	32	28	22	19	18	13	9	6	4	3	2	1	1	0	0	0	0	
100	138	95	68	51	40	31	25	21	17	14	12	8	6	4	3	2	1	1	0	0	0		
105	136	93	67	50	39	30	25	20	17	14	12	8	5	4	2	2	1	1	0	0			
110	134	91	65	49	38	30	24	19	16	13	11	7	5	3	2	2	1	1	1				
115	132	89	64	48	37	29	23	19	15	13	11	7	5	3	2	2	1	1					
120	129	88	62	46	36	28	22	18	13	12	10	7	5	3	2	2	1						
125	127	86	61	45	35	27	22	18	14	12	10	7	5	4	3	2							
130	125	84	59	44	34	26	21	17	14	12	10	7	5	4	3								
135	122	82	58	43	33	26	21	17	14	12	10	7	5	4									
140	119	80	56	42	32	25	20	17	14	12	10	8	6										
145	116	77	55	41	32	25	21	17	15	13	11	9											
150	112	75	54	40	32	26	21	18	16	15	13												
152	111	75	53	40	32	26	22	19	17	16													
154	110	74	53	41	33	27	23	21	19														
156	108	74	54	42	34	28	25	22															
158	107	74	54	43	35	30	27																
160	107	74	56	45	38	33																	
162	107	78	59	48	42																		
164	109	79	63	54																			
166	113	86	71																				
168	122	98																					
170	143																						

USE OF TABLE

To compare two alternative figures, either quadrilaterals or central-point figures, insofar as the strength with which the length is carried forward is concerned, proceed as follows:

(*a*) For each figure take out the distance angles, to the nearest degree if possible, for the best and second-best chains of triangles through the figure. These chains are to be selected at first by estimation, and the estimate is to be checked later by the results of comparison.

(*b*) For each triangle in each chain enter the table with the distance angles as the two arguments and take out the tabular value.

(c) For each chain, the best and second best, through each figure, take the sum of the tabular values.

(d) Multiply each sum by the factor

$$\frac{D-C}{D}$$

for that figure, where D is the number of directions observed and C is the number of conditions to be satisfied in the figure. The quantities so obtained, namely,

$$\frac{D-C}{D}\Sigma[\delta_A^2+\delta_A\delta_B+\delta_B^2]$$

will for convenience be called R_1 and R_2 for the best and second-best chains, respectively.

(e) The strength of the figure is dependent mainly upon the strength of the best chain through it, hence the smaller the R_1 the greater the strength of the figure. The second-best chain contributes somewhat to the total strength and the other weaker and progressively less independent chains contribute still smaller amounts. In deciding between figures they should be classed according to their best chains, unless said best chains are very nearly of equal strength and their second-best chains differ greatly.

NOTES ON SHAPES OF FIGURES

It should be remembered that the strength of a figure as computed from the foregoing formulas and table is affected only by the line which is used to carry the length forward to the next figure. It will be found that a figure very short in the direction of progress, compared to its width, will give a very strong determination for the length of line used in carrying the computations forward. However, the side lines in such figures lie opposite weak angles, and are not satisfactory as junction lines for intersecting arcs of triangulation. Also, progress with such figures is slow.

Generally speaking, a rapid increase or decrease in the width of the scheme will introduce weakness, although not necessarily so. Such variation in width may be necessary in passing from one area into another of greatly differing characteristics. The transition can usually be made without great loss of strength by using acute and obtuse angles in combination as distance angles. The successive triangles are laid out so that the side opposite the larger distance angle in one triangle becomes opposite the smaller distance angle of the next. This principle can be carried even further by taking advantage of the fact that the sine decreases as the angle increases in the second quadrant. Since the triangles are adjusted so as to close theoretically, an error which would make one distance angle too large, should give a similar negative residual in the other. Hence in a triangle in which one angle exceeds 90°, if the colog sine of the first is small the log sine of the second should be large and errors will tend to compensate. By reference to the table, it will be found that a triangle with distance angles

265164°—41——2

of 40° and 120° has the same strength as one with angles of 55° and 60°. It will be noted that figures expanded by this method follow the law that strength is gained by shortening the figure in the direction of progress.

PERMISSIBLE FIGURES

(A) **Simple quadrilateral.**—The simple quadrilateral (see A, fig. 1) is the best figure, and it should be employed wherever possible. It combines maximum strength and progress with a minimum of essential geometrical conditions when approximately equilateral or square and therefore the square quadrilateral is the perfect figure. It has a strength factor,

$$\frac{D-C}{D} \text{ of } 0.6.$$

(B) **Four-sided central-point figure with one diagonal.**—When one diagonal of the quadrilateral is obstructed, a central point, which is visible from the four corners can be inserted. (See B, fig. 1.) This figure requires the solution of two side equations and five angle equations, and hence adds to the labor of adjusting. Its strength factor is 0.56.

(C) **Four-sided central-point figure without diagonal.**—At times, neither diagonal can be made visible and the figure becomes a simple four-sided central-point quadrilateral (see C, fig. 1) with a strength factor of 0.64. The central point in this case should be carefully located to maintain the strength of the R_1 chain of triangles. An excellent location is near one side line and about midway along it. If too near the side line, however, refraction errors may be almost the same for the closely adjacent lines, and furthermore the R_2 value will be so large as to be of little value as a check on lengths computed through the R_1 triangles.

(D) **Three-sided central-point figure.**—This is a simple and usually very strong figure. (See D, fig. 1.) It is often used to compensate for a great variation in length of the side lines of adjacent quadrilaterals, and to quickly change the direction of the scheme. Its strength factor is 0.60 and the equations required for its adjustment are the same as for a regular quadrilateral.

(E) **Five-sided figure with four diagonals.**—This figure may be considered as a four-sided central-point figure with one diagonal, in which the central point falls outside the figure. (See E, fig. 1.) It is used to afford a check when either a diagonal or a side line is obstructed. It has the same strength factor, 0.56, as the above four-sided central-point figure with one diagonal, (*B*), and requires the same adjustment equations and precautions against making any of the angles too small. This figure can often be used by the observing party when a side line of a quadrilateral is found to be obstructed.

(F) **Five-sided figure with three diagonals.**—This figure is similar to the four-sided central-point figure, (C), except that the central point falls outside the figure. (See F, fig. 1.) The strength factor is 0.64.

(G) **Five-sided central-point figure with two diagonals.**—This figure is an overlap of a central-point quadrilateral and a simple quadrilateral, and is the most complicated figure employed. (See G, fig. 1.) It has been used to carry the scheme over difficult or convex areas. This figure can generally be made very strong. Its strength factor is 0.55.

(H) **Five- and six-sided central-point figures without diagonals.**—Any polygon with a central point (see H, fig. 1), having separate chains of triangles on either side of the central point, will give a double determination of length, since it is permissible to carry the two lengths through the same triangle provided different combinations of distance angles are employed. However, the five- and six-sided central-point polygons are the only ones that should receive consideration, and they are inferior to the simpler quadrilaterals. The factors of strength are 0.67 for five sides and 0.68 for six.

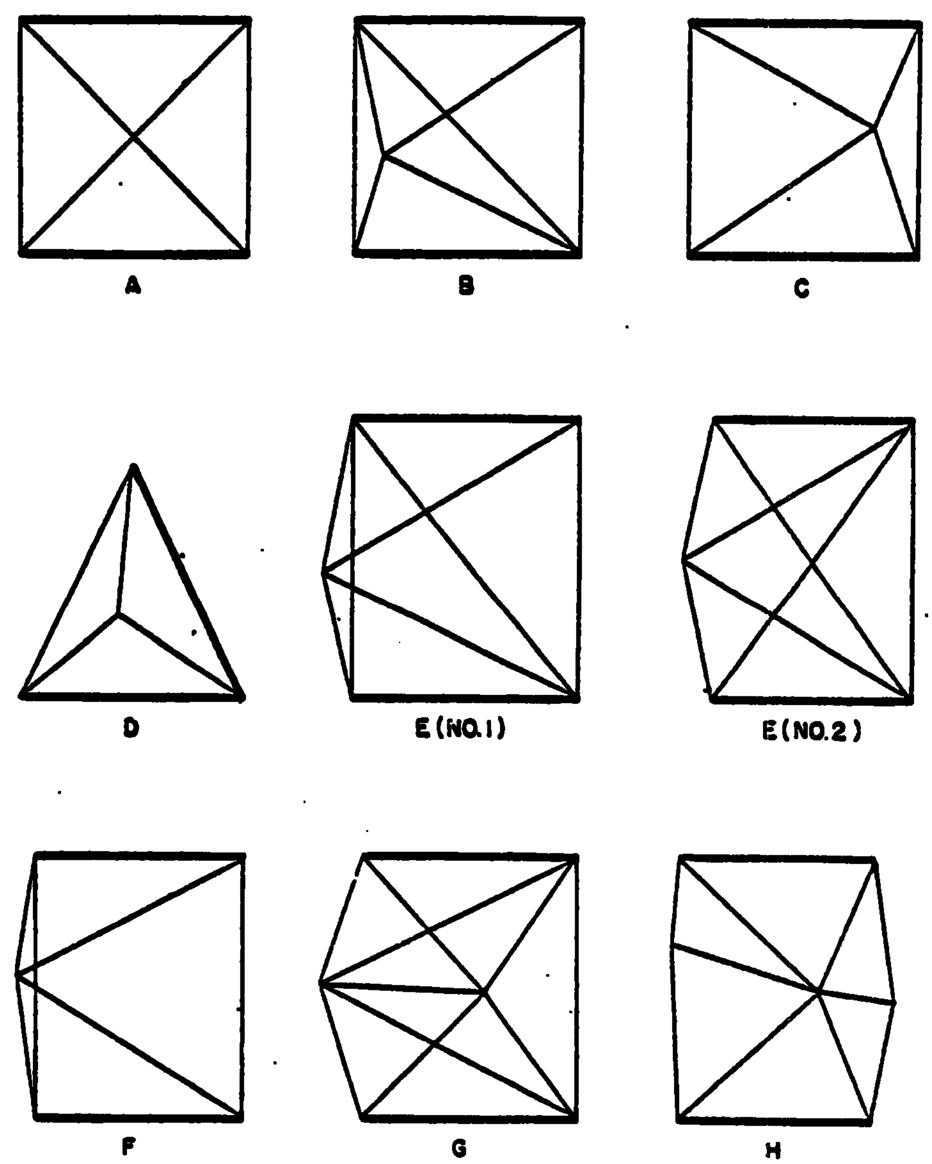

FIGURE 1.—Different types of figures used in triangulation.

UNOCCUPIED STATIONS

In case an azimuth mark is not required, a supplemental station, or station of some other organization, need not be occupied but it should be determined by observations from three or four established stations. To secure a check, observations must be taken from at least three stations, but if taken from more than four, the computations become unduly complicated. Good intersections, satisfying the conditions of figure strength, should be secured. All intersections should be taken from adjacent stations in the main scheme which are preferably in a single figure.

ELBOW FIGURES

Circumstances sometimes arise which require the scheme to be offset to one side, under conditions unfavorable for ordinary methods of changing direction. This may be accomplished by placing the adjacent figure alongside, so that a side line of one is common to a side line of the other. (See fig. 2.) The strength of the two figures is, of course, computed through the common side line.

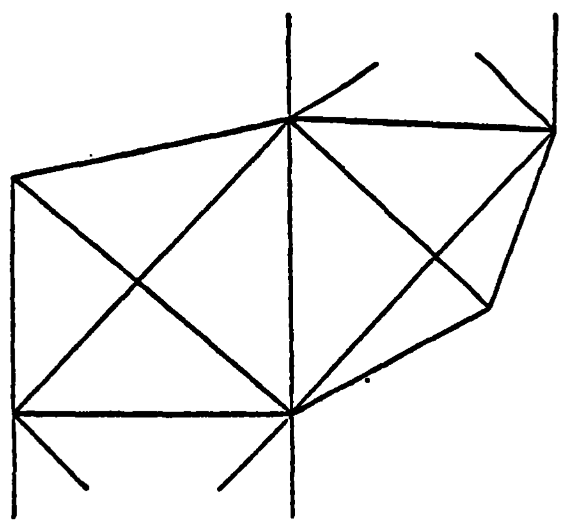

FIGURE 2.—Elbow figure.

AREA TRIANGULATION

Area triangulation consists of a scheme expanded by adding triangles in all directions to form a spider web effect. This method has replaced the method of wing triangles formerly used. Since the introduction of new methods of adjustment and new calculating machine equipment, the simultaneous solution of area triangulation is not a formidable problem.

The area method was initiated when it became necessary to provide coverage over areas completely bounded by arcs of triangulation. When these areas, which should not be elongated in any direction, are reduced to a size of about four figures across, the area method of reconnaissance and triangulation is employed. Single triangles should be used (see fig. 3) and a complete connection made to all bounding arcs. In this figure the heavy lines represent the established arc triangulation, the medium lines indicate the main scheme area reconnaissance, and the light lines are for supplemental stations.

as otherwise a serious discrepancy might be found later in case a connection were made between two stations fairly close together which had been established from different arcs. The adjustment of these

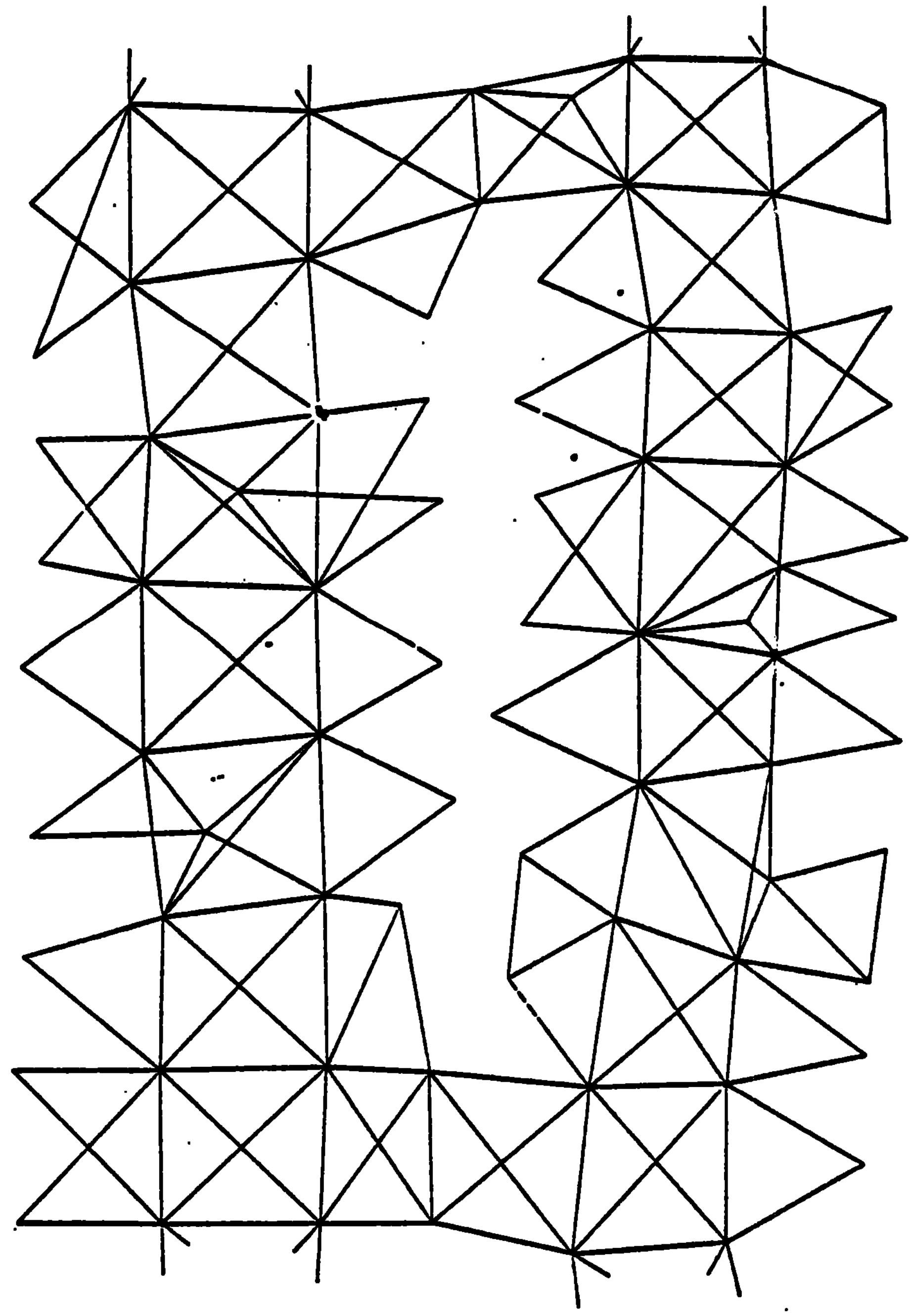

FIGURE 3.—Modified area triangulation.

cross arcs can be made by determining the positions, lengths, and azimuths in each intersection figure by weighted means of converging data, and then adjusting the separate short arcs between these figures. Since such arcs of triangulation will be short, a more general use of single triangles is permissible.

Chapter 2—FIELD PROCEDURE

SOURCES OF INFORMATION

The first operation in starting reconnaissance in a new territory is to assemble all the existing data concerning the area that will be of help. Various types of maps may be secured from several Federal agencies and from State and county governments. The common road map distributed by oil companies is also a valuable source of information. Unless the climatic characteristics are known, United States Weather Bureau records may well be consulted. The more useful information that is obtained before the work is started, the greater will be the ease in doing the field work.

The best detailed maps for the purpose are the topographic sheets of the United States Geological Survey, which now cover nearly one-half of the United States. These vary greatly in scale, usefulness, and accuracy according to their age and to type of country covered. The older sheets are often broadly generalized and show only main trends of drainage and dividing ridges but the more modern ones are excellent maps. The reconnaissance engineer should realize, however, that many of the contours are sketched by estimation and that, especially in timbered country, many of the elevations at some distance from bench marks may depend on barometric determinations. When the profile taken from the contour map indicates a close clearance of a line, it is advisable to actually check it on the ground.

Next in order of importance are the county soil survey maps published by the Bureau of Plant Industry, United States Department of Agriculture. These maps, especially the later ones, are sufficiently accurate as to roads, drainage, man-made features, etc., but do not give elevations except in a few cases in which the contours are copied from Geological Survey sheets of the same area. Since certain types of soil are apt to be found on the higher ridges, especially in a region where the topography is due to erosion, because of the fact that the harder formations naturally resist erosion and stand out as the higher elevations, the Soil Survey maps can be used for considerable preliminary laying out of the scheme as soon as these characteristics are learned.

The county post-route maps compiled by the Post Office Department are next in line of usefulness. They show roads with a fair degree of accuracy, and the drainage system roughly. In sectionalized States, these maps serve at once to locate the section in which a station is placed and form a good base for plotting the reconnaissance sketch.

The sectional aeronautical charts of the Coast and Geodetic Survey are of great aid in regions where no larger scale maps have been made. These charts are compiled from all available data and show railroads and main highways, major streams, towns, air beacons, and zones of elevation. Their use by reconnaissance parties also affords an opportunity to check the compilation.

In addition to the above Federal maps, county and district maps can often be secured from State highway departments, Forest Service offices, county engineers, and commercial map compiling agencies. These maps vary from good to very poor and their utility will naturally depend upon their quality.

State maps are published by the Geological Survey, the General Land Office, and the Post Office Department. The Geological Survey base maps on a scale of 1 to 500,000 are available for all States and are very useful. They show the projection in intervals of 1°, county lines, townships, railroads, locations of all cities and villages, and the general drainage system. They are very useful as work sheets and, in the absence of more detailed maps, should be used as a basis in laying out the preliminary scheme. The Public Roads Administration of the Federal Works Agency publishes district maps which show all the roads in the areas covered.

MAP STUDY

After securing the available maps, the location of the scheme, as specified in the instructions, is laid out on the State map. A careful study is then made of the drainage system of the area, since the divides between major stream basins should ordinarily be of the highest general elevation, although this assumption is not reliable in areas of sand dunes and glacial moraines. This gives a start in deciding the size of figures and the general plan. If contour maps are at hand, a tentative scheme is then drawn on them and the profiles of the lines are taken from the contours. If topographic maps do not exist, which is generally the case, a very rough tentative scheme is laid out by judging possibilities from the stream divides, and this scheme is marked on the best available maps with pencil. This is done a figure at a time, as work progresses, and is only a guide in localizing the search for station sites.

The map study, supplemented by a general knowledge of the geography, will indicate to the observer what type of country he will find. More detailed information is secured by a preliminary inspection of the area in case the observer is not already familiar with it. This information will include the type of topography, height of trees, quality of roads, etc., and will, of course, govern the detailed methods of reconnaissance. The types of terrain encountered include wooded and bare mountainous areas, rolling timbered regions, prairies, plain areas with breaks, buttes, and mesas, old lake bottoms and coastal plains that are practically flat, and glaciated regions with extremely irregular topography.

SELECTION OF METHODS ACCORDING TO TERRAIN

Reconnaissance methods may be divided into two classes depending on whether lines are checked (*a*) by relying on direct visibility or (*b*) by instrumental profiling or "blind reconnaissance." Generally speaking, the first method is applicable to mountainous or very hilly areas and to open plains. The second method must be resorted to in level or rolling timbered areas, although many lines in such areas can also be checked by direct vision. Actual visibility over a line is, of course, the most desirable and accurate test as no further effort need be expended upon that line.

DIRECT INTERVISIBILITY OF POINTS

Points intervisible from the ground will prevail in western mountainous regions, and to a certain extent in the Great Plains and in the eastern mountains. The reconnaissance is comparatively simple. First, select the line of existing triangulation that will best serve as a starting line for the new arc. Then visit the existing stations in order to recover the old marks. Should any of these be destroyed, select other starting points, the best that can be recovered. From each of these stations inspect the area to be covered for likely locations for new stations and make a notation of their descriptions and magnetic azimuths in a notebook. Each possible location should be carefully studied so that it may be identified with certainty when seen from different positions. Each hill or mountain will have some individual characteristics, such as shape, size, peculiar formations, patches of brush or snow, outstanding trees, etc., which should be impressed on the memory. In more inhabited regions, there will be fields, groves, buildings, and windmills to be noted.

It is well for the reconnaissance engineer to adopt a system of notes that suits his own convenience. These should be complete, but not voluminous, and may often be supplemented by horizon sketches, with the azimuths of prominent features placed directly above them. These sketches are usually made with the aid of binoculars, and can be made to exaggerate certain peculiarities or the vertical scale to advantage. Each observer will soon find what notes and sketches are best adapted to his own needs. The purpose of these is to have a fund of information that will enable him to identify and find any point he has observed from some distance.

The points that appear best suited to the scheme are then plotted on the work sheet, which generally will be a State map on a scale of 8 miles to the inch. Distances must at first be estimated, but after the successive points have been visited and bearings taken, intersections can be plotted on the work sheet to give more accurate positions and distances. The positions on the map will show the locations of the points with respect to the nearest settlements and will suggest a route for reaching them.

The foregoing operations require that the observer train his memory to retain details of what he sees. He should be able to remember topographic features without making an especial attempt to do so. This knowledge will often make possible a quick solution of a difficult problem. A good plan is to sit down with binoculars and spend half an hour or more intently studying the entire area visible from the vantage point selected. He should never be in haste to leave a station, nor should he let anything interfere with his concentration on his task. Memory is mainly the result of concentration and is invaluable to the reconnaissance engineer.

The map study will suggest the best points for completing the figure under consideration. However, the observer must carefully avoid devoting too much attention to a predetermined plan to the exclusion of other possibilities. This is very important as even the best tentative scheme is sure to break down sooner or later and require revision. If comprehensive data are not secured at each point it may become necessary to revisit the points to the rear. Also, factors such as inaccessibility of tentative points may make it desirable to alter the preliminary plan, and this can be done without loss of time if the proper notes are at hand. A great aid to progress and to the securing of smooth, strong figures, is to acquire a knowledge of the country one or two figures ahead of the finally located stations. It is often possible to shift a location without harm to the figure to the rear, and thus greatly improve the figure ahead. It is not good practice to definitely select stations solely to complete a figure without considering also the succeeding figures as this will often limit the possibilities for the next figure, and may result in a complicated and rough scheme. The observer should make a practice of considering alternate plans carefully before adopting one.

The observations made at the two ends of the starting line will indicate the best tentative locations of stations for rapid progress and to maintain figure strength. These tentative locations are next found on the ground by making use of the best road map available and by local inquiry when necessary. The operations are here repeated in the same manner as at the first stations. It is well always to read the azimuths to the rearward stations both as a check, and to improve the accuracy of the subsequent sketch. When a location is finally selected, notes are made describing it and the best routes of approach for use of the observing party. Such notes should be kept also for any promising point visited, even when it does not enter into the immediate plan, in order to avoid revisiting it should this point be selected later.

By the continued application of these methods, the scheme will be developed. Considerable imagination and skill are required to select the best compromise to meet all the conditions. The requirements for station sites are given briefly on page 63. All stations selected should be visited and the best route of approach determined and described. When alternate routes may merit consideration, it is well to suggest or describe them briefly.

In approaching the connection to another fixed line, particularly if it is in old work, the reconnaissance engineer will do well to go forward and recover the necessary stations when still two or three figures short of reaching them. Frequently, the best placed stations are not recoverable, or the plan for making the connection must be altered for other reasons. The distance thus allowed permits the diversion of the scheme to the new connection without abrupt bends and irregularities.

Generally, the reconnaissance engineer will have little difficulty in finding the necessary lines of visibility to build up his scheme in mountainous or open country of prominent relief. His problem will be mainly one of securing stations of greatest accessibility, and his errors will most often result from mistaken identity. Too much emphasis cannot be placed on the certain identification of distant points. This may appear difficult to the beginner, but the ability can be acquired by careful application. The main thing is to note the pertinent and unusual features of any landscape, and not to bother the mind with the commonplace. Just as a woodsman will pass miles of birch and poplar trees without notice, but immediately remember a lone pine, so the skillful reconnaissance man will glance over many uniformly wooded ridges and instantly recognize one having a tree with a peculiarly forked snag.

The reconnaissance engineer must remember that, as the architect of the structure, he is in charge of the plan for the finished triangulation scheme, and that thoroughness and accuracy are required to fulfill his duty to the observing party.

HORIZON SKETCHES

Horizon sketches give a very useful means of identifying objects or features which it may be desirable to refer to at a later time.

In open country, an outline sketch of a considerable arc of the horizon may be made which may show also the outlines of intervening groves, hills, etc. These may be valuable later when the observer can verify his position by lining them up with features on the horizon. In areas of this character, the sketch may be made conveniently and with good detail by looking through the transit telescope. If this is inverting, the book may be held upside down and the sketch drawn as seen. When the book is righted, the picture will be true. Sketches are less used in wooded areas but are very convenient at times. They can be made from the tops of structures or trees with the aid of binoculars.

A common use of sketches is to aid in identifying a point the observer is leaving, from some distant point. Groves and buildings do not appear the same from close by as from a distance. It is customary, therefore, to drive some distance from the feature in the direction from which it will be seen and make the sketch from there.

FIGURE 4.—Example of horizon sketch.

A considerable amount of detail is desirable, because outlines often vary greatly from slightly different angles of view. The positions of windmills in respect to buildings, chimneys and ventilators on roofs, etc., often clarify an object that would otherwise be doubtful.

Overlapping vistas.—A short cut occasionally used in proving two points to be intervisible when they cannot be identified positively one from the other, or when the view is obstructed by haze, etc., is known as "overlapping vistas." Suppose that from a given point some object in the middle distance is visible with a distant horizon beyond it near the azimuth of the point to which the visibility is in question. Then, if from this second point, the object is also visible, with a distant horizon beyond it, the line of sight between the points is probably clear. Also, in times of low visibility, if the vista is clear from each station for a distance well in excess of one-half the distance between stations, it is probable that they are intervisibile.

LAYING OUT THE SCHEME IN AREAS REQUIRING PROFILING

Under conditions which prevent direct visibility over many or all lines, resort must be had to instrumental methods of investigating the various lines in order to compute the required heights of signals. Generally, the procedure is to select promising points for station sites from a study of maps and from views from points of vantage such as water tanks, buildings, fire lookout towers, derricks, trees, bald hills, etc. These tentative points are then plotted on a work sheet which may be an existing map or one compiled by the reconnaissance party for the purpose. The conditions affecting visibility along the lines between these points are next investigated by the methods that follow. If any of the lines are obstructed, a new tentative point is selected with the aid of information gained in testing the original point, and the lines are investigated as before. The ability of the reconnaissance engineer to pick his tentative points with accuracy, so that the great majority of lines will be clear, is largely the measure of his skill as attained by experience and application.

The name "profiling" is given to the process of finding the relative elevations of critical points along a prospective line, and determining the visibility from the two ends by analyzing the results. A complete profile is not made as obviously only the highest elevations need be considered, although considerable work is required at times to locate these critical points in flat country. As soon as a section of the line is shown to be clear, further investigation of it is dropped. The elevations are obtained either by vertical angles, by altimeter, or by a combination of these methods. (See pp. 32–43.)

As was the case in mountainous regions, the first step is to lay out the general course of the arc on a State map, and to select and recover the best existing stations for starting the new scheme. The next step is to get a view over the country if it is possible to do so. This may be from a tall tree near one of the old stations, since they are usually on higher ground, or from a water tank or oil derrick. The purpose is to get as accurate a knowledge of the area within the prospective figure as feasible, and possibly to check some of the lines directly. Views from near the stations themselves are best, and a special effort should be made to get them. However, as these may be from tree tops under conditions that preclude the use of instruments the knowledge gained should usually be supplemented by instrumental measurements made from tanks and derricks. A good view from a tree is sometimes difficult to secure. If the timber is hardwood it will be impossible to climb high enough to see over all the neighboring trees, especially when they are in leaf and the observer may have to be content with a narrow vista through a hole in the foliage, or he may have to climb several trees for even a partial view of the horizon. If the station is on a wooded hill, an advantage may often be had by climbing a tree part way down the slope, in the direction of the desired view, as the slope will give it an advantage over the trees below. Pine trees are better for this purpose, as they can usually be climbed to the extreme top, and there is more of a tendency for occasional individual trees of this species to stand out above the general level. Tree climbing is laborious and dangerous but good reconnaissance cannot be done in difficult, wooded regions without it.

Assuming that satisfactory views may be obtained, the observer should study the horizon, noting the prominence and relative distances of all ridge tops and any peculiarities on them that may be helpful in later identification. He should also note all gaps in intermediate ridges. If the area is lacking in prominent features, distance may sometimes be judged by color and shading. This estimate may be made with very fair accuracy if some object whose distance is known can also be seen and compared with the one in question. Magnetic azimuths should be taken to all prominent objects, natural and artificial, and to the horizontal limits of the more distant vistas; that is to points where the view of a more distant ridge is cut off by a nearer one. It is good practice to take the azimuths of obstacles that hopelessly obstruct the view, so that the "zones of obstruction" may be laid down on the work sheet. Horizon sketches can also be used to advantage. The study of the terrain will give the observer a good idea of what can and what cannot be done. Skill in rejecting the impossible comes with practice and is an important ability in carrying on the work economically. No time is lost in further testing the obviously impractical.

In fairly open country it has been found of great advantage to "profile" the horizon from a selected station in the direction of the forward stations not yet located. This "profiling" consists of orienting the plates of the transit in azimuth and sweeping the horizon in the forward direction of the scheme for vertical angles. These vertical angles are recorded as they apply to azimuths, and distances are estimated to various portions of the horizon. Allowances for safety should be made in coordinating verticals with azimuth; i. e., the line of the vertical angle should pass over any obstruction in the azimuth range with which it is recorded.

A sample set of notes might be:

At Station Eagle

Azimuths	Verticals	Estimated distances and remarks
	′	
170-178	+1.5	10-12 miles, bare.
178-189	+2.0	10 miles or slightly less.
189-191	+7.2	7-9 miles, high ridge.
191-202	+3.5	9-13 miles. Some trees +8′.2.*
etc.		

*Trees at azimuth 198 to 200, about 12 miles.

These measurements require very little time in relatively open country, and aid a great deal after tentative selection of the next forward stations. Fairly accurate vertical angles from the back stations to the new ones being selected are available from the notes. The impossible cases can be rejected immediately or the possible cases checked for signal heights.

These notes are to be taken in addition to others explained elsewhere.

If no view of the surrounding terrain can be obtained from the station site, the ground work must start from knowledge gained from map study and from views obtained from tanks and other points of vantage. However, when this condition exists, it is probable that the country is so flat that computing signal heights will be reduced to determining the height of timber and taking account of curvature, and there will be little advantage of one site over another.

In any case the next step is to climb some structure on which it is possible to mount an instrument with a vertical circle. There are, of course, localities in which no such structures exist, but fortunately, they are relatively rare. In the heavily wooded areas of the South, the towns are commonly built on high ground, and their water tanks, standing as they do on some local elevation, are nearly always available as vantage points. Oil derricks are common in the Gulf Coastal Plain and since their standard height is 121 feet they afford good points of view. The densely wooded regions near the Canadian border are perhaps the most difficult in the United States. However, the Forest Service has fire lookout towers in these areas which are of immense value to the reconnaissance engineer. It is thus seen that aids of different kinds are the rule rather than the exception in difficult wooded areas.

From these structures, the same observations are made as from tree tops (see p. 22), except that vertical angles are taken on all prominent summits and more accurate measurements with a horizontal circle are substituted for magnetic azimuths. Some identified object, such as another tank, will serve to orient the directions. These directions, together with distances either estimated or determined by intersections, and elevations computed from the vertical angles, will locate the points where the views are commanding and also the insuperable obstructions. The observations combined with those from other points will also locate many objects that can be plotted on the work sheet. It is well to observe many objects and to study the map for suitable combinations of lines. This may obviate the necessity for revisiting the point later. Sometimes several hours may be spent to advantage on a tank or tower, and the observer should not be anxious to leave so long as there is anything he can learn. The observations will frequently eliminate other previously considered possibilities, and the selection of stations will thus be narrowed to a few localities.

After securing all possible data, the observer is confronted with the problem of using it to construct a good reconnaissance scheme. This is his hardest task, and also the one most difficult for an instructor to teach.

EXAMPLE OF TYPICAL RECONNAISSANCE

There are so many variations in conditions encountered, that definite instructions cannot be given, and the observer must draw liberally on his ingenuity in handling details. A brief outline of the operations followed by an experienced observer under typical conditions may aid by suggestion.

Assume an area typical of the South, with a succession of rolling timbered ridges of nearly the same height with a few higher elevations not high enough to be intervisible in all cases. Although the country is from 25 to 50 percent cleared, the higher ridges are timbered and a view can seldom be obtained from the ground. Use of the vertical circle, except from tanks or other points of vantage, is not possible. By use of existing maps it is found that the proposed scheme crosses a drainage system of small creeks, converging gradually toward a main stream to one side of the scheme. From treetops or tanks it is seen that the stream divides are of approximately equal elevations, being the result of the weathering away of a plateau. These ridges become narrow and lower as the streams converge and have no very prominent elevations, but there are a few slight rises where harder materials have resisted erosion. The cover is pine, with a mixture of hardwoods on the poorer soils of the ridges and tall gums and cottonwoods along the streams. The gums and cottonwoods are on sufficiently lower elevations do not obstruct lines, except for a few groups near the center of a prospective quadrilateral, where curvature on the long diagonals will bring them dangerously close or may require lines calculated to avoid them. The general height of trees is between 80 and 90 feet, with a few between 100 and 110. These will generally be the culls left from logging and will be scattered and will seldom be on the higher ridges. Although fairly large upland areas are cultivated, any wide view will show a uniformly timbered horizon.

OBSERVATIONS AT FIXED STATIONS

The established station (1) on the side toward the main valley is first visited. (See fig. 5.) From it a view is obtained across the lower, narrower divide to a hill (A) at an estimated distance of about 10 miles. This hill fits the new scheme so well and is so prominent as to warrant holding it as a controlling point around which to build the new figure. The starting line and one side line are therefore clear, and the new point appears high enough to see across the scheme to some point on one of the divides between the minor streams, especially since advantage can be taken of the concavity of one of the valleys. It also looks as if it would clear the diagonal which crosses the diminishing ridges, provided some of the above-mentioned belts of timber do not interfere. The diagonal from the occupied station appears to be on a grade line, since distant bits of the horizon are visible but present no prominent features. If this line is not clear it can be broken with a central point, but that expedient should be used only as a last resort.

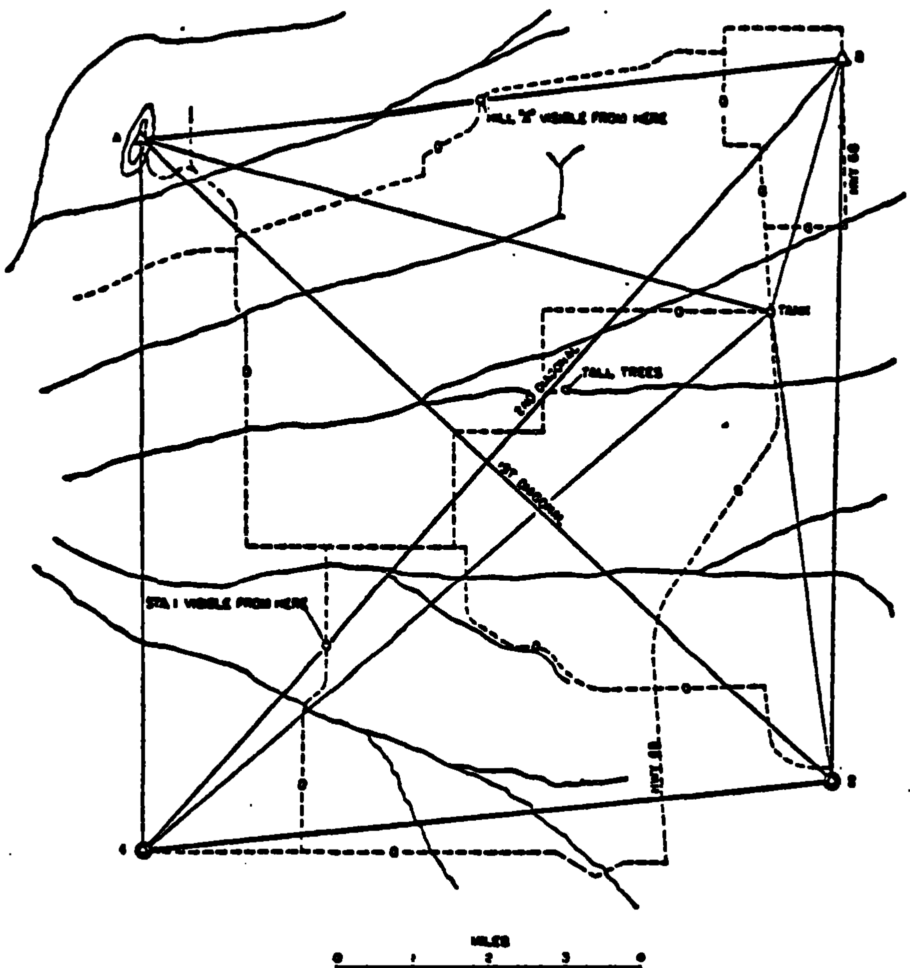

FIGURE 5.—Typical reconnaissance problem.

In searching the horizon in this direction, a water tank is found to the right of the proposed line, and reference to the map indicates that it is in a town near the side line of a suitable prospective quadrilateral and about midway of the line. It appears to be in flat country, although the map shows it to be on one of the minor divides. The bowl of the tank stands about the breadth of itself above the treetops. The standard tank is about 100 feet to the walkway, and the bowls are 20 to 30 feet in diameter, hence, the treetops are probably about 75 or 80 feet above the ground. Since the curvature at the center of the side line of ideal length of 10 miles is about 15 feet, these trees are not insuperable, provided the forward point is located on a favorable elevation.

Several magnetic azimuths are taken, the entire horizon in the direction of the new scheme is carefully studied and a tape is lowered from the tree which shows that the observer is 80 feet above the ground. An estimate of the height of the highest branches around him is 15 feet. The minimum signal height is therefore 90, but 103 feet may be needed because of local obstruction. If the station is accessible by truck there is no advantage in reducing the height, since the triangulation party in such country will carry either 103-foot or 116-foot signals. If the signal must be packed in, the minimum height should be determined and the location of the highest trees should be noted. If the lines will avoid the highest trees a 90-foot signal can be specified as sufficient for local obstructions.

The station (2) at the other end of the fixed line is then visited. From a tree top the water tank is readily visible but appears to be on the horizon, nothing beyond it being distinguishable. It scales 6 miles distant and is 10° off the ideal side line which should be parallel to the tentative one selected on the other side of the figure. Next, looking along the diagonal toward the hill selected for its prominence from the first station, the tops of trees of a hazy blue color are just visible near the estimated azimuth. They appear well beyond any intervening trees, which in turn show up with the same color and detail as those near the water tank. Hence, it seems very probable that this is the hill (A) seen from the first station. It was noted to be the only prominent hill in that vicinity, and it fits the calculated azimuth and distance. It now appears as a ridge of moderate length, but that is explained by the different angle of view. It is not safe to conclude, however, that the identification is positive and that the diagonal is clear. The location of this point rests on estimated distances, and these have not been checked. A careful study of the ridge with binoculars shows that its only special feature is a square notch near one end. This is carefully sketched in the notebook.

It is now desirable to plot positions on a larger map, and, as a post route map is the best available, the existing stations are plotted by latitude and longitude, section lines or topographical features, and the tentatively selected forward point plotted by the intersection of the azimuths taken from these two stations. It falls between two streams, one of which, according to the map, makes a long bend around the

265164°—41——3

area. This is further evidence that the location is correct, and that the hill is one of the gravelly ridges found in such regions.

SURVEY OF AREA FROM WATER TANK

The observer next goes to the water tank. From the walk of the tank, the location of which is accurately plotted on the county map, it is first necessary to select a tentative point for the fourth corner of the figure. Perhaps the tank itself will be the best location. It has been positively identified from the two rear stations, it stands on a slight local elevation, and it is readily accessible for our own parties and subsequent users. Its disadvantage is that it is not sufficiently distant from the starting points to make a well-shaped figure with the hill already selected as the other forward point. Also, a study of the terrain and of the map shows that the prospects of getting a long line ahead to square up the scheme are not favorable. The hill selected for the other point must be identified positively and so its azimuth from the tank is computed. A ridge apparently longer and flatter is found in this direction, but a careful study with binoculars shows the notch seen from the preceding station. On the map the observed azimuth misses the intersection of those from the rear stations by nearly one-half mile. This is a reasonable discrepancy for compass readings from tree tops, and since no other hill has been visible within those limits from either of the starting stations, nor anything observed which might obstruct the view to such a hill from the tank, the identificaion may for the present be considered positive. It cannot be considered absolutely certain until the point itself is visited and the views checked.

The observer now has a completed quadrilateral, provided he decides to accept the distorted figure produced by placing the fourth corner near the tank. If he finds a better location forward, or if the next figure demands a different location, the tank will make a good central point and can be used to replace the doubtful diagonal.

A study of the horizon in the direction of the ideal location shows a uniformly flat area. By using a small theodolite with the telescope clamped in vertical motion, a gradually descending grade will be found between this location and the other forward station, as was expected from the map study. Part of this apparent decline will be due to curvature because of the increasing distance but the possibilities still appear favorable.

Reference to the map shows that a graveled State highway (No. 68) crosses a broad area between two streams, at a distance of about 4 miles from the tank. This point will serve nicely to complete a symmetrical figure, and has the advantage of accessibility and hence should be tested for visiblity. The theodolite is set to the approximate azimuth, and a vertical angle observed on the tree tops at the new location which are found to be 10 feet lower than the instrument as calculated from an estimated distance and corrected for curvature. The height of instrument is found to be 105 feet and therefore if the trees are 80 feet high the ground must be about 15 feet higher at the forward point than at the tank.

When climbing the ladder of the tank, it was found that the treetops were reached at 75 feet, or about 30 feet below the instrument. A vertical angle is now read on the starting station directly to the rear and found to be minus 6 minutes on the treetops. The distance is 6 miles and the notebook shows the trees at this station to be 85 feet high. Calculation shows the apparent elevation of the treetops to be 55 feet below the instrument which, corrected for the curvature at 6 miles, gives a true relative elevation of minus 34 feet. The ground is therefore 119 feet below the instrument or 14 feet lower than at the tank. The curvature correction at the tank is about 14 feet. A line of sight from ground to ground between the two stations would therefore pass 89 feet below the treetops, and 90-foot signals at both ends, allowing for the effect of the superstructure, would clear the line.

The estimated distance to the forward point, the estimated height of trees there, and the visibility of the tank from there must be verified before the results are final. Since the line does not pass directly through the tank but about a mile to one side, the relative elevation of the trees at that point must be considered. A descent of the ladder to the elevation of the treetops shows a distant horizon visible beyond the point where the line crosses. As a distant horizon in this area is almost certain to be of minus elevation because of curvature, the tops of the trees where the line passes are no higher than those at the tank. Additional check can be made with a hand level, by altimeter and estimated height of trees at the point of crossing, or by vertical angles on the tank if it is visible from the ground at that point.

One more operation is necessary from the tank: that of investigating whether the second diagonal is clear. Vertical angles and directions are taken on two or three of the highest clumps of trees near the middle of this diagonal, and the leveled telescope is swung along the horizon to see if there are any swells unnoticed by the eye. None are found. A vertical angle on trees at the first existing station completes the observations. Since the rearward stations are definitely selected it is not necessary to study the horizon in this direction. A calculation of the height of obstruction along the diagonal, based on the observed vertical angles and scaled distances, shows a possible obstruction of several feet, and further investigation of this line is therefore required.

TESTS AT FORWARD STATIONS

The possible forward site near the State highway is now visited. The speedometer is set to zero before leaving town and the truck is driven to the summit of the divide. The mileage makes it possible to plot the point rather accurately on the map. If there is doubt as to the highest swell, recourse may be had to the hand level, altimeter, or theodolite. The ridge proves to be quite flat, with cotton fields on the left of the road for a distance of one-half mile as the summit is approached. The rise in the length of this clearing is about 10 feet. The crest of the ridge is covered by a dense growth of pole pines, all practically of the same height, making it impossible to see out except across the cleared field. This view shows the water tank, and checks the calculations for the side line. The trees measure 75 feet in height. No view can be had along the doubtful diagonal nor the cross line. Knowledge gained from the tank indicates that these are probably clear and a run ahead with altimeter shows a gradual slope into a broad valley which the next figure will span.

It appears desirable to locate a station here, at least tentatively. One side of the highway is wooded and on the other side is a tenant house standing in the corner of the cleared field, with a bare yard in front. This tenant house itself is not permanent, but a good brick-lined well and cistern will undoubtedly hold the site for a long time to come. A location for the station is selected between the well and the road, back from the property line, and where an azimuth mark near the distant end of the field will be visible from the ground. Distances are paced, a description written, and the owner's name, as well as that of the owner of the land across the highway, is secured from the tenant.

A diagonal can be broken, but a cross line must be clear. The line between this and the opposite station, A, is therefore next drawn on the map for study. It is found that the line crosses but one valley, intersecting the stream at an acute angle and there should therefore be no intermediate ridge. A post route road parallels the stream, at some distance from it and evidently on the higher ground, and this road is followed to the approximate point of its intersection with the line drawn on the map. Occasional views show that a valley opens up beyond the road. From the top of a tree, the ridge already tentatively selected is readily visible. The observations at the tank had shown a gradually declining grade along this line and so there is no chance of its being obstructed at the point of leaving the ridge or plateau. Hence, this line may safely be considered clear with signals at each end although some additional differences in elevation are measured by altimeter and recorded.

The diagonal is the next and last line to be checked. It passes over very flat country which can only be explored by altimeter. The line is drawn on the map and a route picked over the available roads for running the altimeter profile. The methods used for this work are described on page 33. For a distance of three-fourths the length of the line, the forward and backward altimeter lines indicate that the ridge tops lie in a uniform and gradually descending grade line. These ridges are separated by shallow valleys of minor streams. At the three-fourths point, a larger valley is encountered, and from a field on the slope a view of the end station can be obtained. Therefore it is unnecessary to carry the altimeter line further except to connect to the station. This is done by observing vertical angles and scaling the distance. The result shows that the station stands 40 feet above the projected grade line. The line scales 14.6 miles long. At the midpoint, the elevation of the fixed station gives the height of line of sight above ground to be 20 feet, and the curvature correction is 31 feet. The ground to ground line will therefore pass 11 feet below the surface and signals must be 11 feet higher than the trees to give a grazing line.

The pines do not exceed 85 feet, but tall hardwoods have been noted that stand above the pines. The line is now retraced by road as much as possible, and on foot when necessary, to investigate the trees. The large trees are found in the shallow valleys and are in limited groups. One group of cottonwoods is found very near the plotted line, and as this line is subject to some error in location, they must be checked. A measurement gives their height as 112 feet, and the altimeter connection to the nearest recorded elevation of the previous run indicates the valley to be 20 feet below ground grade, thus making the effective height of trees 92 feet. The trees are 5.75 miles from one end of the line, so that curvature effect [1] at their location is 29 feet, and a 92-foot obstruction must be cleared. Because of the 40-foot elevation at one station, 103-foot signals will meet this condition and the others already found, and so this height is specified for both ends of this diagonal.

There remains a visit to the last corner of the figure, which is the prominent hill selected as the controlling point from the first station visited. The roads shown on the map are followed to its vicinity. The notch observed proves to be a small clearing for an old gravel pit, with passable road leading to it, and with open woods from there to the summit. A tree in the edge of the clearing is climbed, and the view obtained verifies all calculations. A detailed location is made and marked by blazes, and the observer moves to the forward end

[1] See formula on p. 56.

of the ridge to study the outlook for the next figure. Trees on this gravel ridge are 75 feet high, and 90-foot signals are specified here and at the other end of the diagonal. A description of the best road to this station and the selection of any supplemental points required, complete the reconnaissance of this figure.

To avoid confusion in this example, it has been assumed that the observer's judgment was verified in all cases. This is not always true of course, and the observer should not be discouraged if he is compelled to discard carefully laid plans and try again.

ALTIMETER PROFILING

The altimeter is a high grade aneroid barometer, graduated in feet, and equipped with a setting device so that elevations may be read directly from the dial. Those in use by the Coast and Geodetic Survey are of two types: the direct reading and the statically balanced, or Paulin type. The first is essentially a cylindrical bellows-like drum exhausted to a high degree of vacuum with the heads or diaphragms held in position by a strong U-shaped spring. As the atmospheric pressure on the diaphragms increases they press harder against the resistance of the spring and as it decreases the pressure against the spring decreases. The resulting movement is communicated to the indicator needle by a suitable linkage and causes it to move along the scale.

In the Paulin type, the main part of the instrument is of precisely the same construction but the method of indicating the movement on the dial is different. Instead of a direct linkage, there is a pair of auxiliary calibrated coil springs the tension of which is adjusted by turning a thumbscrew on the dial. This thumbscrew is turned until the distorting effect of the atmospheric pressure is just balanced by the tension of the auxiliary springs, and the static position of the diaphragms restored. This point is shown by the centering of a fine needle known as the balance indicator needle. The needle by which the elevation is read is attached to the thumbscrew, and its movement over the dial indicates how much the screw is changed to restore the balance. It will be seen that the first type is read with the diaphragms in distorted position, the distortion varying in degree with the change in pressure. In the Paulin type, the reading is always made with the diaphragms in the same position. For this reason, the latter type is theoretically somewhat more sensitive and accurate over the whole range of the scale. It is also more delicate and requires greater care in use. Both types are quite expensive, and should be given the care of delicate instruments.

These altimeters are so sensitive that they will readily indicate the difference in elevation between a table and the floor, but elevations indicated by them are subject to all the errors of fluctuating atmospheric pressure. Air pressure is of course dependent upon other factors than elevation, principally temperature, humidity, and atmospheric disturbances caused by winds and storms. Elaborate tables of corrections are available but, since atmospheric conditions are subject to continuous and irregular variation, these tables are not of great help unless another instrument is maintained at a fixed station as a standard. This is not practical on a reconnaisance party, and so the accuracy is dependent upon running lines forward and back, or in loops, checking on datum points with a minimum of elapsed time. The error in closure is then distributed in proportion to the time elapsed, and the elevation taken as the mean of the corrected readings. This method has been found to give fairly satisfactory results.

TEST OF LINE BY ALTIMETER

In testing a line by altimeter, the line is first drawn on the best map at hand, and a route selected over the available roads which most nearly follows the line. The instrument is first read at the starting station and recorded with the time and speedometer reading. It is not necessary to set the altimeter to read true elevation of the point even if this is known, although it should be so set that subsequent negative readings are avoided, as they are apt to cause confusion. Either the altimeter is read from approximately the same height above ground at all stations or a correction is applied for this height which is usually that of the observer seated in the truck, or of his chest when he is standing on the ground. The truck must be stopped but, with a smooth running motor, it is not necessary to get out of the truck. Readings should be taken on all summits or swells, unless it is definitely established by seeing over a section of the line that no point in the section is of critical height.

If the area is devoid of noticeable ridges, readings should be taken at intervals of about 1 mile, and at every place where the road crosses the line. If the truck cannot be driven directly to the line at a point where a reading is desired, the elevation may be read at the road, and the difference in elevation from this point to the true line estimated with a hand level. In some cases it will be necessary to carry the altimeter by hand to the required points. If the observer is accompanied by a truck driver, he may walk along the line from road to road, meeting the truck at intervals. If alone, he must run his lines as spurs, retracing his steps to the truck. In either case, the altimeter is read both when leaving the truck and when returning to it. On the return trip with the truck, only these points need be read, and the elevations run on foot are adjusted to them.

For all altimeter readings the time is noted, and at truck stations the speedometer reading is also recorded. The best results will be obtained by proceeding quickly from one station to another and by returning over the line as promptly as possible. This is because, in the simplified computations for this work, the altimeter readings are considered to vary as a linear function of time. This is only approximately true, and the error is minimized by reducing the time interval. The curve of the corrections to readings rises rapidly in the early morning and falls rapidly in the late evening, and so these hours should be avoided. The best results are obtained on foggy or rainy days when the temperature and pressure are nearly uniform for long periods. Much altimeter profiling can thus be done on days when other observations are impossible.

The altimeter should be carried through continuously from one end of the line to the other, and then back to the starting point. On the return trip, readings at many points, shown by the first run not to be critical, are dropped. Closely agreeing results should be secured at all critical points and in case of discordant readings a third run should be made or a round trip to the nearest point established with certainty.

On completion of the return trip to the starting point, the results are adjusted according to the time elapsed between the readings. The elevations of all truck stations are adjusted first, and then the spur lines are adjusted to them. For example, on the forward run, the starting point A reads 100 feet and the time is recorded as 10 a. m. Point B is read as 110 feet at 10:15 a. m. and so on to the end of the line. The return run is begun immediately, and this time point B reads 138 feet at 11:50 a. m. and point A, 132 feet at 12 a. m. The closing error on A is 32 feet, and the total elapsed time 2 hours. The adjustment applies a correction of 32/2 or 16 feet per hour of time from the initial reading, which is used as the datum. The corrections to the readings at B are −4 feet for the forward run, and −29.3 feet for the return trip, and the corrected readings are 106 feet and 108.7 feet, respectively. As their mean is 107.3 feet, the adjusted difference in elevation from A to B is 7.3 feet.

When a considerable delay occurs at any point on either run, such as may be incurred by a spur line, an inspection trip, or a stalled truck, the altimeter is read both at time of arrival at the point and departure from it. The difference in the two readings, and the time elapsed between them are then deducted from the closing error and the total elapsed time, respectively, before the adjustment is made.

Notes for typical altimeter profile

[Weather—cool, overcast]

Station	Time	Speedometer (set)	Altimeter	Correction	Adjusted reading	Elevation
A (F)	10:00A	00.0	863	0	863	------
(B)	1:56P	39.6	922	−59.0	863	863
B (F)	10:10	2.8	859	−2.6	856	------
(B)	1:50	36.8	915	−57.4	858	857
C (F)	10:18	4.2	864	−4.8	859	------
(B)	1:46	35.4	915	−56.3	859	859
D (F)	10:32	6.6	858	−8.5	[1] 850	849
						6
(B)	1:38	33.0	903	−54.2	849	855
E (F)	10:40	8.8	840	−10.6	------	------
Spur from E:						
X (F)	10:55	------	858	−3.6	854	------
X (B)	11:05	------	860	−5.6	854	844
E (F)	11:15	8.8	848	−18.6	829	------
(B)	1:32	30.8	884	−52.6	831	830
F (F)	11:24	11.2	846	−21.0	825	------
(B)	1:24	28.4	873	−50.5	825	825
G (F)	11:36	13.5	847	−24.2	823	------
Spur from G:						
Y (F)	11:48	------	880	−2.8	877	------
(B)	11:56	------	882	−4.7	877	853
Z (F)	11:52	------	885	−3.7	881	856
G (F)	12:06P	13.5	854	−31.2	823	822
(B)	1:14	26.1	870	−47.8	822	------
Road junction.						
H (F)	12:12	14.3	878	−32.8	845	846
(B)	1:10	25.3	893	−46.7	846	------
I (F)	12:18	16.1	887	−34.3	------	------
(F)	[2] 12:32	16.1	890	−37.3	853	------
(B)	1:05	23.5	900	−45.4	855	854
J (F)	12:40P	19.8	912	−39.5	872	------
(B)	12:50P	19.8	914	−41.5	872	872
End of line.						

[1] Bank +6.
[2] Delay for measuring trees.

In the profile shown in the table, the observer started with an initial reading at A and proceeded by indirect road to a crossing of the line at B, thence on to another crossing at C; thence to another at D, where it was observed that the road was in a 6-foot cut and a note is made that the elevation of the bank is +6 feet above the point where the altimeter was read. The truck was then driven to E, where it was seen that the line crossed a swell about one-half mile from the road. After taking a reading here the observer walked to X, where the altimeter was read at once. He then spent 10 minutes studying the area, re-read the altimeter at X, and returned to the truck at E, again taking a reading there. The truck was driven past F to G, where it was necessary to walk again to the line as from E. After reading at Y, which is on the line, the observer saw another ridge one-fourth down the line and walked to it at Z. The altimeter was read only once at Z. The return was made by way of Y, where a backward reading was taken, to the truck at G. At H was found an important road junction where it was desired to set an altimeter "bench mark," and the regular readings were taken. The line was again crossed at I, where 14 minutes were spent measuring the height of trees, and an additional reading was taken on leaving.

The end of the line was reached at J. Ten minutes were spent studying maps before starting the return trip. Since the points X, Y, and Z are tied into E and G by double runs, it was not necessary to revisit them, and the truck was driven continuously to A, with the altimeter read at all truck stations established on the forward run.

ADJUSTMENT OF ALTIMETER PROFILE

The total elapsed time was 236 minutes and the altimeter read 59 feet higher on point A than at the beginning. The adjustment is made as follows:

Total time=236 minutes	Total closing error= +59 feet
Time out at E=35	Change at E= +8
Time out at G=30	Change at G= +7
Time out at I=14	Change at I= +3
Time out at J=10	Change at J= +2
Total=89	Total= +20

Net time spent on main loop=147 minutes.

Net change during running of main loop= +39 feet.

Change per minute=39/147=0.265 feet.

Correction to readings to be applied per minute of elapsed time = −0.265 feet.

This correction is applied to all forward runnings to point E, at which it amounts to −10.6 feet. To this is added the change in the altimeter during the interval in which the spur line was run, giving a correction of −18.6 feet to the reading made on leaving point E. This then becomes the new origin to which the regular corrections are applied up to G. The change is similarly added here, and the value of the correction becomes −31.2. The same is done at I and J. The return trip, with a correction of −41.5 feet to the reading at J, is continuous, and the regular corrections of 0.265 feet per minute are applied to the successive readings. The final correction at A should, of course, equal the closing error of 59 feet except for a small tolerance for dropped decimals. The means of the forward and backward corrected readings are then taken as the elevations at the various points.

The next step is to adjust the two spur lines which are handled in the same manner as the main run. At station E the elapsed time is 35 minutes, of which 10 is time out between readings at X, leaving a net interval of 25 minutes. The closing error is 8 feet less the 2 feet change while the altimeter was not in use at X, or 6 feet. The correction is therefore 6/25, or −0.24 foot per minute and this gives a correction of −3.6 feet to the first reading at X. Because of the change of 2 feet, the second reading receives a correction of −5.6. The return trip takes 10 minutes, and this gives a correction of −2.4, which added to −5.6 checks the total change of 8 feet in the two readings at E.

At station G, a similar adjustment is made except that there is no elapsed time nor altimeter change at Z to deduct. The time is 30 minutes and the closing error is 7 feet. The corrections are therefore 7/30 times the number of minutes elapsed since the first reading at G.

It will be noted that these corrections are applied to the initial readings of the spur lines, that is, to the first readings at E and G. In the case of point X, its mean corrected altimeter reading is 854 feet which is 14 feet higher than the initial reading at E. The corrected elevation at E is given by the main adjustment to be 830. Hence, the elevation at X is 830+14, or 844 feet. This can also be computed by adding algebraically the correction from point A to the spur's initial reading at E and the correction from E to X. The sum subtracted from the reading at X gives the corrected reading at X referred to A. In the above example, this would be −10.6+(−3.6), or −14.2, which is added algebraically to the reading at X, 858, giving the elevation of 844 as above.

The method of using the net time and net change in the altimeter during the time it is in use on the main circuit is a refinement to reduce somewhat the error introduced by assuming that the atmospheric pressure varies as a linear function. If all the corrections were applied according to the time elapsed since the initial reading the results in the example given above would not differ appreciably from those shown. The correction would be −0.250 foot per minute and would amount to —10.0 feet on the first reading at E instead of −10.6. Two different elevations would be obtained at such points as E and G corresponding to the two forward readings taken at different times.

Directions for reading the different altimeters are furnished by their makers. It is good practice to bring the indicator needle of the Paulin altimeters to center and after reading to throw it off center and repeat the reading. Frequently, this repetition will serve to detect anomalous readings.

The final elevations as given by the altimeter are subject to errors larger than may be indicated by the computations. In other words, the altimeter profile is not strictly reliable and, if possible, it should be given a factor of safety. It is the experience of reconnaissance engineers of the Coast and Geodetic Survey, however, that lines determined to be clear by careful altimeter observations are very seldom found to be obstructed. In many cases, it affords the only feasible means of investigating the line.

If the elevations of both ends of the line are known from other sources, the altimeter profile may be based on a single running, provided the results check reasonably well. The error of closure is adjusted in the same manner as described above. Similarly, if the observer walks along a section of the line between two elevations determined by the truck profile, only a single running need be made unless the discrepancy is too large.

SPECIAL USES OF ALTIMETER

An alert observer can find many short cuts in altimeter profiling. Connections to available bench marks will often save time as well as increase the accuracy. Coast and Geodetic Survey bench marks are available in almost any locality, along highways or railroads. In some areas bench marks have been established by the Geological Survey in advance of their topographic surveying. Elevations of the track in front of railroad stations can usually be obtained from railroad companies. By running short loops from convenient bench marks to critical points on the line, very accurate results are quickly obtained. A single running, if connected to bench marks, will often give reliable results with a minimum of labor.

Other savings may be made by using the water level of a lake as a datum and running short spurs from the shore to points in question. A special adaptation of this was made along the lower Mississippi River by using backwaters from a flood as datum. In this particular case, it would have been impossible to carry the line through directly on account of the flooded condition of the valleys. The ridges were followed to the points where they were crossed by the line being tested, and an altimeter was then used to connect this point with the edge of the backwater. This method gave the relative elevations of all ridges crossed. The river itself, or any large stream of low-fall, can be used in the same manner. The altimeter investigation often resolves itself into determining the elevations of one or two intermediate ridges, instead of a continuous profile. If reliable elevations from any source can be found in their vicinity, or a water level datum exists, the altimeter work is greatly simplified and the accuracy improved.

It is often difficult in a wooded area to determine the highest elevation in the vicinity or the highest knoll along a ridge. Readings with the altimeter will quickly indicate the superior elevation. If a tape is not available, the height of a tree may be found by carrying the altimeter to the top.

VERTICAL-ANGLE PROFILING

Determinations of elevation along lines of triangulation can sometimes be made by the use of a transit with vertical circle. The method is superior in accuracy to the altimeter method, but it is applicable only to rather open country and to wooded regions in which advantage may be taken of tanks, towers, etc. It is especially suited to rolling prairie and plains areas where only one or two intermediate ridges are critical.

The instrument commonly used is a 4-inch theodolite with full vertical circle read by opposite verniers and carrying a sensitive bubble on the vernier frame. In a region well supplied with roads, some observers prefer a 7-inch theodolite because it is more accurate. Its disadvantage is its weight. A special instrument could be designed which would combine the advantages of both the 4-inch and 7-inch instruments.

The method consists simply of determining elevations from vertical angles corrected for curvature. The combined effect of curvature and refraction in feet is approximately 0.574 times the square of the distance in miles and is always of the sign to make the distant object appear lower than it actually is. A full discussion of curvature corrections will be found on page 55.

RELATIVE HEIGHTS BY VERTICAL-ANGLE OBSERVATIONS

A simple illustration of this method is the determination of the height of signals required when it is found that the termini of a prospective line in quite open country are not visible over one intervening ridge. The line is plotted on the work sheet, and the theodolite set up about on line on the intermediate ridge. The two ends of the line are visible from the ridge and are identified by natural objects near them, which have previously been noted. Vertical angles are measured to both ends with telescope direct and reversed. The vertical angles should preferably be taken to the ground at the ends but if the ground is not visible the instrument may be pointed on the top of some object such as a tree, barn, or silo, the height of which is known or can be closely estimated. This height is introduced as a correction into the calculations for signal height. Where the occupied ridge is smooth, it is not required that the theodolite be exactly on line, and it is often necessary to set the instrument off the line to secure visibility. Any difference in elevation of the instrument and that of the point over which the line passes may then be applied as a correction. The vertical angles are customarily measured to minutes and their means carried to 30 seconds. The angles are measured as elevation or depression angles, above or below the horizontal. (See fig. 6.)

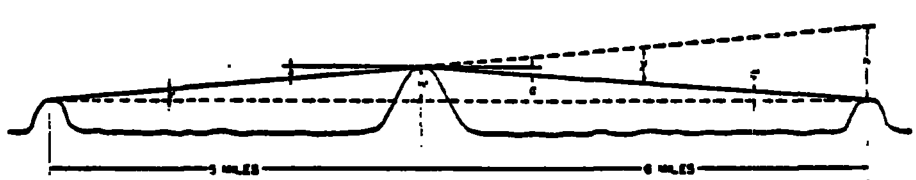

FIGURE 6.—Relative elevations by reciprocal vertical angles.

Suppose that with instrument at B, the observed vertical angle, a, of the ground at point A is -3 minutes, and angle c of the ground at C is -4 minutes. It is required to find the height of signals at A and C to clear the bare ridge at B.

The solution may be made in two ways. For the first solution (see fig. 6) extend the line from A through the instrument to a point above C. The angle y between this line and the line from the instrument to C will be a plus c or 7 minutes. The scaled distance from B to C is 6 miles. Hence the value h, or height above C, at which the projected line will pass is 64.5 feet, which is the signal height at C necessary to see the ground at A through the axis of the instrument at B. The height of obstruction at B, h', is in the same proportion to h as the length AB is to AC (in this case 5/11) and is therefore 29.3 feet. Hence, signals of 29 feet would give a line of sight through the instrument height at B, which is about 5 feet above ground. It is always desirable to clear the ground by at least 10 or 15 feet, hence the signals required at A and C will be of the minimum standard height of 37 feet.

The value of h may be computed by a simple approximate formula as follows: Since vertical angles in any country requiring such computations will be very small, their sines may be considered proportional to the angles. The sine of one minute of arc is 0.000291, and the chord subtended at a distance of 1 mile is 1.536 feet. h therefore becomes 7 (minutes) $\times$ 6 (miles) $\times 1.536$, or 64.5 feet. The value of the chord subtended by an angle of 1 minute at a distance of 1 mile is commonly taken as 1.6 feet, and the calculations are made mentally. It will be noted that no curvature correction is made. This is because the instrument is between the two points A and C and the effect of curvature is therefore included in the values of the angles a and c.

The second solution gives h', the obstructing height at B, directly. In figure 6, the sum of the angles a' and c' is equal to the sum of a and c. By the approximation described in the preceding paragraph, they may be considered proportional to the lengths opposite them. Hence

$$a' : BC :: c' : AB$$

or

$$5a' - 6c' = 0$$

and

$$a' + c' = 7 \text{ minutes}$$

Solving these equations gives $a' = 3'.82$ and $c' = 3'.18$. $h' = 3.82 \times 5 \times 1.536 = 29.3$ feet, the same as derived by the first method. Similarly, h' can be checked by computing it from the value of c' and the length BC, or 6 miles.

NONRECIPROCAL VERTICAL-ANGLE OBSERVATIONS

This method may be used when the intervening obstruction is timbered, inaccessible, or for another reason not conveniently occupied.

It may also be used in a preliminary study of an area. It gives results slightly less accurate than those of the method described above, as it requires corrections for curvature. It requires also that the same object be observed from both ends unless allowance is made for "least favorable condition" as discussed later.

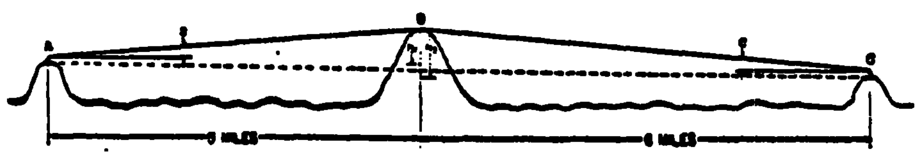

FIGURE 7.—Relative elevations by nonreciprocal vertical angles.

Suppose that with instrument at *A* (see fig. 7) the observed vertical angle, *a*, on obstruction, *B*, is +4 minutes and at *C*, the vertical angle, *c*, is +3 minutes. It is required to find the heights of signals at *A* and *C* to clear the obstruction at *B*.

The *apparent* value of h_1 as seen from *A* (see p. 40) uncorrected for curvature, is $+4\times5\times1.536$, or +30.7 feet, which added to the height of instrument, taken as 5 feet, gives +35.7 feet. Similarly, h_2 as observed from *C*, is $+3\times6\times1.536$, or +27.6 feet, which added to the height of instrument equals +32.6 feet. The two results do not agree because *A* and *C* are not of the same elevation and are not the same distance from the obstruction. It is next necessary to find their relative elevations and for this the curvature corrections must be computed. From *A* the effect of curvature on *B* is approximately (see p. 56) $5^2\times0.574$, or 14.4 feet. The curvature effect is always a positive correction, that is, must be added to the *apparent* elevation of a distant object in order to obtain the true elevation.

The elevation of *B* above *A* is therefore 35.7 plus 14.4 or 50.1 feet. If we assume the elevation of *A* to be 100 feet (to avoid minus quantities), the corresponding elevation of *B* is 150.1 feet. In a similar manner, the curvature correction for *B* observed from *C* equals $6^2\times0.574$ or 20.7 feet, and the elevation of *B* above *C* equals 53.3 feet. The elevation of *C* on the assumed datum is therefore 96.8 feet. The relative elevations of *A*, *B*, and *C* are all that are necessary to compute the amount of obstruction at *B*.

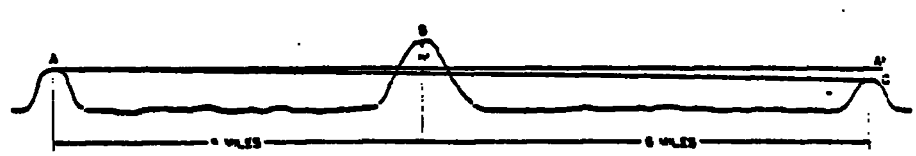

FIGURE 8.—Determination of obstructing height.

In figure 8, the line *AC* is the theoretical line of sight from *A* to *C*; *h′* is the elevation of *B* above this line, or amount of obstruction: and *AA′* is a horizontal grade line. The height of *AA′* over *AC* and *B* is in the same proportion to *A′C* as *AB* is to *AC*. We have already found that *A′C*, the amount that *C* is lower than *A*, is 3.2 feet and this multiplied by the ratio of distances 5/11 gives 1.5 feet as the divergence of the two lines at B. The curvature correction at B as affecting the two points A and C is $5\times6\times0.574$, or 17.2 feet. The elevation of the line AC at B is therefore 100 (elevation of A) $-(1.5+17.2)$, or 81.3 feet. The elevation of the obstruction at B is 150.1 feet, and h' is therefore $150.1-81.3$, or 68.8 feet. After making proper allowance for clearance, it is thus seen that 77-foot signals should be specified for A and C.

The following simplified method for computing the heights of the signals at A and C to clear the obstruction at B (see fig. 7) has been devised by L. G. Simmons, Associate Geodetic Engineer.

For two stations at the same elevation, the vertical angle due to curvature of one as seen from the other (see pp. 40 and 56) is

$$t=-\frac{0.574d^2}{1.536d}=-0.374d$$

where t is the vertical angle in minutes and d is the distance between the stations in miles. t is the angle between the tangent at the one station and the chord between it and the other station. By simple geometry, the angle between the verticals at the two stations is twice this or $2t$, which equals $0.748d$.

Since the distance from A to B is 5 miles, the angle between the two verticals is 0.748 times 5 or 3'.74. The line AB makes an angle of 4' with the horizontal at A. Therefore this line will make an angle of $-4'\ -3'.74=-7'.74$ with the horizontal at B. In a similar manner it can be shown that the vertical angle at B on C is $-3'\ -4'.49=-7'.49$.

In the triangle ABC, the sum of the angles at A and C is equal to $7'.74+7'.49=15'.23$. The angles themselves are inversely proportional to the distances between each of these stations and B, since the angles are small. Therefore at A the angle is

$$15'.23\times\frac{6}{11}=8'.31$$

and at B it is

$$15'.23\times\frac{5}{11}=6'.92.$$

If signals of equal height are used at A and C, the height of signal required for a grazing line is

$$6.92\times6\times1.536=63.8$$
$$63.8+5\ \text{(for height of instrument)}=68.8$$

as computed from C, or

$$8.31\times5\times1.536=63.8$$
$$63.8+5=68.8$$

as computed from A.

Should the relative elevations of A and C be known from any other source, such as maps or connections to bench marks, the vertical angle observations at either A or C may be omitted and the elevation of B computed from the single nonreciprocal observations.

COMPOUND PROFILING

The term "compound profiling" is applied to profiling when a series of ridges obstruct the line between the two ends, and it is impossible to see from any one of them to both termini of the line.

The procedure followed is to start at one end and determine the relative elevation of each ridge in succession until the farther end of the line is reached. This may be accomplished by either of the methods outlined above, or by a combination of them.

For example, it is desired to test the line from A to E, which is obstructed by ridges B, C, and D (see fig. 9). B and C are accessible,

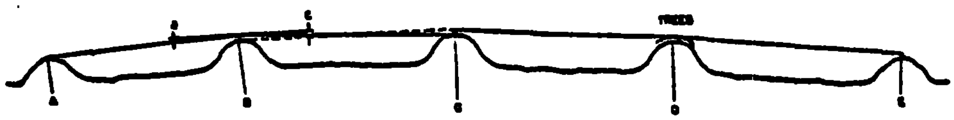

FIGURE 9.—Example of compound profiling.

but D is a wooded summit from which the instrument cannot be operated.

With instrument at B, observe vertical angles a and c. Elevation of B in feet is then obtained by the formula: (Elevation of A) + [a (in minutes) $\times AB$ (in miles) $\times 1.536$] $-$ [AB^2 (in miles) $\times 0.574$] $-$ (height of instrument). The elevation of C in feet is (elevation of B) + [c (in minutes) $\times BC$ (in miles) $\times 1.536$] $-$ [BC^2 (in miles) $\times 0.574$ feet] $-$ (height of instrument). The signs of vertical angles a and c are plus when the object sighted is above the horizontal and minus when below. If refined values are not needed, the allowance for instrument height at B may be omitted.

In a similar manner, the instrument may be set up at C, and the elevation of treetops at D may be obtained. It is not necessary to observe the reciprocal vertical angle to B, but it should be done as a check. The profile is completed by observations on D from E, and the elevations of all obstructions obtained on the same datum. An inspection of these will usually show which is the critical one. The obstructing height is then computed. If there is doubt as to which ridge presents the greatest obstruction, several may have to be computed. It should be noted that the comparison cannot be made until after the effect of curvature is introduced. A ridge of lower elevation near the middle of the line may need such a large curvature correction as to require higher signals for clearance than a ridge of greater elevation near one end.

There will, of course, be any number of conditions encountered in compound profiling, and any suitable means of obtaining the elevation of successive obstructions may be used. Altimeter methods may sometimes be combined with vertical-angle methods as, for example, when the obstructing elevation is a broad, level, wooded area.

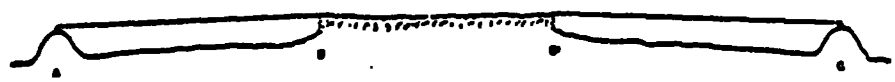

FIGURE 10.—Obstructing height determined by vertical angles and altimeter.

Figure 10 illustrates such a condition. From *A*, near the edge of a wooded tableland, *BB'* is visible. The other edge of the tableland can be seen from *C*, but *B* and *B'* are not intervisible. By vertical angle observed at *A*, the elevation of the tree tops at *B* relative to *A* is obtained. Similarly, the elevation of the tree tops at *B'* is determined with respect to *C*. *B* and *B'* are then connected by altimeter, corrections are applied for height of trees at *B* and *B'*, and the elevations of *A*, *B*, *B'*, and *C* are reduced to the same datum plane. The height of the required signals may then be computed as in the foregoing examples. Any critical elevation between *B* and *B'* may be detected with the altimeter.

Another method is to set up the instrument at *B* and *B'* and observe vertical angles on *A* and *C*, respectively. This concentrates all the instrumental work on the obstruction and is more economical especially when *BB'* is of small extent or travel difficult.

INDIRECT PROFILING

In all the foregoing examples, it is assumed that the instrument can be mounted directly on the line, or very close to it. This is not always the case. When direct observations along the course of the line are precluded, recourse may be had to indirect profiling. This is done by determining the relative elevations of points along the line by observing on them from one or more points of vantage, such as a fire tower, tank, or bare summit.

The instrument is set up at the vantage point to one side of the line and the points where the line passes over obstructions are located by estimation or a combination of azimuths and estimated distances. Vertical angles are then observed on these approximate crossings and their elevations computed. In figure 11 it will be seen that considerable error in choosing the critical points will not greatly affect the accuracy, and the error will be on the safe side.

Suppose that it is required to determine the height of signals needed at *A* and *D* to clear obstructions at *B* and *C* under conditions rendering observations directly along the line impractical. (See fig. 11.)

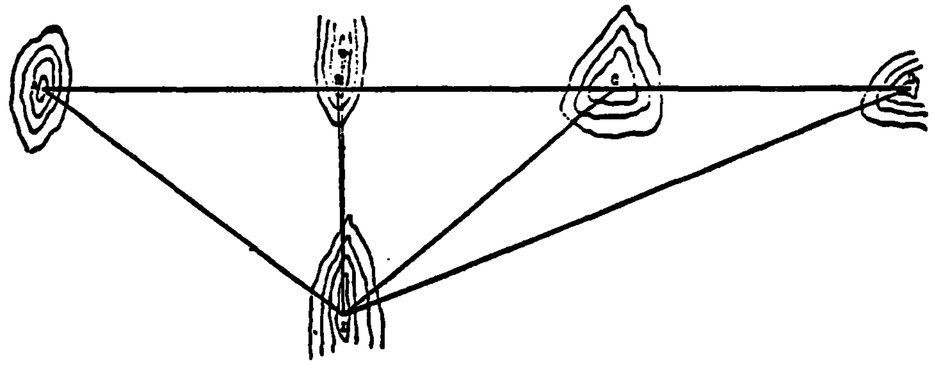

FIGURE 11.—Indirect profiling.

The instrument is mounted on a lookout tower at *I*, which is plotted on the work sheet. Vertical angles are observed on the ridges *B* and *C* as well as on the end stations *A* and *D*. The azimuths to all these points are also observed. The intersections of these lines with the line *AD* give the distances from the instrument to the obstructions, from which the elevations can be computed. However, the line *AD* crosses between the observer and the highest apparent elevation at *B′*, and since the definite location of the crossing cannot be identified from *I*, the vertical angle is taken on *B′*. This, of course, gives an erroneous elevation for *B*, and the actual obstruction at *B* must be somewhat less than the computed value if the line of sight from *I* to *B′* is nearly level. In case the point *I* will not see all the obstructions, some other instrument position must be found from which the observations can be completed. As in the preceding examples, the elevations of all possible obstructions, referred to the same datum, are required. Parts of the line may be investigated by direct vertical-angle methods or by altimeter. After the elevations are obtained the signal heights are computed as previously explained. Work of this type will usually occur in wooded and brushy country, and the vertical angles will be on the tree tops. The elevations must be corrected to ground level before computing signal heights. The obstructions are, of course, the tree-top elevations.

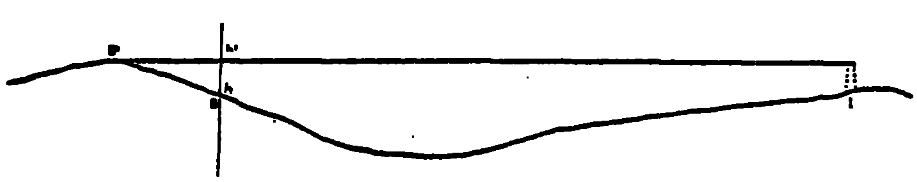

FIGURE 12.—Checking clearance of line from side point, case 1.

In figure 12, the error from pointing on *B′* instead of *B* is shown graphically. *h* is the true elevation of the obstruction crossed and *h′* is the computed elevation.

Figure 13 shows the case in which the highest apparent point *B′* is between the instrument and the line crossing at *B*. It will be seen

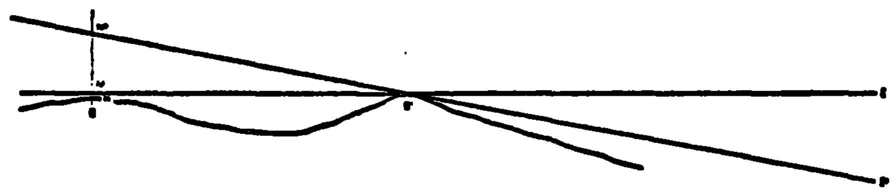

FIGURE 13.—Checking clearance of line from side point, case 2.

that whether I is higher or lower than the obstruction the computed values of h' and h'', respectively, are still higher than h. It should be noted, however, that if the distance between B and B' is great, the excess elevation of h' will result in the specification of signals entirely too high. Some idea of the true proportion may be gained by treetop views from A and D (see fig. 11), and the alert observer can readily eliminate any gross errors.

EXAMPLE OF INDIRECT PROFILING

A specific example of the solution of a field problem by methods similar to the above may be of value. In the reconnaissance of a difficult, heavily wooded area in Northern Michigan, points A and C (see fig. 14) were found to be the only reasonably accessible locations for stations that would carry the scheme forward through an acceptable figure. The obstruction at B figure 14 was visible from a lookout

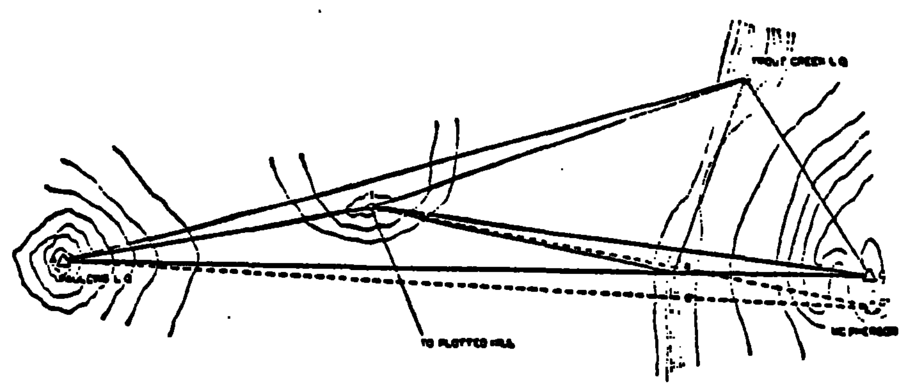

FIGURE 14.—Example of indirect profiling.

tower at A and, through a narrow opening between trees, from the ground a short distance from C. Because of inaccuracies in the map used as a work sheet, C was plotted erroneously at C', and the line investigated was actually AC'. The lateral position of ridge B was located by angle from Trout Creek Lookout, and was therefore accurate. Vertical angles from A, Trout Creek Lookout and the point near C gave an elevation of B' too high to be cleared by the highest signals available. However, it was noted that the obstructing ridge sloped down sharply to the north, and the distant horizon was visible in the vicinity of I from treetops near C. The unreliability of the map was also known, so hope of clearing the line was not definitely abandoned. A careful sketch was made of the obstructing ridge and all azimuths to controlling points were taken.

Next, two alternate possibilities were studied, but these presented greater problems as well as considerable difficulty of access. The only recourse, in case AC would not clear, was to a much weaker figure. Hence, a further study of the line AC was made. A burned-over hill was found at I that would see A, B, Trout Creek Lookout, the trees near C, and in addition a point to the south that was accurately plotted. The position of the instrument was determined by a strong three-point fix from A, Trout Creek Lookout and this point to the south. The azimuth of C, which was still thought to be at C' was scaled and laid off on the circle, and the trees thought to be near C, but not identified with certainty, were found to the left of the line, thus strengthening the belief that C was misplotted. The plotting of C was corrected to the observed azimuth and the line AC drawn. Next the azimuth of the crossing of this line over the obstruction at B was scaled and laid off. It was found to miss the highest part of the ridge and vertical angles gave an elevation which could be cleared by signals.

The next step was to verify this fact. A careful sketch was made of prominent trees near B, and also additional ones on line between B and I. The ridge B was found to be located in a cut-over wilderness, but was reached on foot in the late afternoon. By taking frequent compass bearings on A and Trout Creek Lookout, the trees at B were found, and the most likely one climbed. The identification was verified by observing that the check trees were in line to I. B was also approached from the direction of C, and, from near that station, an identifying tree approximately on line CB was selected and sketched. From the tree at B, repeated compass bearings on A and this tree, indicated the observer was about 35 yards north of the true line AC. A hand level showed nothing within 100 yards to the south to be any higher than the observer's position, and this verified what had been determined by vertical angles from I. The formerly computed obstruction, B', could now be seen to be at an elevation 60 or 80 feet higher. It was now reasonably verified that the line AC would clear with signals of reasonable height as might have been guessed from I.

METHOD OF "LEAST FAVORABLE" CONDITION

Under certain conditions ordinarily requiring compound profiling, the following short cut may be used provided the relative elevations of the two ends of the line and the distance between them is known. This method has been designated by some engineers as the "least favorable condition" since it gives the maximum possible obstruction to be considered from vertical angles observed on the visible horizon from the two end stations. This is a very rapid method in fairly open country for determining the heights of signals that will be certain to clear the line.

The observations consist only of taking the vertical angles at the end stations on the highest objects that might obstruct the line. With instrument set up at one station the azimuth to the other is laid off by compass or other means, and the vertical angle read on the highest object on the horizon near this line, allowing of course for small errors in the azimuth. This process is repeated at the other end of the line. The point where these two lines of sight, tangent to the horizons, meet will represent the greatest possible obstruction in the line, and if signals sufficient to clear this point are erected, they cannot fail to see each other. However, if the objects to which the vertical pointings are made from the two stations are at considerable distance from each other, the computed signal heights may be greater than the practical limits. The nearer the two objects are together, the more nearly will the computed signal heights represent those actually required to just clear the line. It may happen that the two verticals are taken on the same intervening ridge, hedge, or woods. The observer's judgment as to distance and other factors will of course help him to evaluate the results. It also happens very often that the signal heights computed in this manner are no higher than those known to be necessary for other lines, and further investigation of the line in question is therefore eliminated. This method is particularly suited to two observers working on opposite sides of the scheme.

EXAMPLE OF "LEAST FAVORABLE" CONDITION

The necessary computations are as follows (see fig. 15): The line AB represents the grade line or what would be the line of sight between A and B, in case no obstruction existed. h is the distance above AB

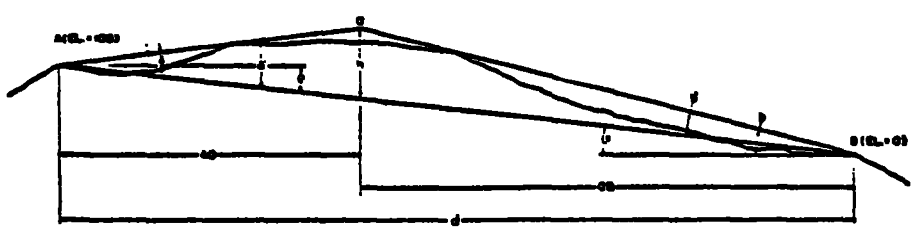

FIGURE 15.—Determination of obstructing height by method of "least favorable" condition.

of the intersections of the two lines representing the observed vertical angles. t_1 and t_2 are the vertical angles between this line and the horizontal planes at A and B, respectively. Since they are due to the combined effect of difference in elevation of A and B, and to curvature, they may be computed by the following formula:

$$t \text{ (in minutes)} = \frac{H-0.574\ d^2}{1.536\ d}$$

in which H is elevation of distant station minus elevation of occupied station in feet, d is distance between stations in miles, 0.574 is the coefficient of curvature, and 1.536 is the chord in feet subtended by one minute at a distance of one mile. The angles are plus if above the horizontal and minus if below.

In the triangle AOB, $a'=a-t_1$

and, $b'=b-t_2$

By approximation (small angles)

$$a':OB :: b':AO$$

and, $AO+OB=d$

By substituting the numerical values of H, d, a, and b, and solving the equations, the values of a', b', AO and OB are readily found. h may then be computed from the formula

$$h=1.536\ a'\times AO, \text{ or } 1.536\ b'\times OB$$

The height of signals at both A and B to clear the maximum possible obstruction, O, is therefore h feet plus height of instrument. In case signals of different heights are desired, they may be adjusted in proportion to AO and OB as outlined elsewhere.

The solution of this problem may appear rather difficult for field use, but it is easily done if a slide rule is used. For example, in figure 15, if $a=+5$ minutes, $b=+8$ minutes, and $d=10$ miles,

$$t_1=\frac{-100-57.4}{15.36}=-10.25 \text{ minutes}$$

$$t_2=\frac{+100-57.4}{15.36}=+2.77 \text{ minutes}$$

$$a_1=(a-t_1)=(5+10.25)=15.25 \text{ minutes}$$

$$b_1=(b-t_2)=(8-2.77)=5.23 \text{ minutes}$$

$$(a'\times AO)-(b'\times OB)=0$$

$$AO+OB=d$$

Substituting, $15.25\ AO-5.23\ OB=0$

$\underline{AO+OB=10 \text{ miles}}$

Solving, $AO=2.55$ miles

$OB=7.45$ miles

$$h=(1.536\ a')\ AO=59.7 \text{ feet}$$

Check, $h=(1.536\ b')\ OB=59.8$ feet

All of the above multiplication and division may be done with sufficient accuracy on the slide rule.

DETERMINATION OF DISTANCE

In the foregoing illustrations, it was assumed that the required distances are known. These may be found by a variety of methods.

SCALING FROM PLOTTED POSITIONS ON MAPS

This is the simplest method for points actually visited and plotted or for those that are already shown on a good map. When a point is visited, the exact location is plotted with reference to such adjacent topographic features as may be shown on the map. If the maps are inadequate in this respect, speedometer and paced distances or compass bearings and intersections from section corners are often used. In nonsectionalized areas, recourse may be had to three-point fixes on tanks, spires, etc., or a speedometer compass traverse may be run in from some known point. Sextant angles on objects known in position are sometimes taken, and even solar observations may be used to determine a rough position.

PARALLAXING, HORIZONTAL BASE

In fairly open country, when circumstances permit, a method called "parallaxing" gives good results with very little labor. This is an application of the solution of a concluded triangle with a short base. It has been developed and perfected by L. G. Simmons, Associate Geodetic Engineer. The procedure is as follows:

The distance and relative elevation of an object not more than 12 miles or so away can be determined in 5 or 10 minutes with an accuracy of about 0.2 mile and 5 to 10 feet of height. No mathematical tables are needed. All that must be known is that the earth's curvature in feet equals 0.574 times the distance squared (in miles) and that an arc of 1 minute is subtended by 1.536 feet at the distance of 1 mile.

In figure 16 it is required to find the distance d from the instrument position at M to an object at P. (The angle at P in this figure is greatly exaggerated.) Select a point N at a distance of s feet from M and at about a right angle from P. Measure angle A; then set over point N and measure angle B. Angle P is equal to B minus A. In other words a distance of s at the observation point subtends the angle P at the distance d of the object observed. The distance d then becomes $s/1.536\ P$, d being in miles, s in feet and P in minutes. The principle involved here is, of course, very simple. Difficulties arise, however, in actually accomplishing this measurement in the field in a reasonable time and with an accuracy sufficient to make the result of any value. It will readily be seen that the instrument must be very accurately centered over M and N and in windy weather this takes considerable time. This centering difficulty may be overcome by selecting a second distant object Q (see fig. 17) at least one-fourth mile distant. This object does not necessarily have to make a right angle with P but may make any angle from say 35° to 145°. The nearer this angle is to 90°, however, the more effective will be the base.

The instrument is now set up over M and sighted toward Q (see fig. 17) and the point N lined up with Q at a convenient distance, perhaps an even 100 feet. Angle A is now measured by sighting on Q and P. Leaving the plates reading angle A, the instrument is set over N and the angle B is "unwound" from P to Q. The angle remaining on the plates is angle P, negative in this case. If angle B

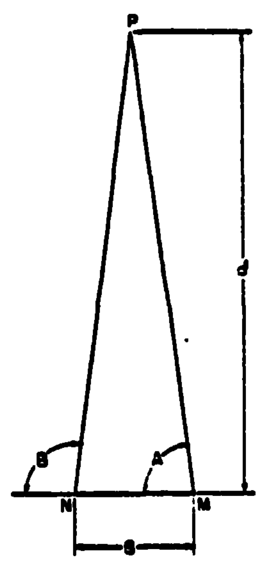

FIGURE 16.—Distance determination by "parallaxing."

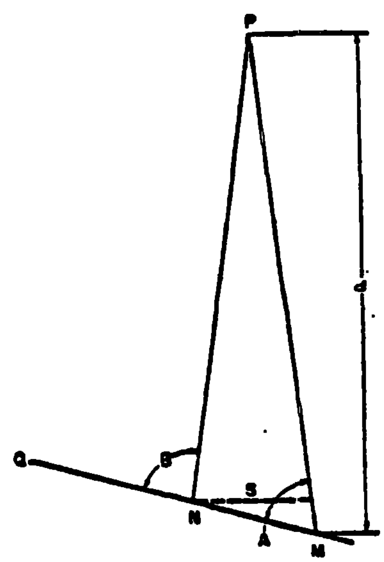

FIGURE 17.—Distance determination by "parallaxing," improved method.

is measured first, then the value P on the plates will be positive after the mechanical subtraction. If a transit reading to minutes is used and the distance d is very great, angle A should be "wound up" three times at M and "unwound" three times at N, leaving a value of $3P$ (negative) on the plates. The 100-foot base (MN) is reduced to the effective base s by multiplying by sin A with a slide rule. If d is about 10 miles, an error in the base of 1 foot will affect the result only about 0.1 mile, and an error of several inches in the alignment of point N, if Q is at a considerable distance, will have no appreciable effect on the result. Point M need not be marked on the ground at all, and N only with a rock or stick until the instrument can be placed over it. No plumb bob is needed, as the instrument can be placed over M and N closely enough by eye. If one man is working alone, the point N can be occupied with the instrument first and M then lined up with N and Q by eye and the desired distance laid off by hooking the tape to the instrument over N and dropping a rock in line at this distance.

For distances d up to about 5 miles, an accuracy of better than one-fourth mile can be determined merely by setting up at M, measuring A, picking up the instrument and pacing 100 feet toward Q and "unwinding" angle B at N. Points P and Q may be any object on which a fine pointing can be made, such as the top of a water tank, the gable of a house, a branch of a tree, or a rock on a hill. A greater accuracy can be obtained by increasing the length of the base, but 100 feet is usually sufficient for distances up to about 12 miles, and is convenient to lay off with a 100-foot tape. The relative elevation of P can easily be determined, of course, from the vertical angle to it, after the distance is known. Many times during the profiling of a line the elevation and distance of an intervening possible obstruction are desired. These can be determined with sufficient accuracy in about 2 minutes of time by the "pacing" method mentioned above.

PARALLAXING, VERTICAL BASE

Any object of known or closely estimated height may be used as a vertical base for rough determination of distance. This method is inferior to the horizontal base method, but is sometimes made necessary by conditions rendering a horizontal base impossible, as, for example, in a wooded country where the view is limited to a narrow opening in the trees. An object such as a barn, windmill, tree, telephone pole, fence post, etc., at the distant ridge is picked out, and the vertical angles observed on the top and bottom of this object. The base may be assumed to be normal to the line of sight and the distance may be computed from the formula

$$d=\frac{h}{1.536(a-a')}$$

in which d is the distance to the object in miles, h is the vertical distance in feet between top and bottom of object, and $(a-a')$ is the difference in minutes in the vertical angles observed.

As an example (see fig. 18) suppose that from A the vertical angle, a, on the base of the barn at B is $-4'$, that a', on the comb of the barn, is $-1'$, and that h is 40 feet. By using the formula we find that

$$d=\frac{40}{1.536(4-1)}=8.7 \text{ miles}$$

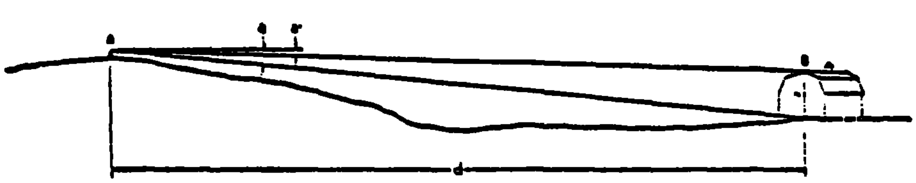

FIGURE 18.—Vertical angle "parallaxing."

If the instrument is equipped with a movable vernier frame, the angle $a-a'$ can be obtained directly without subtraction. Point the telescope on one extreme of the vertical base and with the vernier frame tangent screw set verniers to zero. Then point the telescope on the other extreme of the base, and verniers will read the value of $a-a'$.

The value of h can be accurately obtained only by previous or subsequent measurement. However, for rough results, estimated heights sometimes may be used. A large hay barn is about 40 feet high and a two-story house 35. Windmills are usually of standard heights of from 30 to 60 feet, and may be closely estimated if the panels are counted. An observer soon becomes acquainted with customary heights of such features in the area through which he is working.

Range finders have been suggested at various times for use by reconnaissance parties. However, as now developed, they are too bulky and expensive and too subject to injury to justify their use. If a small convenient type can be developed, it will be very useful, especially in measuring distances from treetops.

LOCATING POSITIONS ON WORK SHEET

A problem that constantly arises in the field is the locating or plotting of points on the map that serves as a work sheet. This must be done for all points investigated and for the points selected as stations. The necessary accuracy will vary but for station plotting it is desirable that the error should not exceed one-fourth mile. The following methods may be used:

If the available maps are accurate and show sufficient detail, the point in question may very often be located with reference to adjacent topographical features. Section lines are very useful and a section line grid can sometimes be made up when no map exists. Positions may be found by speedometer distances from section corners. On the compiled state map of the United States Geological Survey, railroads, towns, and county lines are quite accurately located and afford fair points of reference when more detailed maps are not available. The sectional airways maps of the Coast and Geodetic Survey have many features, especially air beacons, which are plotted with a high degree of accuracy. These maps are available for the entire continental area of the United States.

A distant object may be located from the intersection of instrumental or magnetic azimuths from two or more known positions. An adaptation of this method in sectionalized country is to use the section line roads for base lines and measure the length by speedometer or to use known section and quarter-section corners as base end stations. Quite accurate work can be done in this manner when the base is of suitable length.

Resection, or three-point fix, is the inverse of intersection, and when several objects of known position are visible it may be used to locate the observer's position with a saving of time and truck travel. The solution is practically always a graphical one and is simplified by taking the observations as azimuths, either magnetic or true. Only two known objects are required to fix a position, if their azimuths are known. Azimuth orientation can often be taken from section line roads, buildings, etc.

SPEEDOMETER-COMPASS TRAVERSE

From a known position on the map a fairly good position may be obtained for an unlocated point by measuring distances with the truck speedometer and directions with a hand compass. If the road consists of fairly long tangents the work is not laborious but in cases of very crooked roads it is apt to become so. The method ordinarily used is to stop the truck only at every second change in direction of the road and take forward and backward azimuths with the compass. It is necessary to walk 15 or 20 paces from the truck to get away from its magnetic influence on the compass.

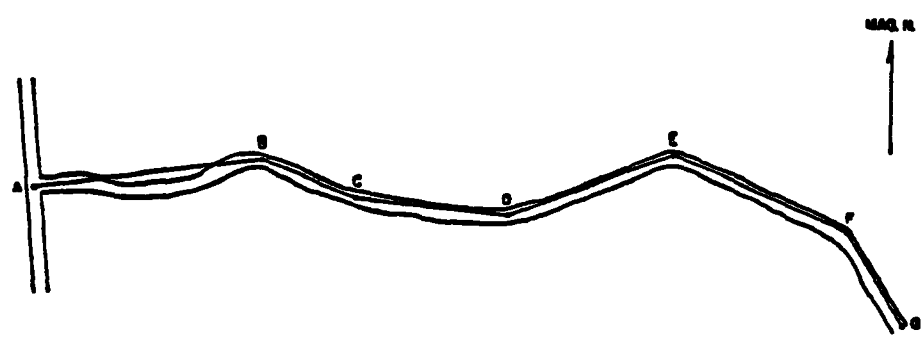

FIGURE 19.—Traverse by speedometer and compass.

In figure 19 it is desired to determine the position of *G* from the nearest known feature, which is a road fork at *A*. Starting with a zero setting at *A*, the speedometer is read at *B*, the point farthest from *A* from which *A* is visible. The truck is then driven 20 yards beyond the turn, and the observer walks back to *B* and reads the compass back azimuth to *A* and to the forward limit of visibility at *C*. The truck is again driven ahead and the speedometer read at *C*. At *D*, the limit of sight from *C*, backward and forward azimuths are read on *C* and *E*, respectively, in the same manner as at *B*. This same procedure is followed until point *G* is reached.

The notes may be kept conveniently as follows:

Traverse notes

Point	Speedometer reading	Distance	Back azimuth	Forward azimuth
A	0			
		0.8	260	(80)
B	0.8			
		.4		106
C	1.2			
		.6	273	(93)
D	1.8			
		.7		78
E	2.5			
		.7½	286	(106)
F	3.2½			
		.4½		160
G	3.7			

The forward azimuths shown in parenthesis are the reversed back azimuths and are listed for convenience in plotting the courses of the various lines.

CURVATURE EFFECT

A factor entering into many field calculations is the correction introduced by the earth's curvature. Combined with the curvature effect is that of vertical refraction which is about one-seventh as large as the curvature effect and opposite in sign. Their approximate resultant is:

$$h \text{ (in feet)} = K^2 \text{ (in miles)} \times 0.574$$

where h is the height in feet that a line horizontal at the point of observation will be above a level surface at a distance of K miles. If h is the known quantity the formula may be written,

$$K \text{ (in miles)} = \sqrt{h \text{ (in feet)}} \times 1.32$$

The following table gives corresponding values of K and h.

Correction for earth's curvature and refraction

Distance	Correction	Distance	Correction	Distance	Correction	Distance	Correction
Miles	*Feet*	*Miles*	*Feet*	*Miles*	*Feet*	*Miles*	*Feet*
1	0.6	16	146.9	31	551.4	46	1,214.2
2	2.3	17	165.8	32	587.6	47	1,267.7
3	5.2	18	185.9	33	624.9	48	1,322.1
4	9.2	19	207.2	34	663.3	49	1,377.7
5	14.4	20	229.5	35	703.0	50	1,434.6
6	20.6	21	253.1	36	743.7	51	1,492.5
7	28.1	22	277.7	37	785.6	52	1,551.6
8	36.7	23	303.6	38	828.6	53	1,611.9
9	46.5	24	330.5	39	872.8	54	1,673.3
10	57.4	25	358.6	40	918.1	55	1,735.8
11	69.4	26	388.0	41	964.7	56	1,799.6
12	82.7	27	418.3	42	1,012.2	57	1,864.4
13	97.0	28	449.9	43	1,061.0	58	1,930.4
14	112.5	29	482.6	44	1,111.0	59	1,997.5
15	129.1	30	516.4	45	1,162.0	60	2,065.8

FORMULA FOR CURVATURE AND REFRACTION

The general formula for determining how much a line of sight between two stations will clear or fail to clear an intervening obstruction is as follows:

$$h=h_1+(h_2-h_1)\frac{d_1}{d_1+d_2}-0.574d_1d_2$$

in which

h =elevation of line at obstruction. in feet
h_1=elevation of lower station. in feet
h_2=elevation of higher station. in feet
d_1=distance from lower station to obstruction. in miles
d_2=distance from higher station to obstruction. in miles

The first part of this formula is a solution of similar triangles. The last term is the curvature (and refraction) correction which has the effect of reducing the height of the line of sight. or conversely of increasing the apparent elevation of the obstruction.

If it is assumed that the two stations are at the same elevation and that the obstruction will be cleared by the construction of signals of equal height, then the above formula becomes simply,

$$h=0.574\ d_1d_2$$

It will be noted that for a given length, K. between stations the elevation required at one station to see the other. across a level surface such as water, is $K^2\times0.574$. The elevation at one end, required to see a similar elevation at the other is $(K/2)^2\times0.574$, or one-fourth that required at one end only. The problem, therefore, generally resolves itself into a determination of the height of equal signals at both ends of the line required to clear the obstruction. For simplicity the signal heights are nearly always computed in this way. and any desired variations are then introduced. Sometimes a higher signal must be specified at one station for some other line than for the line under consideration and this permits a lowering of the other signal. When the obstruction is much closer to one station than the other, it is more economical to build a higher signal at the station near the obstruction, and a lower one at the other signal. other conditions being equal. The amount that one signal may be reduced in height for a certain increase in the height of the other is proportional to the distances of the two stations from the obstruction. Across water. or other level surface, the obstruction due to curvature is midway between the two stations if they are of equal height.

The case often arises that a series of obstructions occurs along a line of sight and it may not be possible to pick out by inspection that one which requires the maximum heights of signals to clear. A lower elevation near the middle of the line, where the curvature effect is a maximum, may require higher signals to clear than a greater elevation near one end. The simplest way to determine the critical obstruction is to compute the signal heights for each one in turn. The following examples will illustrate some typical problems:

EXAMPLES OF CORRECTIONS

Two stations are at water level on opposite shores of a bay 18 miles wide. What is the height of equal signals to make the line of sight graze the surface of the water? According to the formula on page 56, $h=(K/2)^2\ 0.574=(18/2)^2\ 0.574=46.5$ feet. As seen in figure 20,

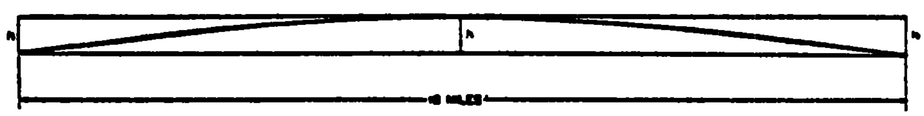

FIGURE 20.—Signal heights for line over water.

h is the distance the theoretical line of sight from the surface level at the two ends passes below the surface at its center. Since the obstruction is equidistant from the two stations, h will also be the required height of equal signals at the two ends needed to clear the line of sight.

In actual practice it is generally necessary to provide a certain amount of clearance over obstructions in order to reduce horizontal refraction. Over water, this clearance should be at least 10 feet, but the clearance required over other obstructions varies with their nature and with the specific conditions encountered. No attempt will be made to specify the clearance in these examples.

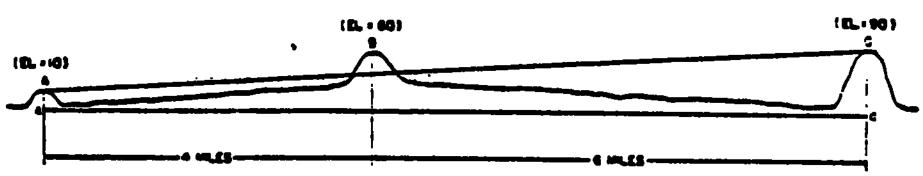

FIGURE 21.—Effect of curvature at intermediate obstruction.

In figure 21 is shown the problem when the two end stations are not at the same elevation and the obstruction is not at the point midway between them. In applying the formula, most observers prefer to determine first the amount of curvature at the obstruction at B, and then add this to the true elevation at that point to obtain an "effective elevation" or "plane elevation" of B, i. e., its elevation above the chord ac. The "effective elevation" of the grade line from the ground at A to the ground at C, where it passes through the vertical of B is next computed by the principle of similar triangles, using the lengths AB and BC. The "effective elevation" of B minus the "effective elevation" of the theoretical line of sight gives the amount of obstruction at B.

From the numerical values given on the diagram, the curvature at B is $4\times6\times0.574=13.8$ feet, the "effective elevation" of B is $80+13.8=93.8$ feet, the "effective elevation" of the "ground to ground" line of sight is $10+[(90-10)\times\frac{4}{10}]=42$ feet, and the amount of obstruction at B is $93.8-42=51.8$ feet.

When nonreciprocal vertical angles are observed on a distant object, its elevation can be computed by the formula:

$$H=H_1+(a\times1.536K)+K^2\times0.574$$

where

H=elevation of distant point in feet
H_1=elevation of instrument telescope in feet
K=distance of object in miles
a=observed vertical angle in minutes

a is plus if the object is above the horizontal plane through the instrument and minus if below it. The factor 1.536 is the length in feet of arc subtended by an angle of 1 minute at a distance of 1 mile. (See p. 40.) The effect of curvature is always positive, making the true elevation of the distant point always greater than its apparent elevation.

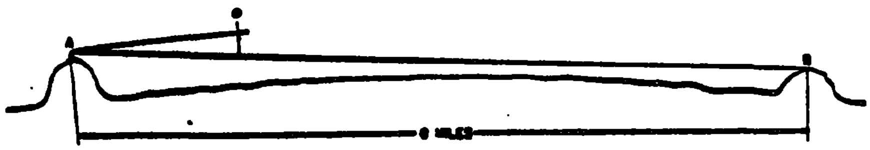

FIGURE 22.—Effect of curvature on apparent height of distant object.

In figure 22 suppose the elevation of the telescope at A to be 100 feet, the observed vertical angle on the ground at B, -3.5 minutes, and the distance from A to B, 8 miles. Substituting in the formula above,

$$H \text{ (of } B) = 100 + (-3.5\times1.536\times8) + (8^2\times0.574) = 93.7 \text{ feet}$$

Conversely, if the elevation of the ground at B is given as 100 feet, and it is required to find the elevation of A, the solution would be as follows: The height of the telescope at A is taken as 5 feet.

$$H \text{ (at } A) = 100 - [(-3.5\times1.536\times8) + (8^2\times0.574)] - 5 = 101.3 \text{ feet}$$

REFRACTION CHARACTERISTICS OF LINES

It is well known that some lines are affected by abnormal horizontal refraction and that good angle closures in the triangles of which they form a side can be obtained only by undue effort and expense, if at all. The reconnaissance engineer should, therefore, endeavor to avoid lines likely to give refraction trouble.

Horizontal refraction is caused by layers or currents of unequally heated air along the line of sight. The varying densities of the air produces a condition similar to that encountered by a beam of light passing through a series of very flat prisms. The light is both refracted and dispersed. These effects cannot be fully eliminated, but the extreme cases can usually be recognized and avoided. The most pronounced cause of this condition is the drainage of large quantities of cool air from higher to lower elevations. Lines passing near the

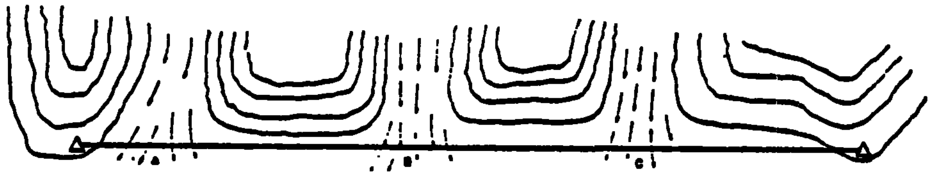

FIGURE 23.—Horizontal refraction due to air currents from ravines.

base of a mountain range or bluff will be affected by air currents flowing down side canyons and ravines. A line passing for some distance near the slope of a large hill or table land will show large horizontal refraction unless the wind is blowing directly against the slope. However, if the slope is the face of a small local hill, or of a ridge narrow in the direction of the line of sight, little difficulty will be found. The kind of cover or vegetation, the range in temperatures between day and night, the direction and velocity of the wind, and the humidity, are all important factors.

A valley through an open plain and bordered by bluffs on either side is a very easy route to span with triangulation but it will almost always give serious refraction trouble. The valley of the Platte River in Nebraska is an example of this kind. When such a condition cannot be avoided, the stations should be placed back on the table lands as far as possible. Lines between headlands and parallel to the valley will give the worst results and should be avoided even at the expense of additional signal building and stations.

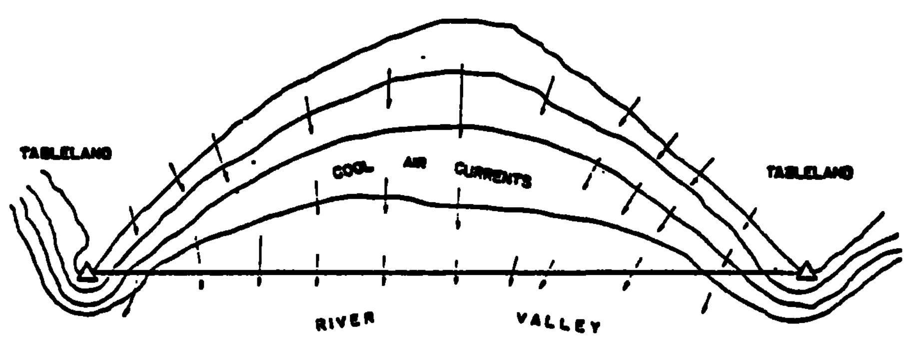

FIGURE 24.—Horizontal refraction due to air currents down slope of hill.

Horizontal refraction is much greater in barren or open country than in wooded areas. Over heavy timber, the effects of air currents are small, and since there is usually considerable difficulty in securing clear lines in such areas, the reconnaissance engineer may generally ignore these effects.

On calm nights there is a tendency of the atmosphere to stratify into layers of different temperature and density. This results in a coefficient of vertical refraction much larger than normal, and tends to lift distant objects above the horizon. This abnormal nighttime refraction is frequently as large as 3 minutes and occasionally may be as much as 5 minutes. A "refraction line" is one that is normally obstructed but becomes visible at night. A study of results indicates that the directions observed over refraction lines are not unduly affected horizontally and their use is sometimes permissible. They should be used only as a last resort, however. On stormy or windy nights the air strata are broken up and the effect of abnormal vertical refraction may entirely disappear. If the air strata are inclined, as is usually the case over sloping ground, there will be a horizontal component of the refraction. Lines should always be kept well clear of bare ground.

CLEARANCE OF LINES

The required clearance of lines of sight over obstructions to avoid excessive refraction and dispersion of the light will vary with the type of vegetation cover and with other physical conditions of the line. The determining factor seems to be the amount of heat transferred to the atmosphere by the ground over which the line passes. Regions combining a bare ground surface with a large diurnal temperature range require the greatest amount of clearance and areas heavily timbered and with a humid climate require the least.

Determining the amount of clearance required for a line is largely a matter of experience. The following are average minimum values.

1. Over water surfaces—10 feet.

2. Over open plains where the sun is hot during the day and the atmosphere dry—30 to 40 feet. This condition is found in the Great Plains area from the Dakotas to Texas.

3. Over cultivated land interspersed with wooded areas—15 to 20 feet. The clearance over trees generally governs in such regions so that the height above ground will usually be ample.

4. Over tree tops—lines may be grazing. Experience has shown that lines grazing over tall trees, or even partially interfered with by the branches, give no trouble. Such grazing lines are, of course, accidental and in specifying signal heights 10 feet is ordinarily considered the minimum proper clearance.

The above figures may be qualified by special conditions. If the obstruction is a narrow ridge, with relatively small capacity for heat radiation, the above clearances may safely be reduced. Conversely, if the line is parallel to the ground practically the entire distance between stations, the clearances may have to be increased. Extremes of heat and drought give special problems. The usual solution under unfavorable conditions is to specify the highest signal that the triangulation party is equipped to build economically.

In computing signal heights reconnaissance parties customarily ignore the effect of the 10-foot superstructure and this gives an added factor of safety. Another factor of safety is that in those regions requiring greatest clearance, the greatest vertical refraction is apt to occur.

AVOIDANCE OF OBSTRUCTIONS

It often becomes necessary to locate stations so that the lines of sight will not pass over obstructions that would require signals of impractical or uneconomical heights. In open country, these obstructions will be visible and the remedy will be evident. In heavily timbered areas, there will often be found blocks of unusually high timber left from logging operations or growing under especially favorable conditions. These blocks must be plotted on the map and care taken to make sure that all lines miss them unless they are located on lower ground. Such areas are frequently found in the sectionalized parts of the United States. Intersections from water tanks and section corners give the best positions of the obstructions. Quite accurate work can be done in this manner, and there are many instances on record where lines have been carried through gaps in extremely tall trees, often not over 50 feet in width, without there being any obstructed lines. To have built high enough to clear these trees might have required signals up to 150 feet in height instead of the signals of moderate height actually used.

MEASURING HEIGHT OF TREES

In wooded regions it is constantly necessary to measure heights of trees. The simplest and most accurate measurement is secured by lowering a tape from the top of a representative tree. Since it is usually necessary to climb the trees for other purposes, the measurement is often obtained without extra effort. A 100-foot steel tape is convenient for making the measurements. If the tension on the reel is adjustable, this may be set to permit the tape to play out by the weight of the descending reel. The zero end of the tape is held in the hand, and the reel allowed to descend to the ground. The free end is then dropped, and when the observer reaches the ground the tape is read at the point where it enters the reel. Stainless steel tapes are apt to snarl when dropped in this manner, so that it is best to attach a weight, such as a binocular case, to the zero end, and play out the tape from the reel until the weight touches the ground and then reel it in before descending the tree. The height of that part of the tree which is above the observer must be estimated and added to the taped height. The heights of trees may sometimes be obtained by climbing some structure near them, and measuring the distance to the ground at the point where the distant horizon becomes visible over their tops.

There are various instrumental and improvised methods of measuring the heights of trees from the ground. The more practical ones call for the use of a small instrument with vertical circle or an inclinometer. A celluloid triangle may be employed for rough measures if instruments are not available. With the theodolite, the usual procedure when the reconnaissance engineer is alone is to fasten the end of a 100-foot tape to the base of the tree, back up to the 100-foot mark, and observe the vertical angle on the tree top. The height of the tree above the telescope axis will be 100 tan a, where a is the vertical angle. This computation may be made on a slide rule or by using a table of natural tangents. The height of the telescope above the base of the tree is added to this computed height to obtain the height of the tree.

The inclinometer is a hand instrument for measuring vertical angles. It may be used in the same way as the theodolite. Another convenient method is to set the inclinometer at 26°34′ (or approximately 26° 30′) and back up from the tree until its top cuts the line of sight. The height of the tree above the eye, is then one-half the distance of the observer from the tree. This may be measured or paced depending on the accuracy required. Of course, if the inclinometer is set at 45°, the height of the tree above the eye will equal the distance from the tree. This angle is somewhat too high for convenience in observing, however.

If only a celluloid triangle with a 45° or 30° angle is at hand, fairly accurate results are obtained by sighting one edge at the base of the tree, and walking back until the other points toward the tree top. The tree height is then computed in the same manner as when a theodolite or inclinometer is used. Some observers lay out a 45° angle on the cover of the record book as a handy means for estimating.

Ground methods have the difficulties that the actual top of the tree is hard to observe with certainty and that in a dense forest it may be impossible to see the top of a tree at the necessary distance from its base. In the first case, the vertical angle will probably be taken on a tangent to the tree top and this will give an excessive height. Of course, in measuring the distance from the tree the end of the tape should be placed vertically under the top of the tree to avoid a serious error. In swampy regions, a good estimate of the height of trees may be obtained by measuring fallen trees. Trees are selected which have fallen from old age, as they represent about the maximum height attained.

SELECTION OF STATION SITES

The final selection of a station site is a compromise of several requirements which are principally: Intervisibility of stations, permanence of marks, strength of figures, wishes of property owners, and accessibility.

Intervisibility of stations is a very important requirement which has already been considered under the topics of curvature, clearance, refraction, etc. The possibility of securing visibility by signal building at optional locations should also be investigated. Of course, the essential lines must be clear and this condition must first of all govern the selection of site.

With regard to permanence of marks no one can accurately predict what changes will occur at a given site over a long period of years, but it is the duty of the reconnaissance engineer to consider the possibilities to the best of his ability. He may be certain of a few things. All main roads will be widened, and the grades will be reduced and curves eased. Most cities will continue to expand for some time at least. Suburban areas will be enlarged and residences will be built on what is now farm land. All main road intersections are desirable sites for gasoline stations and other establishments catering to the motoring public and should be avoided as station sites.

The right-of-way fence of an established highway is a good location, provided the road is of full width. Since triangulation stations are naturally placed on high ground, through which the highway may pass in a cut. the necessity of keeping well back from the centerline can be readily seen. Most States are widening their roads, even the county roads. Michigan and Texas have laid out some boulevards with 300-foot rights-of-way. On the other hand, most railroad property is fairly well-established, and the right-of-way lines are quite permanent. The exceptions are branch lines and electric lines that may be abandoned.

Cultivated land provides a fairly safe location but involves probable damages to crops each time the mark is used and precludes the use of a surface mark. Some landowners will permit the use of a surface mark in cultivated land, but advantage of such permission should never be taken as subsequent owners may think differently. Line fences between farms are often good sites for stations, and signals can be built over them without trouble. Fences between fields, however, are seldom permanent and are frequently removed for tractor cultivation. Consulting the owner about his plans for the future development of his property may be very helpful.

In intensively cultivated sections, some of the best sites are in the vicinity of the farm buildings, or in groves maintained for shade and wind breaks. Over a large part of the country the buildings are generally located on knolls or fairly high ground, so that these locations are often suitable for station sites. Their disadvantages are the greater danger when signals are erected close to buildings, and the difficulties often experienced in placing the azimuth mark where it will be visible from the ground. Public parks and buildings are generally in permanent locations. The grounds of city and consolidated schools are also excellent for permanency. The one-room country schools on the other hand are going out of use and their lots will eventually be subject to cultivation. Small hills that may be worked as gravel pits should of course be avoided.

In mountainous country, it is usually the natural physical conditions that determine the permanence of marks. These conditions include the quality of rock, the amount of frost action, and the rapidity of erosion. Tops of sandhills are often blown away, or marks are engulfed by "blow pits" which may be started by the mark itself. If such localities cannot be avoided, a long iron pipe mark should be specified.

The reconnaissance engineer must give careful consideration to all the various conditions that are apt to affect the station marks. In spite of all possible care, however, some of the marks will be lost. The judicious placing of reference marks will reduce the losses of stations.

In the final selection of station sites, the reconnaissance engineer must sometimes decide whether to accept a weaker scheme in order to obtain a better station site, or vice versa. Both are quite important but of course strength of figure must be maintained within the prescribed limits.

Landowners frequently have preferences as to the location of stations on their property because of future plans, sentimental reasons, etc. Their wishes should be respected if possible both to promote good feeling and also to obtain their cooperation in insuring the safety of the mark.

Accessibility is important both for the party establishing the station and for all subsequent users of it. Unfortunately, the most accessible sites are often the most exposed. It is believed that ease of access should be subordinated somewhat to other conditions affecting the probable life of the mark.

INTERVIEWS WITH PROPERTY OWNERS

The proper approach to the owner of a prospective station site is one of the most important services that the reconnaissance party can render to the triangulation party. Under ordinary circumstances, the property owner should always be contacted in some manner. It is a trait of human nature to be inclined to grant a request but to resent what appears to be the taking of undue liberties. A man who will readily give permission to enter his property may strenuously object to having that right appropriated without his consent, and once committed to that attitude he is likely to stick to it. When first approached he is open to reason but after having suffered a feeling of injury he is apt to close his mind to all argument and to all attempts of reparation. Except in the mountainous and wasteland areas of the United States, the great majority of stations must be placed on private property, usually that of a farmer, who may never have heard of control surveys and may never have had prior contact with Government agencies. In the same way when public lands such as parks, school grounds, rights-of-way, etc., are used it is necessary to see the proper authority, not only for permission but to learn of plans for development and of required safety regulations.

By far the best contact is a personal interview. Most landowners will readily give their permission after a frank and simple explanation of the work and how the various operations will be conducted. The others may be divided into two general classes; the ignorant and suspicious, and the acquisitive. In some cases, argument is useless and it is best to select some optional location. On the other hand, the use of simple explanation and avoidance of salesmanlike tactics may prove effective. The average person is curious and the prospect of seeing something unusual will interest him. He usually takes pride in owning the highest ground in the vicinity and feels a certain sense of importance in having a Government monument on his property, especially if his name is stamped on it. He should be met as an equal and an effort made to impress him with the public value of the marks. A full explanation of the work of the triangulation party should be given and no effort made to conceal any inconveniences or damages that may arise. It is better to stress these rather than minimize them. The Government regulations relating to damage claims should be clearly explained when necessary. A good plan is to estimate the damages for the owner but clearly to make no promises that might be considered binding on the triangulation party. If the owner is not inclined to be fair it is better for the reconnaissance party to find it out and thus avoid trouble later on. It is assumed that the contact man of the building party will again interview the owners before anything is done.

A printed form to be signed by the landowner is not considered advisable on account of the reluctance of the average man to sign any paper presented to him by a stranger. It is better to impress the owner with the fact that he is entering into a gentleman's agreement and that he may expect to be treated as one granting a favor.

Different individuals should be approached by different means and the success of the reconnaissance engineer in this field will depend on his ability to adapt his method to the circumstances.

LETTERS TO PROPERTY OWNERS

In the case of absentee owners that cannot be reached in person, or those not at home when called upon, a letter explaining the work and asking consent should be addressed to the property owner. An addressed return envelope should be enclosed to facilitate the reply. It should be remembered that it is natural for the owner to neglect to reply, hence he should be asked to state any objections he may have rather than to give his permission, the implication being that a failure to reply will denote consent. In practice, the great majority of letters are answered, and answered satisfactorily. The use of official stationery and the evident consideration of his rights create a feeling of confidence on the part of the owner. The letters should not be form letters but should deal with the individual case. Pamphlets or other literature covering the work of the Coast and Geodetic Survey may be enclosed. A sample letter is given below.

Dear Sir: The Coast and Geodetic Survey plans to extend an arc of triangulation between ____________ and ____________ during the coming summer. This work is part of the Government's program of providing precise survey monuments at frequent intervals throughout the State for use in making maps and in improving the accuracy and permanence of existing Government surveys in your vicinity, with which you may be familiar.

In carrying out this work it is necessary to select and mark permanently a number of observation stations located on high ground from which other distant stations may be observed to complete the survey. I have tentatively selected, subject to your wishes, one such station on your land, on what appears to be the highest ground in your neighborhood. I did not find you at home when I called and I am therefore writing you this letter.

The point I have selected is on the summit of the wooded knoll, about one-fourth mile north of your house and 200 yards east of the lane along the west side of the grain field. The exact position is in the small opening, just west of a large oak, and south of the fence crossing the hill.

The permanent marks we wish to leave on your property are of concrete, about 14 inches square, projecting about 6 inches above ground, and bearing the standard Government survey tablets. One of these would be at the point mentioned and two would be in nearby fence lines at such points as may be satisfactory to you. On account of the timber, it will be necessary to erect a temporary steel signal resembling a windmill tower, about 90 feet high on top of the hill. Its purpose is to elevate the observer and his instruments so that he may see out over the trees in all directions. As soon as the observations are completed, it will be entirely removed. It will probably stand for 1 week or less. Its erection will require the digging of three holes, about 3 feet square and 3 feet deep, for the anchors. These holes will be filled when the signal is removed, and nothing will be left on the property except the concrete marks which we wish to be permanent.

It will be necessary to haul this signal to and from the station by truck which would have to follow the fence east from the lane about 100 yards across the grain field. Should our survey party arrive before harvest some damage would be done to your crop. If so, you may expect just and reasonable payment. Before anything is done, a foreman of the signal-building party will call on you and enter into an agreement with you as to the amount of the damages. At various times while the signal stands other men will visit it, some of them at night. These men will be instructed to close your gates, watch out for livestock, and cause no annoyance.

I will greatly appreciate an early reply from you and, if this location conflicts with any plans or wishes you may have, we shall be glad to change it. I enclose for your reply an addressed envelope which requires no postage.

Thanking you, I am,

Very truly yours, ——— ———.

The good will of the public is essential to any enterprise and particularly to one maintained by public funds. All operations, including the final removal of the signal, should be conducted in a courteous manner but the first contact by the reconnaissance party is probably the most important.

DESCRIPTIONS OF STATIONS

The description of station is one of the most important parts of the work of the reconnaissance engineer and represents his finished product, to be passed on to the triangulation party. The modern use of multiple observing parties demands a greater amount of detail and accuracy in station descriptions than was formerly thought necessary.

The description should specify locality, landownership, directions for reaching station, signals and supplies required, and any special information. There are two general forms in use, the straight description, or word picture, and the more recently introduced tabular form. Both have certain advantages and little, if any, preference has been expressed by triangulation parties. The advantages of the former type are that it is more easily read, it forms a mental picture of the site which is more easily retained in the memory, and it is generally more concise than the other. The advantages of the tabular style are that it is more systematic, it gives a double check on mileages, and it is more easily scanned for important directions.

Either type of description should include the following data:

General location with respect to State and county and distances and directions from larger towns or other well known and easily found features.

Location with respect to local features, namely townships, highways, topographic features, section corners with tier and range, etc.

Landownership and whether consent of owner has been obtained with special agreements, if any.

Directions for reaching station starting from sizable towns and adequately describing roads and junctions and stating mileages and including descriptions of alternate routes, if advisable.

Detailed location, with respect to roads, fence lines, buildings, trees, etc., including paced or measured distances and directions and noting special markings as necessary.

Special information such as state of cultivation, arrangements about crop damages, amount of clearing and special type of mark required, seasonal or wet weather restrictions, etc.

Height and type of signal required, and location of supplies.

In mountainous or desert country, information should also be supplied as to camping sites, water supply, and facilities for lightkeeper.

Brevity is desirable but should not be emphasized at the expense of clarity or accuracy. Lightkeepers and sometimes other members of the observing party must frequently go to stations in the night, when people residing in the locality are in bed. The description should make it possible to find the station without recourse to local inquiry. Not only should speedometer distances be given, but forks and junctions should be identified by reference to some local feature such as a house, tree, bridge, etc. To avoid errors in direction at turns, both the direction of the turn and of the new course should be given, as "thence left (west) at crossroads." An error in direction is a frequent source of trouble which is often caused by recording the data on the return from the station, instead of on the approach. To avoid such errors, some systematic check should be used in the notes, such as to invariably face toward the station while recording the directions.

Another source of error is a mistake of an even unit, usually 1 mile, in recording a speedometer distance. It can be detected by comparing the sum of the distances along all courses with the difference between the first and final readings of the speedometer. This error is particularly troublesome in sectionalized country, where the roads are usually 1 mile apart. Many of the trucks in service are not provided with trip odometers, so that all mileages must be obtained by subtracting the accumulated odometer readings. With a trip odometer that may be set to any desired reading, a check is readily obtained. In recording speedometer distances, the effect of errors for speedometer variations over long distances may be minimized if the distance to the station from the nearest fixed detail, such as crossroad or bridge, is given.

A final verification should be made by proofreading the description and checking it against the reconnaissance sketch. If the roads on the latter are drawn to scale, as they should be, a reversed direction can be readily detected.

Under certain conditions, such as are usually found in mountainous or sparsely settled areas, some parts of the description may be stressed or modified. In mountainous regions a description of the adjacent topography, such as a reference to the highest peak, to the end of a long sharp ridge, or to some other natural feature is sometimes very helpful. It is well to give a brief description of the appearance of the selected point, and to record its azimuth and distance from some accessible point.

Pack stations require extra information as to the availability of pack animals, time required for the trip and recommendations as to back-packing or horse-packing. Pack horses are usually not needed unless the distance exceeds 3 miles and if the way is too rugged they cannot be used at all. Such conditions should be noted by the reconnaissance party, together with the estimated time, distance, and difference in elevation of back packs. For some stations, the amount of clearing required, the value and size of trees, and the tools needed should be stated and recommendations should be made as to the desirability of using signals of native timber. A note regarding availability of rocks for marks may be helpful.

Adequate descriptions of stations in wilderness areas are very desirable, but often very difficult to write. These stations are frequently on forested hills or ridges that have no outstanding characteristics to distinguish them from others. The means of approach are generally indirect and directions are easily confused. Under such conditions the reconnaissance party may sometimes resort to trail cutting and blazing. Such work is laborious, but may save the triangulation party much wasted effort. In some very difficult areas, transportation by canoe may be resorted to, and stations may be described by giving the courses along streams or across lakes and by sketching the shore line at landing points from which trails are cut to the stations.

TEMPORARY MARKINGS

The reconnaissance party should be sure that all station sites can be recognized without question by the building party. In well settled districts, this may be done by reference to nearby buildings, fences, trees, etc. Various markings may be used if conditions require them. In the woods, the customary mark is a triangular blaze, which is used to mark the station site and important points along the route to it. On mountain summits, small rock cairns are usually erected. Since many persons visiting mountain peaks build such monuments, they should have some peculiarity, such as a triangular form, and should be adequately described. In prairie regions, a good mark is a triangular trench about 4 feet on the side, cut through the sod, with the soil piled up into a mound inside the trench or beside it. Such mounds and trenches have been found in good condition after a lapse of several years. They will not be confused with an ordinary excavation and the mound will usually be visible for some distance. Sometimes posts and signboards may be used but they are more apt to be destroyed than are the other types of marking.

It has been suggested that all reconnaissance parties adopt some standard form of marking, such as a painted or inscribed stake. Such marks have not been used because they are conspicuous and are more apt to be destroyed. It seems best to use local materials that will not invite destruction by the curious. The number and type of marks should, of course, be such as to insure against loss of station through operations like cultivation, clearing, etc.

It has also been suggested that reconnaissance parties should select locations for reference and azimuth marks. Under certain conditions this appears advisable, but since the azimuth mark must be seen both from the ground and from the tripod head at stations requiring high towers, it is well to await the erection of the signal. Conditions in the vicinity of the station may undergo considerable change, particularly if a period of years elapses between the reconnaissance and triangulation observations and these may make necessary entirely different locations for the various marks. It is believed that, generally, the placing of azimuth and reference marks should be left to the triangulation party.

RECONNAISSANCE SKETCH

The working reconnaissance sketch will contain considerable information beyond the lay-out of the scheme, such as the location of roads to be used by the triangulation party, location of principal geographical points, projection lines, heights of signals, and sometimes rough elevations. It is desirable that the finished sketches be standardized to some extent as outlined below. They should be made on tracing paper or cloth with the aid of drafting instruments.

The maximum size of sketches for convenience of drawing and of use in the field is about 5 square feet, or 16 by 48 inches. For use by triangulation parties, largely on high signals, a larger size would be objectionable. Most triangulation arcs of the Coast and Geodetic Survey are approximately east and west or north and south and are so nearly straight that a narrow width of sketch will usually suffice. For an oblique arc, the size may be reduced by skewing the border to a direction parallel to the arc. If this is done, however, it is best to have all lettering, scales, etc., oriented with the projection instead of with the border. The length of 48 inches will give room for an arc about 175 miles long on the usual scale of 4 miles to 1 inch. An arc this long between fixed connections will not occur often, and the fixed points are convenient limits for the sketch. If two or more sheets are required to cover an arc, it is advisable to make them approximately equal.

The scale may vary in special cases, but for the usual scheme, with figures from 6 to 25 miles across, a scale of 4 miles to the inch is best. The scale should be such as to show necessary detail without crowding and to give lines of sufficient length to use for sighting lamps and heliotropes but not to make the sheet so large as to be unwieldly. The scale should be in units of miles per inch to facilitate scaling the spherical excess. In cases where the standard scale is not suited, it is usual to select one of 2 miles to the inch or 8 miles to the inch. With the latter scale, the Geological Survey state maps may be used in making the pencil sketch and the construction of a special projection avoided.

Reconnaissance sketches do not require a precise projection. For sketches long in an east and west direction, and relatively narrow, a Mercator projection is generally used. If the north and south dimension is the longer one or if the arc is an oblique one an approximate polyconic projection may be used. Precisely drawn projections are not necessary and would be difficult to construct with the drafting facilities available.

Tables and instructions for laying out polyconic projections will be found in Special Publication No. 5, and for the Mercator projection in Special Publication No. 68. Sometimes a projection may be copied from an existing map.

The locations of all roads that may be of use to the triangulation party have been shown on reconnaissance sketches during the past few years, and this information has been found to be very useful. The roads are indicated by relatively thin dashed lines. If existing maps can be copied or the reconnaissance notes contain sufficient information, these roads should be quite accurate as to scale and alignment. Besides being a distinct help to the triangulation party, the road locations serve as a check on the accuracy of the written description. Where there are alternate routes to a station, showing them on the sketch will save detailed reference to them in the description. A symbol should be placed at intervals along the plotted roads to indicate their type. Initial letters may be used, such as "p" for paved, "g" for gravel, "d" for dirt, "sc" for sand clay, etc. Other information such as "heavy sand," or "impassable when wet" may properly be noted on the sketch. Straight roads are drawn with a ruling pen and straight edge, and winding roads with a fine pen, free hand.

During the course of the reconnaissance the observer will note a great many objects such as tanks, spires, stacks, etc., which the triangulation party will later locate by intersection. Very little extra labor is required for the reconnaissance party to locate and identify these on the sketch and to show short lines toward the main scheme stations from which they are visible. If this is done the observing party will be able to include all important intersection stations, even under conditions of low visibility, and to record them under the proper name. The naming of these stations is of especial value when several observing units observe on a station simultaneously, as they will then record it under its proper name. This avoids confusion and the difficulty of identifying intersection stations which are named according to appearance from a distance. The increasing use of air-photographic methods of mapping makes it very desirable for the observing units to locate as many objects as possible. The reconnaissance party can be of considerable aid in accomplishing this end.

Since the correction for reduction to sea level becomes appreciable above an elevation of 1,500 feet, it may be necessary at times to determine roughly the elevations of high stations. Formerly, this was done by triangulation parties by observing vertical angles at all stations but this method is now seldom used because of the time required. It frequently happens that the reconnaissance party can supply elevations of sufficient accuracy which have been obtained by profiling. The profiles may be carried out on sea-level datum if ties can be made to bench marks or other known elevations. The resulting elevations should be noted on the sketch near the station names. Specific instructions will be issued when elevations are required.

In open country, relative elevations of all stations can easily be determined from prominent objects such as water tanks, grain elevators, hills, etc., and in sectionalized country, where all points can be plotted accurately, distances need not be determined but only the vertical angles. One reconaissance party has recently been supplying elevations of all stations after making ties to known sea-level elevations. At times it has been as much as 200 miles between ties, but the elevations have failed only once to check better than 25 feet, and in that case it was only 40 feet.

STANDARD SYMBOLS

It is desirable that the sketches and the symbols used on them be standardized so far as practicable. An equilateral triangle about three-sixteenths inch on the side is used to indicate occupied stations. A triangle with a circumscribed circle is used to denote an established station. A station of another organization connected or incorporated in the scheme is indicated by the initials of the organization after the station name. If an existing station must be occupied eccentrically, the abbreviation "ecc." is given after the name. Intersection stations that are to be marked are indicated by a triangle and other intersection stations by small circles.

Towns and cities are shown by circles varying in size to indicate the size or importance of the place. Small villages are usually designated by a circle about one-eighth inch in diameter; towns up to 10,000 population, by a heavier circle three-sixteenths inch in diameter; cities up to 50,000, by two concentric circles; and cities up to 100,000 by a similar symbol except that the inner circle is solid. Cities over 100,000 population are shown by cross hatching. A recurring feature, such as a fire lookout tower, may be given a special symbol which should be explained in the legend.

Different orders of triangulation are indicated by different weights of line. In any case, the weight should be sufficient to cause the scheme to stand out boldly on the blue print, which must often be used at night with poor lighting. The proper weight for main-scheme lines is about one-thirty-second inch and for secondary lines about one-sixty-fourth inch. Projection lines are usually made about as thin as the ordinary ruling pen will permit. The projection lines are customarily placed at intervals of 15 or 20 minutes of latitude and longitude and may be shown merely as crosses at the intersections, consisting of lines about 1 inch long, or they may be drawn continuously from border to border. The advantage of the latter is that they readily permit scaling the azimuth of any line with a protractor. The lines are numbered only around the border.

Lettering may be free hand or may be drawn with some type of lettering guide. Reconnaissance sketches need not be elaborate examples of drafting but should be complete, legible, accurate, and neat. The letter guides are a great help with the titles but probably are not worth while for smaller letters, particularly if the draftsman has a fairly neat freehand style. Station names should be in capitals about one-eighth inch high placed near the station and always parallel with the parallels. Names of towns should be in lower case from one-sixteenth to three thirty-seconds inch high according to importance.

The title should if possible be placed in some open area so as not to increase the size of the sketch. The customary form is as follows:

UNITED STATES COAST AND GEODETIC SURVEY

LEO O. COLBERT, DIRECTOR

RECONNAISSANCE SKETCH

FIRST ORDER TRIANGULATION

PROJECT G

MICHIGAN

HILLSDALE TO SAGINAW

.... CHIEF OF PARTY

.... ASSISTANT

JULY, 1930

All the lines are in capitals, and are usually made with LEROY lettering guides Nos. 280 to 120, according to the space available and the judgment of the draftsman.

A graphical scale of miles should be drawn in a convenient place. It is usually made about 6 or 8 inches in length. An arrow indicating magnetic north may also be added and the magnetic declination should be given, especially in mountainous and open areas. The compass is not used to any great extent on steel tower work. A border of the smallest dimensions required to enclose it completes the sketch.

PARTY ORGANIZATION AND OUTFIT

The most efficient reconnaissance party is one man equipped with the proper instruments and a light truck. An expanded program of triangulation, however, may necessitate training new men, many of whom may have had no previous experience in geodetic surveying. In general the inexperienced men should be kept with an older engineer and gradually assigned duties of increasing responsibility until they appear capable of carrying on regular work under supervision. They are then sent out alone with their own equipment but required to report daily to the chief of party. As soon as they demonstrate ability to work without supervision, they are assigned a section of the main arc and made fully responsible.

In some sections where mountain climbing or tree climbing are apt to be particularly dangerous, an assistant may be assigned because of the liability of accidents. However, the ability of a man to take care of himself alone should be carefully considered before giving him a reconnaissance assignment.

The following items of equipment should be provided for each party:

INSTRUMENTS

1 theodolite, 4-inch or equivalent.
1 altimeter.
1 binocular, prismatic, 8-power with wide field.
1 compass, azimuth.
1 hand level or declinometer (Abney level).
1 draw telescope, 30- to 35-power.
1 tape, steel or metallic, 100-foot.
1 slide rule, 10-inch, Polyphase.
1 engineers' scale, 12-inch.
1 protractor, 6-inch, full circle, celluloid.
1 set drawing instruments.
1 T-square or straight edge, 24-inch.
3 triangles, celluloid.
1 drawing board, 24 by 30 inches.
1 book, 5-place logarithms.
1 sextant (optional).

GENERAL PROPERTY

1 truck, ½- or ¾-ton capacity, enclosed body.
1 pair lineman's climbers.
1 ax, small, or hand ax, or both.
1 shovel, D handle, round point.
1 prodding bar, 5 feet long.
1 O-bag (canvas bag for record book, small instruments, etc.)

The above list may be modified for specific projects as, for example, one in open country where such items as tree climbers are not needed.

The type of truck usually employed is the ½-ton panel delivery or the sedan delivery. The former has about twice the loading capacity, costs less to buy, and costs about the same to operate. The sedan delivery is somewhat neater and easier to drive. Its disadvantages are small loading space and low clearance. A party working in well settled country and living in hotels can make good use of the sedan type. For more remote regions, or where camping is necessary or desirable, the panel truck will be found preferable.

265164°—41——6

Chapter 3.—SPECIAL PROBLEMS

BASE LINES

A base line can be measured over any ground where the maximum grade between tape ends will not be more than 10 percent. Since the introduction, in 1930, of the four-point tape support for taping on railroad rails, base lines have been located on railroad tangents where-ever possible. This method of support permits the required accuracy by eliminating the tendency of the tape to cling to the rail and thus not be subject to the proper tension. Prior to its introduction, many base lines had been located to one side of railroad tangents in order to take advantage of the cleared right-of-way. An important advantage of the rail base is that it eliminates the necessity for clearing and staking, except for short sections near the end stations. The disadvantages of the rail base are that its location and length are fixed by the track and that in hilly or rolling country it is usually situated in a valley thus tending to complicate the expansion figure. Another disadvantage is that the rail base usually requires offset end stations, but with proper care these will introduce little, if any, error in the length. The bad refraction conditions along a railroad track are largely eliminated by the use of high steel signals which may safely be erected adjacent to the roadway. Careful study on the part of the reconnaissance man will overcome most of the disadvantages and therefore the railroad base should ordinarily be selected if possible.

RAIL BASES

The track for base measurement should be well-surfaced and aligned. A well-kept main line is excellent unless traffic is very heavy. A track with badly battered rail joints should be avoided if possible although experience has shown that good results may be obtained on it by the use of proper precautions. Imperfect alignment usually takes the form of long drifts or bows from a true tangent. The errors introduced by them are surprisingly small. A bow with a middle ordinate of about 30 inches in a kilometer will cause an error of only one part in 1 million and this error can be largely eliminated by computing an approximate correction based on the angle of deflection. However, a track that is full of zigzag kinks is unsatisfactory for base measurement.

If alternate sites are available, it is well to consider all factors such as physical condition of track, number and speed of train movements during daylight hours, and accessibility of the line at frequent intervals, but the actual conditions imposed by the scheme of triangulation seldom permit of much latitude of selection and the reconnaissance engineer will generally be forced to take the only acceptable location available.

Since a base-end station cannot be placed on or too near the rail, it must be located either on the extension of the tangent or on a normal offset from the rail or from the rail extended at a curve. Obviously the two base ends may be of different types. When it is located on the extension of the tangent, the measurement and computations are more simple and less subject to accidental errors and the station may be placed at a safe distance from disturbances due to new track work or on some elevation more easily observed from the main scheme stations. The extension off the track must be carried on stakes and this is an additional expense, but this extra expense should be disregarded if a material improvement can be secured in the base and the base net. At times the extension on stakes is of such length that the base is said to be a combined rail and staked base.

If the base end is on the extension of a tangent, the reconnaissance engineer should carefully project the line and locate the exact spot for the station which should be clearly described. This is important because the triangulation is usually done ahead of the base measurement. If the triangulation building party fails to set the base station accurately, a troublesome offset will be required when the base is measured.

Offset base-end stations are placed approximately at right angles, or normal to the base line, at the termini of the length measured on the rail. The offset should be as short as possible without seriously affecting permanence of mark, clearance of signals, etc. Very frequently the station mark is placed in or near the right-of-way line, but care must be taken that the offset measurements do not present unusual difficulties. The grade on the offset can exceed somewhat the 10 percent maximum set for the base line proper but it should not be excessive even though it may be necessary to locate the station on lower ground and specify a higher signal.

When an offset station is used, a staked line, extending from the station mark to the base line at a distance of three or four tape lengths from the station, is usually measured by the base line party. It provides a closed triangle, all sides of which are measured, and is a valuable check on the accuracy of the connection. The reconnaissance engineer should note the possibilities for such a shunt line and should so locate the base end as to permit this measurement to be made.

Conditions along a railroad sometimes prevent the measurement of a base as a single straight line and a broken base similar to a traverse line between the two ends must be used. The breaks should be kept as few as possible in the interest of accuracy and simplicity. The maximum deflection permissible is 15° but it should be kept well below that if possible. The points of deflection must be visible from those adjacent or from the base end stations without the use of high signals in order to give a closure in azimuth. The breaks in direction will usually be at the points of intersection of curves. If the curvature is slight the points may fall near the rail, or even between the rails, in which case they must, of course, be visible without the aid of signals. The reconnaissance engineer should locate the breaks in direction, or A stations as they are called, adjacent to the base-end stations so that the triangulation party can mark them and make observations on them.

In railroad location, curves are much more frequent in crossing valleys than in crossing ridges. To obtain a tangent of sufficient length for a base, it is often necessary to place the base-ends on relatively low ground and have the middle of the base higher than the two ends. Generally, this presents no great problem as the line of sight follows the cleared right-of-way and it is only necessary to specify signals high enough to clear the ground level and to give sufficient clearance to minimize effects of heat radiation and refraction from the rails. If the base ends are offset stations they may be placed on opposite sides of the track to advantage. Care must be exercised to avoid interference from telegraph lines along the right-of-way.

STAKED BASES

Prior to the adoption of rail tape supports, many base lines were measured on stakes driven alongside railroad tracks. The right-of-way provided a straight, cleared line with no damages to crops. This method can still be used where track conditions render the rail apparatus unsatisfactory and it can also be used along a highway. The stakes may be driven from 4 to 7 feet away from the nearest rail or in position to be outside of switch posts but inside of building lines. Occasionally a good line can be found near the edge of the right-of-way, but usually this is blocked by buildings or cut up by ditches and borrow pits. Along highways, state laws generally prohibit the driving of stakes within the limits of the shoulders.

Railroad safety regulations in regard to clearance are quite rigid. The loading widths and permissible distances of fixed objects from the rail are usually fixed definitely by the individual roads. In general, no objection is made to stakes or blocks on the ties which are not higher than the rail, except at stations and through switching yards.

Generally, a 2-foot stake is permissible within 4 feet of the rail and a higher structure at a minimum distance of 10 feet. Arrangements can sometimes be made to stake and measure through a restricted area in a single day and to remove all obstructions before night. The reconnaissance engineer should invariably interview or write to the proper railway official, usually the division superintendent, and explain fully the plans for the proposed base. Consent to use the right-of-way will practically always be given.

Under some conditions, it will be found necessary to locate a base line away from railroads or highways, where it must be measured on stakes. The maximum allowable difference in elevation between successive 50-meter tape ends is 5 meters. The center support must not be above the grade of the tape ends. Since modern tapes are graduated at 5-meter intervals, any convenient fraction of a tape length, in multiples of 5 meters, may be used. Rough ground, if it will permit these limits to be maintained, is no serious drawback, nor are ravines that may be spanned by a single tape length. Staked base lines are generally straight although breaks are permissible under the same conditions as for rail bases. In locating a staked base, the reconnaissance engineer should actually follow the line throughout its length in order to note any obstructions and to be able to make suggestions regarding any unusual problems that come up. He should estimate the amount of crop damages, if any, and investigate the nature of the soil as affecting the driving of stakes and their stability. The alignment should be tested carefully where obstructions occur along the line and the base ends should be so placed as to avoid these obstructions if possible. It is desirable that the base line be easily accessible by truck at several places. A road paralleling the line or a series of cross roads is very desirable.

BASE NETS

The allowable accumulation of the quantity R_1 between bases or other fixed lines, as stated elsewhere, is 80 for first-order triangulation. This corresponds with 12 to 16 figures, including the base connections, under ordinary conditions. The figure or figures connecting the base line to the main scheme is known as the base net. It is evident that any appreciable loss of strength in this net will reduce the effective permissible distance between base lines.

The ratio of the length of the base to that of the line of the main scheme, to which the base net is connected, is known as the expansion ratio. It should seldom exceed 3. Several factors, including the inflexible condition of intervisibility, govern the selection of stations for a base net. The location of the base line is usually fixed within rather narrow limits and frequently will lie in an area difficult to reach from the main scheme stations. On the other hand, the figures are less restricted as to economical progress through the scheme, overlapping in area, or surplus lines than are regular main-scheme figures. The expansion should be made as simple and with as great strength as possible.

Since the controlling conditions imposed by nature are so different at every base site, it is impracticable to recommend theoretical expansion figures. Advantage may be taken of the method of length expansion by distance angles in combinations of acute and obtuse angles. (See p. 11.) The table on page 10 shows that the length of a triangle, one of whose distance angles is within the range of

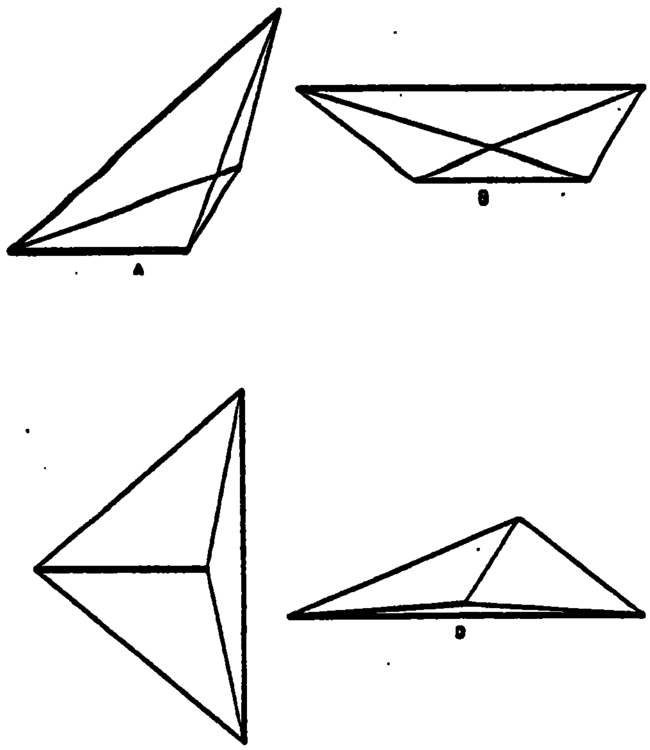

FIGURE 25.—Strong expansion figures, ratio 1 to 2.

35° to 50°, is almost constant with the other distance angle varying over a range of 90° to 130°. For example, a triangle with distance angles of 36° and 124° has an expansion ratio of about 1.41 and a tabular value of 6.6. Two such triangles in series will double the length of the measured base and have a strength of 7.9 if they are combined to form a quadrilateral. There are several ways by which this may be done. (See *A*, *B*, and *D*, fig. 25.) *C* in figure 25 shows a stronger expansion of the same ratio gained by placing the base at right angles to the line to which it is connected. It is believed an observer will be best aided by suggestions found in actual applications to field problems similar to his own, and several such are shown in figure 26.

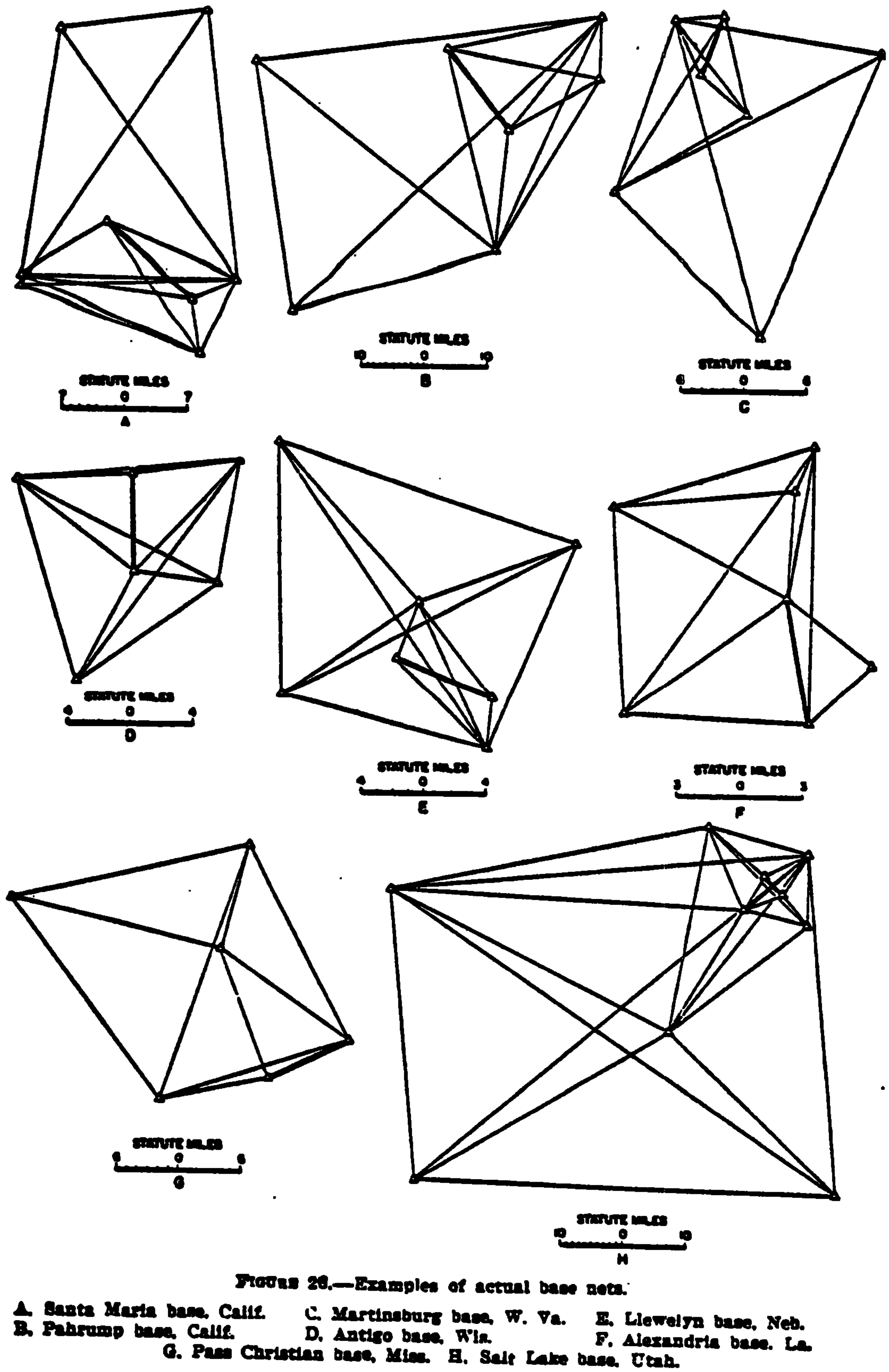

FIGURE 26.—Examples of actual base nets.

A. Santa Maria base, Calif. C. Martinsburg base, W. Va. E. Llewelyn base, Neb.
B. Pahrump base, Calif. D. Antigo base, Wis. F. Alexandria base, La.
G. Pass Christian base, Miss. H. Salt Lake base, Utah.

The reconnaissance engineer should estimate the approximate position of the base required to keep the ΣR_1 within allowable limits well before reaching it. Available maps should be studied for prospective sites and expansion figures. When the site is reached, the net is worked out on the ground exactly as are the main figures. It is sometimes necessary to move the base along the arc some distance in order to find a suitable site. In other cases, an outside figure or short spur to the base site is required. The possibilities of site and the required strength of the net will dictate the expansion ratio and length of base. A long base usually results in a simplified net and is generally to be preferred. The cost of a railroad base 5 miles long is about the same as that of one triangulation station, although an additional station for the base net may not cost as much as a regular main-scheme station.

Most present-day arcs of triangulation are about 10 miles in width. There is little reason for having a base less than half that length. For larger schemes, and especially where a strong net can be worked out, an expansion ratio of about 3 to 1 will be found economical. Occasionally, on a small or moderate sized scheme one of the lines of the regular scheme can be measured as a base and thus eliminate the expansion net entirely by having a base somewhat longer than the ordinary one.

RECOVERY OF OLD STATIONS

One of the duties of the reconnaissance engineer is to recover existing stations to which to connect his work. These are frequently stations of early surveys marked in a variety of ways and the descriptions may be inadequate or out-of-date.

If the original marks are visible, people in the locality can usually point them out. If the surface indications are gone, the recovery often requires much patience and labor. Triangulation stations are ordinarily placed on high ground and in a country of definite relief the highest hill will usually be the site, the immediate vicinity of which can be located from the original description. If the type of soil permits, systematic sounding with a prodding bar may locate the subsurface mark or fragments of the surface mark. When reference and witness marks are noted in the descriptions, some trace of them may be found even for very old stations. A large tree noted in the original description may sometimes be evidenced by a rotting stump or log or by discolored soil. Old signal foundations may be indicated by slight depressions in the surface, by softness of the subsoil, or by penetration of top soil into the subsoil. No digging should be done until all surface indications have been studied. Digging for a subsurface mark over a large area is a large task and there may be objections by the landowner.

Sometimes directions to tanks, chimneys, windmills, church spires, etc., which were observed when the station was established, can be duplicated by trial at the site and a close approximation to the station position thus found. Several subsurface marks have been recovered by the writer by this method after all surface indications had disappeared. In one instance, the directions on four church spires 6 to 15 miles away were duplicated with a 4-inch theodolite and the subsurface mark was found within 18 inches of the point thus determined. If solar observations are used to obtain the azimuths of the lines, it is possible to use this method when only two distant objects are visible.

If a reference mark can be found, not too far from the station, the distance can be taped and the direction determined by magnetic compass. If the distance is fairly large, it can be determined by measuring a short base and two angles as explained on page 50 and the direction can be obtained by a solar observation.

Many old stations were marked with tiles or pottery of various forms. If these marks have been broken, fragments of the materials remain in the top soil almost indefinitely and are of much aid in the recovery of the station. At many old stations broken tile, glass, charcoal, ashes, or other foreign substance was mixed with the soil at the station site. This was an excellent practice and should be revived.

Any digging required to locate a station should be done with care. The subsurface marks at old stations are usually small and fragile, and can be easily broken or displaced by careless digging. For this reason, some experienced man should do the work. Dirt of one depth of the shovel should first be removed and the new surface inspected for foreign materials, voids, soft spots, and discoloration. An old excavation below plow depth will remain soft in most soils for many years, and topsoil penetration into the subsoil is a sure sign of previous disturbance. Such indications will often localize the digging at once. If it be necessary to go deeper, another layer is taken off and investigated in the same manner. Each shovel full of earth should be broken up to see if it contains any fragments or other evidence of the mark. Signs will often be found which will make it unnecessary to excavate the entire area under investigation to the full depth. If there are many rocks in the soil it is necessary to inspect each one before removing it to avoid accidentally destroying the subsurface mark. Sometimes, a little investigation with a knife blade and whisk broom will save a great amount of digging. Some knowledge of the methods used by the party that established the station will greatly aid the reconnaissance engineer and it is also useful to learn if possible how the station was destroyed. The loss of surface markings may be due to local developments, to a fill over the original surface, or to a thorough destruction by vandals.

Cases arise in which it is impossible to recover a station with any reasonable expenditure of effort on the part of the reconnaissance party. It is then permissible to call for a test station in the immediate vicinity of the lost mark. If it appears probable that the subsurface mark may still be in place, the position of the test station may be determined by the triangulation party from the nearest recoverable stations and the distance and direction from the test station to the old station may be found by an inverse computation. The station can almost always be recovered in this manner if there are any remnants at all of the original marks.

A regular reconnaissance description should be written for each recovered station, including a statement regarding the condition of recovered marks, a note covering any irregularities or displacement of the mark, and a recommendation for re-marking if that is necessary. A recovery card should be submitted for every established station visited even though it is not used in the proposed scheme.

CONNECTIONS TO MARKS OF OTHER SURVEYS

Reconnaissance engineers are instructed to make adequate ties to surveys of other organizations in the same area. Such surveys include those of the United States Geological Survey, Corps of Engineers, United States Army, (including Mississippi and Missouri River Commissions, and Lake Survey), General Land Office, Reclamation Service, State Geodetic Surveys, cities and private organizations. The amount of labor and expense to be incurred is left to the judgment of the reconnaissance engineer.

Connections to the surveys of the United States Geological Survey should include one or more position ties to traverse within the the areas of each 15-minute quadrangle sheet, and length, position, and azimuth ties at intervals of 8 to 10 figures to their triangulation, with intermediate position ties if convenient. Since triangulation of the Geological Survey is found only in mountain or open areas, all required ties can usually be made by incorporating their stations in the main scheme or using them as supplemental stations within the figures.

Connections to triangulation of the Corps of Engineers should be made in length, position, and azimuth at points of crossing or intersection. If the new arc is to overlay or parallel triangulation of the Corps of Engineers specific instructions will usually be issued but, if not, length, position, and azimuth ties should be made at intervals of 6 to 10 figures with position ties at intermediate points if convenient.

Connections to surveys of the General Land Office may consist of occasional position ties to section corners to be made by traverse.

Position ties should be made to any special monuments such as those marking base parallels or guide meridians. In some instances special cooperative work has been carried on with the General Land Office.

Surveys of the Reclamation Service are confined to projects. If they are of sufficient extent and are monumented, a length, position, and azimuth tie should be made to them.

During recent years, local control surveys have been carried out in many States under Work Projects Administration auspices, generally by means of traverse. On account of the great variation in quality of these traverses, a position and azimuth tie should be made at intervals of about 10 miles along any line of traverse that lies within reach of the triangulation scheme. Since most of these traverse lines are in the vicinity of cities, where a large number of control stations is needed, the 10-mile intervals should not be considered too costly. Specific instructions will usually be issued concerning connections in this class.

Any city triangulation within the reach of the new arc should have at least one strong connection in length, position, and azimuth. The number of additional connections should be governed by the extent of the city survey and by the ease of accomplishment. Control surveys of private organizations, if of proper accuracy, should be connected in about the same way as city surveys. The desire of the organization for data and its willingness to cooperate should be considered.

If additional stations are needed for connections, the reconnaissance party should consider the signal building requirements, not only from the standpoint of the time required by the building parties to erect the signals but also as to the availability of signals when needed. If more signals are required for any given position of the observing parties than it is possible to build before they are needed, the progress of the observing party will be slowed up. In metropolitan areas, the value of supplemental stations is such that some delay is justified, and in other areas the value of the extra stations will exceed their cost, including the cost of resulting delays. Under average conditions, however, all necessary connections can be made without overtaxing the building parties if careful plans are made. Proper distribution and simplification of the ties will generally give the desired economy. Supplemental and tie stations should preferably be connected to the stations of the main scheme figure within which they lie.

CONNECTIONS TO TRAVERSE

Wherever a line of traverse of the Coast and Geodetic Survey is crossed by the new arc of triangulation, a connection should be made to it. The minimum permissible connection is a single position and azimuth, that is, one station of the traverse incorporated in the triangulation and an azimuth observed from this station to another traverse station. The former may be either a main or supplemental station of the triangulation and the azimuth station preferably one adjacent to it in the traverse, although not necessarily so. (See fig. 27.)

The most desirable connection consists of two traverse stations incorporated in the triangulation with the line between them observed. The two stations need not necessarily be adjacent traverse stations but, if not, an adjacent station should be observed for the azimuth connection. (See fig. 27.)

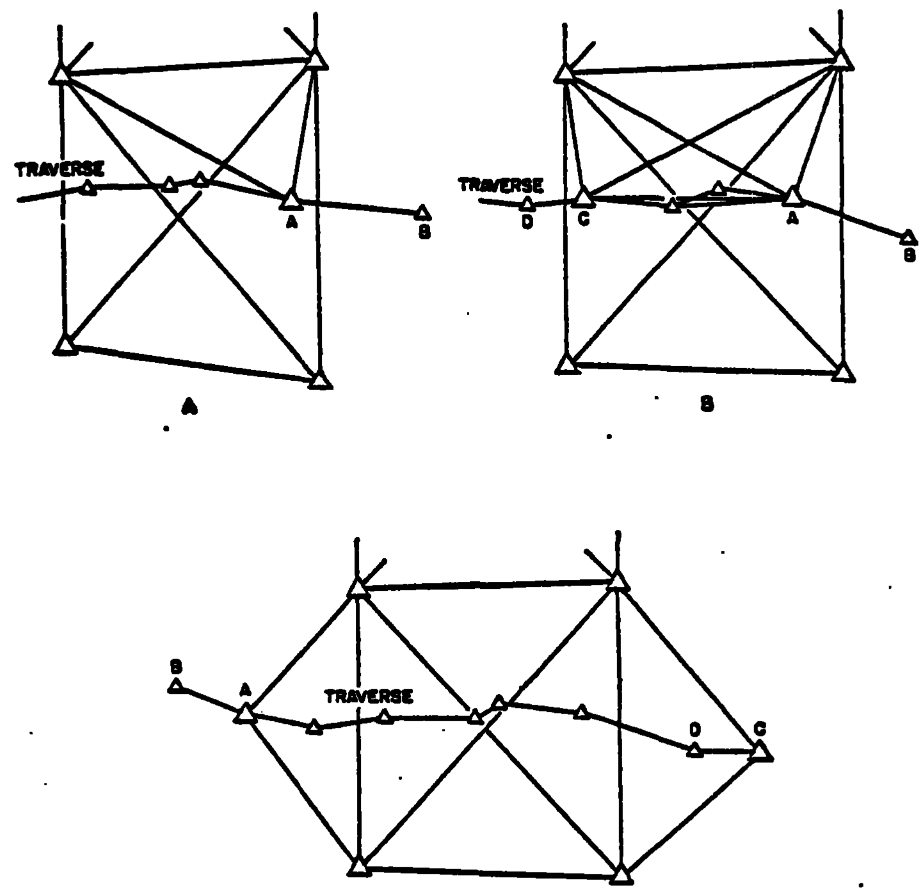

FIGURE 27.—Sample traverse connections.

Since traverse lines usually follow valleys and consist of short lines as compared with triangulation, the above method is often impracticable. As a substitute, two traverse stations may be used as supplemental stations on opposite sides of the triangulation arc, with adjacent stations observed for azimuth connection. This has the advantage of spreading the connection over a considerable length of the traverse and of making a rigid tie in length, position, and azimuth. In case one or both of the azimuth connections cannot be made, the two position ties will orient the traverse in azimuth. (See fig. 27.)

It frequently happens that signals cannot be built directly over traverse stations on account of their proximity to railroad tracks, telegraph wires, etc. It then becomes necessary to use an eccentric point which complicates the accurate connection in azimuth. If proper care is exercised, however, in measuring the eccentricity the connection will be satisfactory and should not be omitted on this account. In any case where the adjacent traverse station is lost, any other one that can be made visible may be substituted.

SUPPLEMENTAL STATIONS

Supplemental stations form an important part of a triangulation arc and will probably receive more and more attention in the future. Such stations are now called for in all towns and cities of over 3,000 population, on the campuses of all engineering colleges and universities, near state highways, and on county lines. Any station established to connect to another survey may be considered a supplemental station for these uses.

An azimuth mark is required at all marked supplemental stations and this requires that they be occupied. A single closed triangle is a permissible connection for a supplementary station although a third line is desirable. If possible, all supplemental stations should be connected to one figure only of the main scheme or to adjacent lines only of two adjoining figures. Intersection stations may be connected to nonadjacent stations and depend on an inverse position computation provided no better tie is possible.

Ordinarily the location of the additional stations depends on the judgment of the reconnaissance engineer. The same conditions govern their selection as for main scheme stations. It is desirable to obtain a fairly uniform distribution of the stations over an area except where special conditions or needs make additional stations desirable. In sections not covered by quadrangle sheets, a supplemental station placed near the corner of four future quadrangles will greatly aid in controlling the topographic mapping.

Since supplemental stations will seldom be used for carrying forward length and position, somewhat weaker figures than those of the main scheme are permitted for reasons of economy. The R_1 for any supplemental figure should seldom exceed 15, however, and stronger figures are, of course, desirable.

STATIONS ON BUILDINGS

Occasionally it is found desirable to place either a main scheme or supplemental station on the roof of a building. Experience indicates that observations taken from good solid structures are fully satisfactory. The use of buildings is often necessary in carrying triangulation through a metropolitan area where the height of obstructions exceeds that of available signals and in extending spurs into the business districts of cities. In some cases the building site may be of great convenience to local engineers.

The disadvantage of stations on buildings is principally lack of permanence. The life of a city structure of the best class is seldom over 50 years and during its life it is subject to alterations and repairs that may destroy or obstruct the station mark. On the other hand, it is often possible to transfer the position and azimuth to street level where they will be reasonably safe. A building affords a point of vantage for extending city triangulation and city surveyors will often take considerable care to protect and preserve such a station. Buildings should usually be avoided as sites for stations of the main scheme but are quite satisfactory for stations primarily for use in the control of a city area.

The best type of structure is the modern steel-frame office building. Modern buildings generally have roofs of sheet lead or of concrete covered with asphaltum. The roof is nearly always surrounded by a parapet wall 4 feet or more in height and there will usually be superstructures such as elevator houses and chimneys. The station must be carefully placed if it is to clear all lines and one or more eccentric set-ups will sometimes be necessary. On roofs of the sheet metal type the regulation disk mark cannot be set and the station is usually marked by a small cross in the metal and referenced to standard reference marks set in the parapet coping. This is easily done if the coping is of stone but if of terra-cotta some smaller type of reference mark should be specified. Permission can usually be obtained to set the standard station mark in a drill hole in concrete roofs. It is then sealed by pouring melted tar over it and will usually be good for the life of the building. Reference marks may be set in the same manner on the coping. Measurements to walls, angles, etc., will make it easy to recover the marks hidden by the tar.

In selecting the location of the mark on a building, consideration should be given to the problem of transferring it to ground level since only in that manner can the position be used for starting traverse.

The parapets and superstructures on some buildings are such as to require scaffolds to secure visibility. These should be avoided if possible both on account of damage to the building and of the danger of objects falling overside.

BOUNDARY SURVEYS

Triangulation is being used to an increasing extent in the surveys of boundary lines, and when triangulation control points become available in all localities it is probable that this method will supersede older methods entirely. The triangulation method consists in determining the positions of points along an established line or in demarking on the ground a given geodetic line. For the latter, triangulation stations are placed near the line and, after their positions are determined, computed offsets are measured to the true line. The reconnaissance party must determine a random line sufficiently close to the true line to make these offsets of convenient size. The stations near the boundary may be either main scheme or supplemental stations. The main scheme arc may be made to straddle the boundary with supplemental stations at intervals along the line inside the main figures, or if conditions permit the stations on one side of the main arc may be placed along the boundary, with additional supplemental stations in the intervals between them. A saving up to 25 percent may be made by the latter method, and the accuracy will be improved. In some cases the main arc may follow a line of least resistance on one side of the boundary and the supplemental stations needed to control the boundary will then be outside the main scheme.

NAMING STATIONS

The reconnaissance party assigns a name to each station selected in order to identify it. Although the triangulation party is authorized to change the name, it seldom does so. Care should therefore be used in selecting a suitable name.

Perhaps the best name is that of some geographical feature or political subdivision at or near the station. If the station is on the summit of some well-known mountain or hill of recognized name, it may be given that name. If it is on a bluff overlooking a river it may be given the name of the river. Similarly, it may be given the name of some nearby town, church, or school, or of the township or county in which it is located. Duplicate names must not be used within a county and preferably not within a State. Many geographical names are too long and unwieldy for use, but abbreviations for brevity are not very satisfactory. The best name is one which will instantly associate the station with a well known feature in its vicinity and an abbreviated name usually fails to do this.

In many cases, the name of the landowner is given to the station. The advantages of this are that it naturally stimulates interest on the part of the owner, provides sufficient variety to avoid duplication, and serves to make the station easy to locate quickly from inquiry in the neighborhood. The disadvantages are that if the land changes hands the name will differ from that of the new owner and that in some cases a part of the marks will be on adjacent property, the owner of which will have a different name. This may seem of minor importance, but

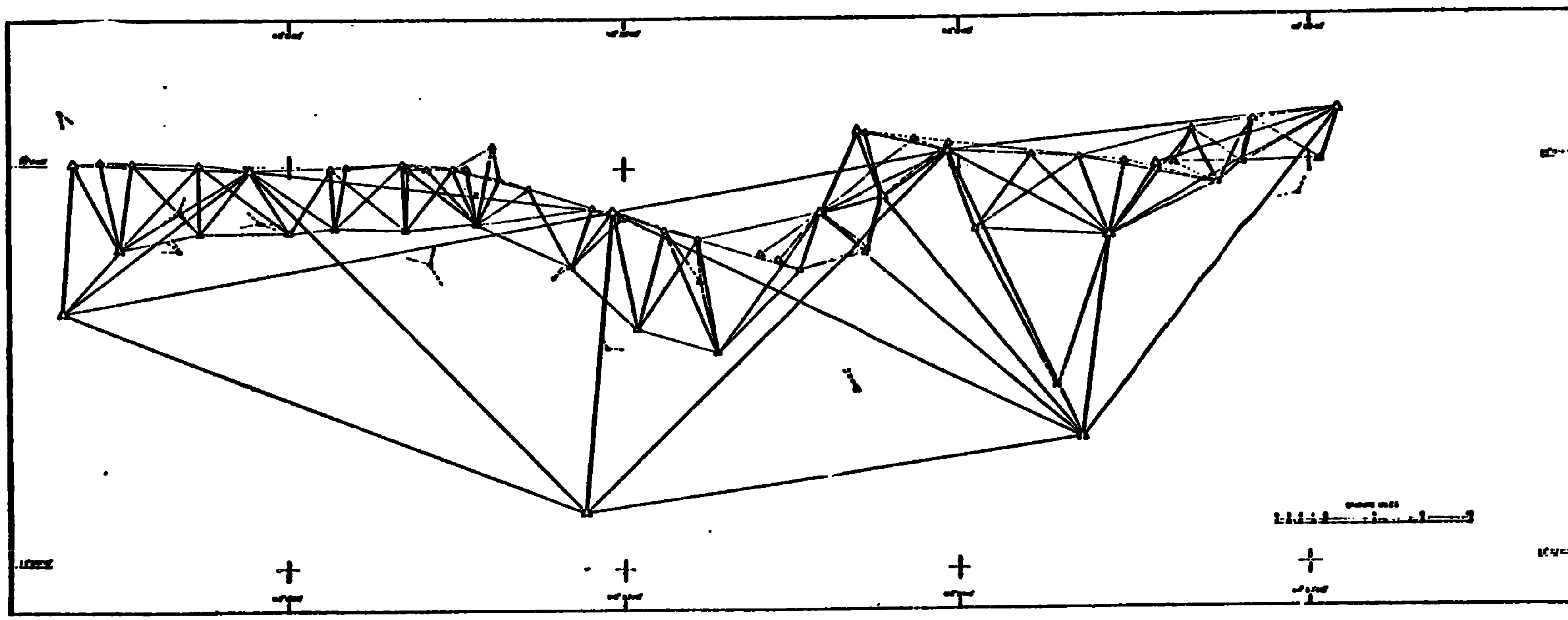

FIGURE 28.—Boundary survey, Maricopa—Yavapai Counties, Ariz.

jealousy between neighbors frequently results in a request for change of name. A tenant may claim ownership and arouse resentment in the landowner when he finds the mark named for his tenant. In a great many cases, however, the owner's name is the only suitable one that can be found and it must be used in spite of the disadvantages. Often a farm will have a recognized local name derived from some former owner, as the "Old Bradley Place." In this case, the name "Bradley" may properly be given to the station if the present owner does not object.

Facetious names should be avoided. The use of names of men on the party, particularly informal or nicknames, should be avoided for obvious reasons. Monosyllabic names without meaning, especially when in a series formed by the variation of one letter such as "Don," "Dot," "Dow," etc., serve as poor identifications. Irrelevant names arising from some minor incident, such as "Flat" for the name of a station at which the reconnaissance truck had a flat tire, or "Mud" because of a strictly temporary condition, should not be used.

The name should serve not only to identify the station but also to suggest its location. Brevity is desirable but if a longer name is required properly to serve the purpose it should be used. Care should always be taken to see that the name is spelled correctly. Geographical names should be accurately derived and personal names should be verified. Many proper names of the same pronunciation are spelled quite differently, as "Schneider" and "Snyder." A misspelled name is apt to cause confusion.

INDEX

265164°—41——7