Serial No. 142

DEPARTMENT OF COMMERCE

U. S. COAST AND GEODETIC SURVEY

E. LESTER JONES, Director

GENERAL INSTRUCTIONS

FOR THE

FIELD WORK OF THE U. S. COAST AND GEODETIC SURVEY

SPECIAL PUBLICATION No. 26

SECOND EDITION

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CONTENTS.

TRIANGULATION.

3. Classification of triangulation.—Triangulation in the United States Coast and Geodetic Survey is divided into three classes:

4. Precise triangulation.—Triangulation which has an accuracy represented by an average closing error of a triangle of about one second with all stations occupied. It is to be used in extending arcs over long distances. The network of arcs of precise triangulation constitutes the bases from which secondary and tertiary triangulation are extended. The general instructions for precise triangulation, reconnoissance, and base measurement are given in Appendix 4, Report for 1911, and in Special Publication No. 19.

5. Secondary triangulation.—Triangulation which has an accuracy represented by an average closing error of a triangle of between two and three seconds. Some of the stations need not be occupied. This class of triangulation is usually employed when carrying the control from precise triangulation to the locality where topographic, hydrographic, boundary, and other surveys are to be made. Such distances are comparatively short, usually less than 100 miles. In the Philippine Islands the main scheme of triangulation is secondary in character. The general instructions for secondary triangulation are given below.

6. Tertiary triangulation.—Triangulation of an accuracy represented by an average closing error between three and five seconds. The coast triangulation of the Survey is of this character and is used for the immediate control of topographic and hydrographic surveys. At intervals along the coast the tertiary scheme is controlled by secondary and even precise triangulation. All triangulation done by United States Coast and Geodetic Survey parties or vessels along the harbors and rivers of the United States, Alaska, Philippine Islands, or other coasts under the jurisdiction of the United States will be tertiary in character unless special instructions designate another class.

7. If it is found impracticable on account of the physical conditions or lack of time to obtain the accuracy in the triangulation called for by these general instructions or by special instructions, the chief of party will make a special report to the office calling attention to the discrepancies and the conditions causing them. In the Philippines such report will be made to the Director of Coast Surveys.

8. The instructions which apply only to secondary triangulation are given in paragraphs 10 to 21. Complete instructions are given for tertiary triangulation. Some of these apply also to secondary triangulation, and a reference to them is given in paragraph 22.

9. The instructions for observation of vertical angles are given in paragraphs 112 to 138 and are to be followed in both secondary and tertiary triangulation.

SECONDARY TRIANGULATION.

10. Character of figures.—The chain of triangulation between base nets shall be made up of figures of from four to seven points each, in which certain stations may be left unoccupied, as indicated in paragraph 25. It may be allowed to degenerate to single triangles in exceptional cases where otherwise the cost and time would be excessive. There must be no overlapping of figures, except that in a four-sided central-point figure one of the diagonals of the figure may be observed, and no excess of observed lines beyond those necessary to secure a double determination of every length. If it is necessary to occupy other stations than those in the main scheme, in order to fix certain positions which are required by instructions to be fixed, connect these additional occupied stations (which will be called supplementary stations) with the main scheme by the simplest figures possible in which there is a check and preferably by single triangles with all angles measured.

11. Strength of figures.—This is the same as for tertiary triangulation. (See pars. 25 to 42.)

12. Length of lines.—The lower limit of length of line is fixed by two considerations. On very short lines it is difficult to get observations of the degree of accuracy necessary to close the triangles within the required limit. Very short lines are apt to be accompanied, though not necessarily so, by poor geometric conditions as expressed by large values of R. (See par. 25.) Past experience in precise triangulation indicates that observations over a line 6 kilometers long are of practically the same accuracy as over the longest lines, and that there is no advantage, in so far as accuracy in the measurement of the angles is concerned, in making the line much longer than this. The lower limit for secondary triangulation is probably considerably below this. Therefore endeavor, in laying out the main scheme, to use the economic length of line; that is, endeavor to use in each region lines of such lengths as to make the total cost of reconnoissance, building, triangulation, and base measurement a minimum per mile of progress, subject to the limitations stated in these instructions. If the economic length of the line is very great, then supplementary or intersection stations must be introduced to meet the needs of those who may wish to start other triangulation from the scheme.

13. Frequency of bases.—The requirements are identical with those for tertiary triangulation (see par. 44) except that the ΣR_1 must be reckoned between measured bases or one measured base and a line of precise triangulation. Also the discrepancy between bases must not exceed 1 part in 10 000 instead of 1 part in 5000, which is the requirement for tertiary triangulation.

14. Base sites and base nets.—Follow the direction given under tertiary triangulation, paragraph 45.

15. Base measurements.—In the base measurements such apparatus and methods should be used as to insure that the constant error does not exceed 1 part in 75 000 and that the accidental errors are not greater than that represented by a probable error of 1 part in 200 000 in the length of the base. No difficulty will be encountered in keeping both classes of errors far within these limits, even when the base is over very rough ground, if it is measured twice with invar base tapes properly standardized. The required accuracy may be obtained by making the measurements with steel base tapes if the work is done at night or on cloudy days and provided the tapes have been well standardized. All of the base tapes of this Survey are standardized at the Bureau of Standards.

16. The method of measurements, form of record, and of computations are given in paragraphs 47 to 55. Base measurements with tapes are described in some detail in the following publications of this Survey: Appendixes 8, Report of 1893, 3 of 1901, 4 of 1907, 4 of 1910, and Special Publication No. 19.

17. Horizontal angle measurement—Standard of accuracy.—In selecting the instrument to be used, the methods of observation, the signals to be used, and the conditions under which to observe, proceed upon the assumption that what is desired is the maximum speed and minimum cost consistent with the requirement that the closing error of a single triangle in the main scheme shall seldom exceed 6 seconds and that the average closing error shall be between 2 and 3 seconds. The observations connecting supplementary stations with the main scheme should be of this same degree of accuracy. This standard of accuracy used in connection with other portions of these instructions defining the necessary strength of figures, frequency of bases, and accuracy of base measurements, will, in general, insure that the probable error of any base line (or line of precise triangulation used as a base) as computed from an adjacent base (or line of precise triangulation used as a base) is about 1 part in 35 000 and that the actual discrepancy between such bases is always less than 1 part in 10 000.

18. Selection of instruments.—Either a direction or a repeating instrument may be used in triangulation of this class. In selecting the size of instrument to be used two opposing factors must be taken into account. If small, light instruments are used and if sun and wind shields are not used, then the weight of the outfit which it is necessary to take to a station will be light, and the cost in time and money to transport the observing party and its outfit will not be large. On the other hand, the larger and better the instrument, up to the limit of the best theodolite available, the more fully it is protected from the sun and wind and the more stable the support provided for it the smaller will be the number of observations necessary to secure the required degree of accuracy and the shorter will be the observing period at the station.

19. Observations in the main scheme with the direction instrument.—An 8-inch direction instrument (No. 140, for example), used on its own tripod and protected from sun and wind simply by an umbrella, will give the required accuracy with from 5 to 10 measures, a direct and reverse reading being considered 1 measurement. This is the type of instrument recommended for secondary triangulation. Five positions of the circle should be used, corresponding approximately to the following readings on the initial signal: No. 1, 0° 1′; No. 2, 72° 3′; No. 3, 144° 5′; No. 4, 216° 7′; No. 5, 288° 9′.

The minimum number of measurements shall be 5, 1 in each position, and the maximum number 10, 2 in each position, unless it shall be found that under particular conditions encountered a larger number is necessary to secure the required degree of accuracy. The backward (additive) reading of the micrometer only should be taken in each position of each microscope. At least once a month a few special readings both backward and forward should be taken on various graduations of the circle to determine the run of each micrometer and placed in the record as a test for run. If the average value of the run for either micrometer is found to be greater than two divisions (= 4 seconds), the micrometer should be adjusted for run. Under these conditions and with the specified positions of the circle the run will be eliminated from the results with sufficient accuracy by the process of taking means. For any other direction instrument the system of positions to be used must be selected with reference to the number of measurements found to be necessary.

With any direction instrument when a broken series is observed the missing signals are to be observed later in connection with the chosen initial, or with some other one, and only one, of the signals already observed in that series. With this system of observing no local adjustment is necessary. Little time should be spent in waiting for the doubtful signal to show. If it is not showing within, say, 1 minute when wanted, pass to the next. A saving of time results from observing many or all of the signals in each series, provided there are no long waits for signals to show, but not otherwise. When the elevations of the stations differ greatly, it is necessary to keep the horizontal axis of the instrument level in order to avoid large and troublesome errors. The magnitude of these errors for various conditions is shown in the following table. Of course, releveling should only be done between positions. (For form of record, see par. 62.)

Corrections to directions for inclination of the horizontal axis of the direction instrument or theodolite.

Inclination of the horizontal axis. (i)	Vertical angle of the line of collimation. (h)	Correction to horizontal direction. ($i \tan h$)
″	′	″
10	20	0.06
20	20	0.12
30	20	0.17
10	40	0.12
20	40	0.23
30	40	0.35
10	60	0.17
20	60	0.35
30	60	0.52

20. Observations in the main scheme with a repeating instrument.—A 10-inch Gambey repeating theodolite, used on its own tripod and protected from sun and wind simply by an umbrella, will give the required accuracy with from one to two sets of observations. This is the type of repeating theodolite recommended for secondary triangulation. A set of observations should consist of six repetitions of the angle with the telescope in the direct position and six repetitions of the explement of the angle with the telescope in the reversed position. The method used in making a set of observations is as follows: Set the circle approximately at zero and record the initial reading. Point on the left-hand object by means of the lower motion and then unclamp the upper motion and point on the right-hand object. Record the approximate reading of the circle. This completes the first repetition of the angle. Next loosen the lower motion and point again on the left-hand object, then unclamp the upper motion and point again on the right-hand object, and so on. A careful reading of the circle must be made and recorded after three repetitions of the angle and again after six repetitions. Next reverse the telescope about the horizontal axis and by means of the lower motion repoint on the right-hand object. Then loosen the upper motion and point on the left-hand object. This constitutes one repetition of the explement of the angle. After six repetitions of the explement the instrument should be back very nearly to the initial setting. The circle should then be carefully read and recorded as before. (See sample record in par. 65.) Slightly change the setting of the circle at the completion of each set of observations and make an entirely independent reading for the initial of the next set. When two or more sets of observations are made on the same angle the initial setting for each set should differ by an amount approximately equal to 180° divided by the number of sets. For example, if an angle is to be measured with two sets of observations, the initial settings should be about 90° apart; if with three sets, 60° apart, etc. If some of the stations observed upon are much higher or lower than the station occupied, it is necessary to keep the horizontal axis of the instrument level, in order to avoid large and troublesome errors. (See table above.) With any repeating theodolite measure only the single angles between adjacent lines of the main scheme and the angle necessary to close the horizon. In the comparatively rare case in which the failure of adjacent signals to show at the same time prevents carrying out this program, make as near an approach to it as possible and then take the remaining signals in another series together with some one, and only one, of the signals observed in the first series, and measure in the new series only the single angles between adjacent signals and the angle necessary to close the horizon. With this scheme of observing, no local adjustment is necessary, except to distribute each horizon closure uniformly among the angles measured in that series. If an attempt is made to use 7-inch repeating theodolites on triangulation of this class, it may be found necessary to make three sets of observations as defined above. (For a form of record of observations with a repeating theodolite, see par. 65.)

21. Observations on intersection stations.—An intersection station is one which is not occupied and whose position is determined by observations upon it from stations of the main scheme, or from supplementary stations. If a direction theodolite is used, one such measurement as is outlined in paragraph 19 must be made on each line to each intersection station. A second such measurement should be made if this can be done without materially delaying the progress of the work. Each series of observations on intersection stations with a direction instrument is to contain some one, and only one, line of the main scheme (or a line used in fixing the position of a supplementary station). If a repeating theodolite is used, the direction to each intersection station is to be fixed by measuring the angle between it and a line of the main scheme (or a line used in fixing the position of a supplementary station) by one set of observations consisting of three repetitions upon the angle with the telescope in the direct position and three repetitions upon its explement with the telescope in the reverse position. No measures introducing station conditions are to be made on intersection stations. It is important with either form of theodolite to have lines to each intersection station from at least three occupied stations in order to secure a check, but a possible intersection station should not be neglected simply because only two lines to it can be secured.

22. *Paragraphs 56 to 58 and 69 to 111 also apply to secondary triangulation, and all persons engaged on that work will comply with the directions given.*

TERTIARY TRIANGULATION.

23. Character of figures.—The main scheme of the triangulation shall be made up of figures of from four to seven points each, in which certain stations may be left unoccupied as indicated under paragraph 25, "Strength of figures." It may be allowed in exceptional cases to degenerate to single triangles with all angles observed where otherwise the cost and time would be excessive. On the other hand, there must be no overlapping of figures, except that in a four-sided, central-point figure one of the diagonals of the figure may be observed, and no excess of observed lines beyond those necessary to secure a double determination of every length. Observations over lines which will make the main scheme any more complicated than that defined above would practically be wasted. The main scheme should be extended to within sight of all portions of the area to be controlled by the triangulation. If it is necessary to occupy other stations than those in the main scheme in order to reach by intersection certain stations which must be fixed to control hydrographic or topographic operations, connect these additional occupied stations (which will be called supplementary stations) with the main scheme by the simplest figures possible in which there is a check. Single triangles with all the angles measured will, in general, be sufficient for the purpose. It frequently happens that tertiary triangulation stops at a place from which it is probable that it will be extended at some future date—as, for example, at the head of a bay or part way up a river. In such a case it is desirable to stop on a line rather than a point, and the last figure should be quadrilateral with one point left unoccupied rather than a single triangle.

24. In the coast triangulation in the Philippine Islands the stations are usually located near the coast and on off-lying islands or on the first foothills back from the coast.

25. Strength of figures.—In the main scheme of triangulation the value of the quantity $R=\left(\frac{D-C}{D}\right)\Sigma\,[\delta^2_A+\delta_A\delta_B+\delta^2_B]$ for any one figure must not in the selected best chain of triangles (call it R_1) exceed 50, nor in the second best (call it R_2) exceed 150 in units in the sixth place of logarithms. These are extreme limits never to be exceeded, except when it is extremely difficult under existing conditions to keep within them. Keep the quantities R_1 and R_2 down to the limits 25 and 80 for the best and second best chains, respectively, whenever the estimated total cost does not exceed that for the chain barely within the extreme limits by more than 25 per cent. The values of R may be readily obtained by use of the "Table for determining relative strength of figures." (See paragraphs 26 and 27 for this table and explanation of formula for R.) One station in each figure may be left unoccupied whenever to do so does not increase the values of R beyond the specified limits. In a figure in which all stations are occupied, if any interruption (as, for example, the failure of a signal to show) makes it probable that such a procedure would save considerable time, certain lines not exceeding three may be observed over in one direction only. In such a case R_1 and R_2 shall be computed as if one outside station of the figure had been left unoccupied, and the value so computed must not exceed the specified limits. For no triangle used in connecting a supplementary station with the main scheme should the value of R be greater than 50.

26. 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	26	22	18	15	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	15	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	43	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	76	59	48	42																		
164	109	79	63	54																			
166	113	86	71																				
168	122	98																					
170	143																						

27. In the table above the values tabulated are $\delta_A^2+\delta_A\delta_B+\delta_B^2$. 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 sine differences corresponding to one second for the distance angles A and B of a triangle.

28. The square of the probable error of the logarithm of a side of a triangle is $\frac{4}{3}(d^2)\frac{D-C}{D}\Sigma[\delta^2_A+\delta_A\delta_B+\delta^2_B]$ in which d is the probable error of an observed direction, D is the number of directions observed in a figure, and C is the number of conditions to be satisfied in the figure. (See Wright and Hayford's Adjustments of Observations, 2d ed., pp. 168 and 169.) The summation indicated by Σ is to be taken for the triangles used in computing the value of the side in question from the side supposed to be absolutely known.

29. In the above formula the two terms $\frac{D-C}{D}$ and $\Sigma[\delta^2_A+\delta_A\delta_B+\delta^2_B]$ 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 figure with respect to length, in so far as the strength depends upon the selections of stations and of lines to be observed over. The strength table is therefore to be used, in connection with the values of $\frac{D-C}{D}$ given hereafter, to decide during the progress of the reconnoissance which of the two or more possible figures is the strongest, and to determine whether a sufficiently strong scheme has been obtained to make it inadvisable to spend more time in reconnoissance.

30. To compare two alternative figures, either quadrilaterals or central point figures for example, with each other in so far as the strength with which the length is carried 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. The quantity so obtained, namely, $\frac{D-C}{D}\Sigma[\delta^2_A+\delta_A\delta_B+\delta^2_B]$, 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 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.

31. Some values of the quantity $\frac{D-C}{D}$.—

The starting line is supposed to be completely fixed.

For a single triangle, $\frac{4-1}{4}=0.75$.

For a completed quadrilateral, $\frac{10-4}{10}=0.60$.

For a quadrilateral with one station on the fixed line unoccupied, $\frac{8-2}{8}=0.75$.

For a quadrilateral with one station not on the fixed line unoccupied, $\frac{7-2}{7}=0.71$.

For a three-sided, central point figure, $\frac{10-4}{10}=0.60$.

For a three-sided, central point figure with one station on the fixed line unoccupied, $\frac{8-2}{8}=0.75$.

For a three-sided, central point figure with one station not on the fixed line unoccupied, $\frac{7-2}{7}=0.71$.

For a four-sided, central point figure, $\frac{14-5}{14}=0.64$.

For a four-sided, central point figure with one corner station on the fixed line unoccupied, $\frac{12-3}{12}=0.75$.

For a four-sided, central point figure with one corner station not on the fixed line unoccupied, $\frac{11-3}{11}=0.73$.

For a four-sided, central point figure with the central station not on the fixed line unoccupied, $\frac{10-2}{10}=0.80$.

For a four-sided, central point figure with the central station not on the fixed line unoccupied and one diagonal observed, $\frac{12-4}{12}=0.67$.

For a five-sided, central point figure, $\frac{18-6}{18}=0.67$.

For a five-sided, central point figure with a station on a fixed outside line unoccupied, $\frac{16-4}{16}=0.75$.

For a five-sided, central point figure with an outside station not on the fixed line unoccupied, $\frac{15-4}{15}=0.73$.

For a five-sided, central point figure with the central station not on the fixed line unoccupied, $\frac{13-2}{13}=0.85$.

For a six-sided, central point figure, $\frac{22-7}{22}=0.68$.

For a six-sided, central point figure with one outside station on the fixed line unoccupied, $\frac{20-5}{20}=0.75$.

For a six-sided, central point figure with one outside station not on the fixed line unoccupied, $\frac{19-5}{19}=0.74$.

For a six-sided, central point figure with the central station not on the fixed line unoccupied, $\frac{16-2}{16}=0.88$.

For a four-sided, central point figure with one diagonal also observed, $\frac{16-7}{16}=0.56$.

For a four-sided, central point figure with one diagonal also observed, with the central station not on the fixed line unoccupied, $\frac{12-4}{12}=0.67$.

32. Examples of various triangulation figures.—The following fourteen figures are given to illustrate some of the principles involved in the selection of the strong figures and to illustrate the use of the Strength Table.

33. In every figure the line which is supposed to be fixed in length, and the line of which the length is required, are represented by heavy lines. Either of these two heavy lines may be considered to be the fixed line and the other the required line. Opposite each figure R_1 and R_2, as given by the Strength Table, are shown. The smaller the value of R_1 the greater the strength of the figure. R_2 need not be considered in comparing two figures unless the two values of R_1 are equal, or nearly so.

34. Compare figs. 1, 2, and 3. Fig. 1 is a square quadrilateral; fig. 2 is a rectangular quadrilateral, which is one-half as long in the direction of progress as it is wide; fig. 3 is a rectangular quadrilateral twice as long in the direction of progress as it is wide. The comparison of the values of R_1 in figs. 1 and 2 shows that shortening a rectangular quadrilateral in the direction of progress increases its strength. A comparison of figs. 1 and 3 shows that extending a rectangular quadrilateral in the direction of progress weakens it.

35. Fig. 4, like fig. 2, is short in the direction of progress. Such short quadrilaterals are in general very strong, even though badly distorted from the rectangular shape, but they are not economical as progress with them is slow.

36. Fig. 5 is badly distorted from a rectangular shape, but is still a moderately strong figure. The best pair of triangles for carrying the length through this figure are *D S R* and *R S P*. As a rule, one diagonal of the quadrilateral is common to the two triangles forming the best pair, and the other diagonal is common to the second best pair. In the unusual case illustrated in fig. 5 a side line of the quadrilateral is common to the second best pair of triangles.

37. Fig. 6 is an example of a quadrilateral so much elongated, and therefore so weak, that it is not allowable in any class of triangulation.

38. Fig. 7 is the regular three-sided, central-point figure. It is extremely strong.

39. Fig. 8 is the regular four-sided, central-point figure. It is very much weaker than fig. 1, the corresponding quadrilateral.

40. Fig. 9 is the regular five-sided, central-point figure. Note that it is much weaker than any of the quadrilaterals shown in figs. 1, 2, or 4.

41. Fig. 10 is a good example of a strong, quick expansion from a base. The expansion is in the ratio of 1 to 2.

42. Figs. 11 and 12 are given as a suggestion of the manner in which, in secondary and tertiary triangulation, a point (A), difficult or impossible to occupy, may be used as a concluded point common to several figures.

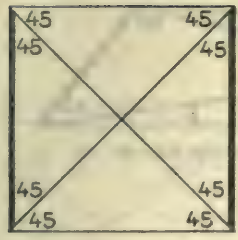

FIG. 1.—All stations occupied. $R_1=5$ $R_2=5$

Same, any one station not occupied. $R_1=6$ $R_2=6$

FIG. 2.—All stations occupied. $R_1=1$ $R_2=1$

Same, any one station not occupied. $R_1=2$ $R_2=2$

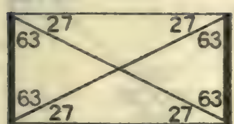

FIG. 3.—All stations occupied. $R_1=22$ $R_2=22$

Same, one station on fixed line not occupied. $R_1=27$ $R_2=27$

FIG. 4.—All stations occupied. $R_1=1$ $R_2=2$

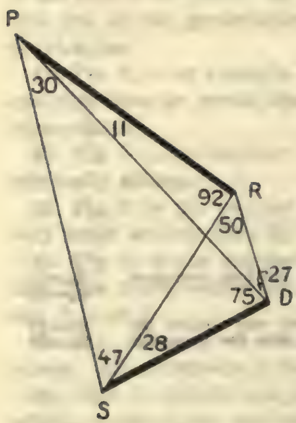

FIG. 5.—All stations occupied. $R_1=10$ $R_2=12$

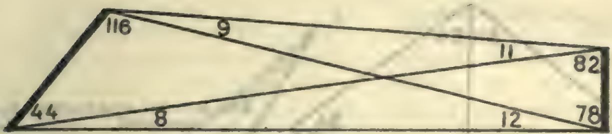

FIG. 6.—All stations occupied. $R_1=164$ (approx.) $R_2=176$ (approx.)

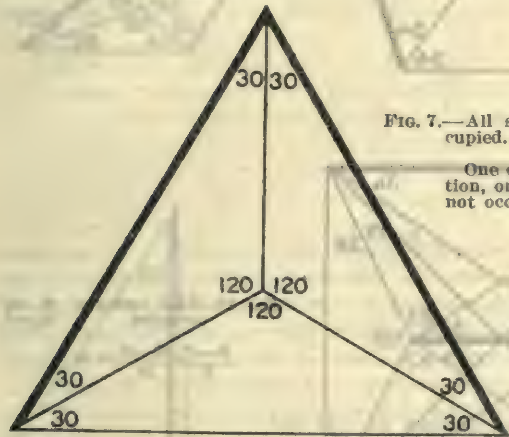

FIG. 7.—All stations occupied. $R_1=2$ $R_2=12$

One outside station, on fixed line, not occupied. $R_1=3$ $R_2=15$

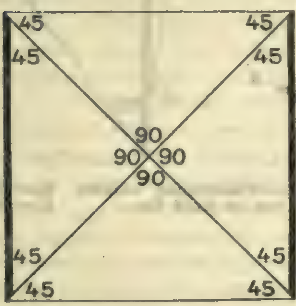

FIG. 8.—All stations occupied. $R_1=13$ $R_2=13$

Same, one corner station not occupied. $R_1=16$ $R_2=16$

Same, central station not occupied. $R_1=17$ $R_2=17$

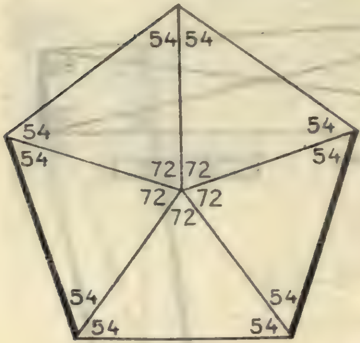

FIG. 9.—All stations occupied. $R_1=10$ $R_2=15$

Same, any one outside station not occupied. $R_1=11$ $R_2=16$

Same, central station not occupied. $R_1=13$ $R_2=19$

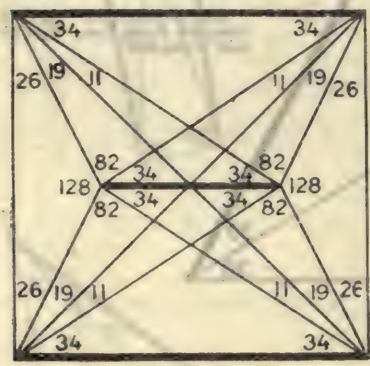

FIG. 10.—All stations occupied. $R_1=5$ $R_2=5$

$$\frac{D-C}{D}=\frac{28-16}{28}=0.43$$

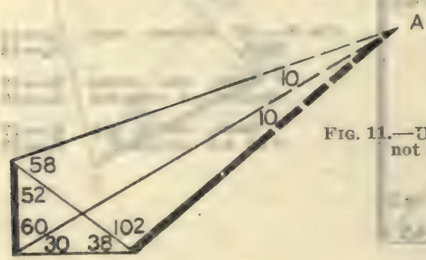

FIG. 11.—Unoccupied station not on fixed line. $R_1=36$ $R_2=102$

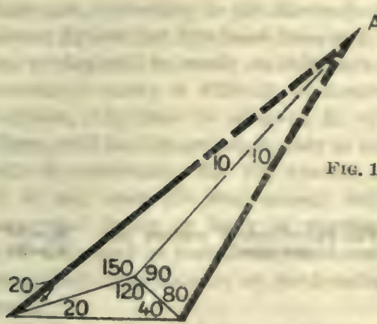

Fig. 12.—Unoccupied station at intersection of fixed line and line to be determined. $R_1 = 4$ $R_2 = 20$

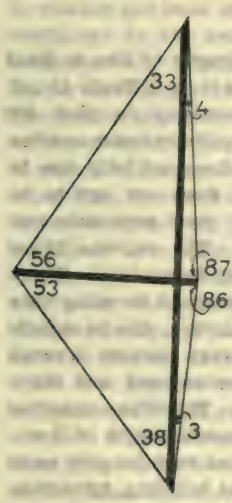

Fig. 13.—All stations occupied. (A strong and quick expansion figure.) $R_1 = 0$ $R_2 = 0$

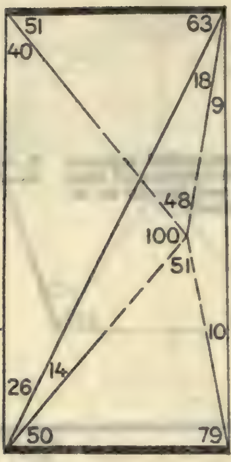

FIG. 14.—Central station not occupied. $R_1=18$ $R_2=24$

43. Length of lines.—The lower limit of length of line is fixed by two considerations. On very short lines it is difficult to get observations of the degree of accuracy necessary to close the triangles within the required limit. They require extreme caution in centering and plumbing signals so that all eccentricity due to these causes may be avoided. Very short lines are apt to be accompanied, though not necessarily so, by poor geometric conditions as expressed by large values of *R*. The extreme lower limit fixed by these two considerations should be avoided. There is no advantage in so far as accuracy is concerned in using very long lines. Long lines are apt to introduce delays, due to signals not being visible. With long lines supplementary stations to reach required points in all portions of the area covered are much more apt to be needed than with short lines. Therefore endeavor in laying out the main scheme to use the economic length of line—that is, endeavor to use in each region lines of such lengths as to make the total cost of reconnoissance, signal building, triangulation, and base measurement a minimum for the area to be covered, subject to the limitations stated in these instructions.

44. 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, or between a base line and a line of precise or secondary triangulation used as a base, should be made about 130. This will be found to correspond to a chain of from 10 to 35 triangles, according to the strength of the figures secured. With strong figures but few base lines will be needed, and a corresponding saving will be made on this part of the work. If topographic conditions make it difficult to secure a base site at the desired location, ΣR_1 may be allowed to approach but not exceed 200. There will be danger when this is done that an intervening base will be necessary, for the reason stated in the next sentence. If in any case the discrepancy between adjacent bases (either measured bases or lines of precise or secondary triangulation used as bases) is found to exceed one part in 5000, an intervening base must be measured or the intervening triangulation strengthened.

45. Base sites and base nets.—A base may be measured over rough ground and steep slopes with steel or invar tapes with the degree of accuracy specified in the following paragraph. Smooth, level ground is a convenience, but not a necessity, for base measurement of this grade of accuracy. There should be no hesitancy in placing the base on rough ground if by so doing the geometric conditions in the base net are improved—that is, values of R made smaller. The length of a base is to be determined primarily by the desirability of securing small values of R in the base net. The longer the base the easier it will be found to secure small values of R, and the smaller the values of R the longer the chain of triangles through which the lengths may be carried before another base becomes necessary. The base net shall consist of a figure or figures of the same character and subject to the same conditions as to strength as the main scheme previously described. If the net is made up of two or more figures they may overlap in space, but there should be no overlapping of figures in the sense of the existence of observed lines which tie together the separate figures. Broken bases are permissible when found advantageous.

46. Base measurements.—In base measurements select apparatus and methods which insure that the constant error does not exceed one part in 30 000, and that the accidental errors are not greater than that represented by a probable error of one part in 100 000, in the length of the base. No difficulty will be encountered in keeping both classes of errors within these limits, even if the measurement is over very rough ground and steep slopes, provided that the vertical measurements on steep slopes are made with sufficient accuracy, that two measurements are made of each section of the base with 50-meter steel or invar tapes, and that the tapes have been properly standardized. The tape should be used on the field under the same conditions as to tension and number of supports that obtained during the standardization. After the measurement of a base or a series of bases the tape should, if practicable, be returned to the office for restandardization.

47. Measurements made with steel tapes in daylight, particularly in sunlight, are subject to constant errors in the determination of the temperature by mercurial thermometers. These errors may exceed 3° C. and produce a constant error in length as great as one part in 30 000; therefore preference should be given to overcast days when practicable, or to measures at night.

48. Bases will in general be measured by steel or invar tapes suspended from stakes. The tape lengths may be marked on the tops of the stakes by marks on copper strips or zinc plates; a 50-meter tape should be supported at 25-meter or 12.5-meter intervals, the support (conveniently a nail in the side of a stake) being in line vertically and horizontally between the end supports. The smaller interval should be used whenever the wind is troublesome. The base tapes are usually standardized while being supported at each of these intervals. When the topography is such as to require high end supports, the intermediate support may be placed above (never below) the grade of the end supports and each half of the tape corrected for grade. Two thermometers should be used, fastened to the tape toward either end. The tape should be carried clear of the ground. Two measurements of a base should usually suffice. Set backs and set forwards may be made with a quarter-meter scale and dividers, and where the lengths run off the stakes, with a pocket tape having proper subdivisions. A tension of 15 kilograms should be applied with a spring balance attached to the forward end of the tape. It is preferable to use a complete tape-stretching outfit, as described and shown in illustrations in Appendix 4, Report for 1910, but a simple staff may be used at each end of the tape. Strips of signal muslin are satisfactory in fastening the tape to the staffs. The use of hard twine or rope for that purpose tends to twist the tape.

49. The spring balance used in the base measurement should be verified before and after the measurement by comparison with a spare or standard spring balance, or with a standard testing weight furnished for that purpose.

50. The base measurements may be recorded in "Horizontal angle" record books by changing the headings or in the "Traverse measurements" record book (Form 590). A duplicate of the base measurement record should be made on computing paper.

and attached to the List of Directions. Each record of base measurement should be preceded by a description of the measurement showing what tapes were used, their lengths, coefficients of expansion, method of support, number of supports, the tension applied, how the thermometers were used, and all information necessary to a clear understanding of the measurement.

51. Form for record of base measurement.—

From stake No.	To stake No.	Thermometers.		Set backs.	Set forwards.
		2183.	2184.		
		° *C.*	° *C.*	*Meters.*	*Meters.*
NE. base	176	5.0	4.9		
176	175	4.7	5.0		
175	174	4.9	5.3		0.0121

REMARKS.

Time of beginning: 9h. 5m. p. m.
Began at NE. base station mark.
Backward measure.
Fifteen kilograms tension applied with spring balance No. 170.
Tape No. 403 on three supports.
Balance tested and found correct.
Wind, moderate, NW., at right angles to base. [a]

Under the column of remarks give also the names of the persons recording and making the forward and rear contacts.

52. Example of computation of length of base.—Standardization formula for tape No. 403, supported at ends and in middle, with a tension of 15 kilograms:

0 to 50 m. = 50 m. + 8.32 mm. + 0.568 mm. (t − 14°.56 C.)
± .039 mm. ± .003 mm.

Twenty tape lengths; mean corrected temperature 15°.58 C.

		Meters.
20 (50 m. + 8.32 mm.) = 20 (50.00832) =		1000.1664
Temperature correction: 20 (15.58 − 14.56) (0.568 mm.) =	+	.0116
Set forwards, sum	+	.0133
Set backs, sum	−	.0060
Inclination corrections (see table, par. 55) sum	−	.2283
Length of base		999.9570

[a] To be entered on right-hand page.

53. In case the standard length is given for a tape supported throughout its length, the catenary correction C is to be applied to each span of tape, as follows:

$$C=-\frac{1}{24}\left(\frac{W}{t}\right)^2 l^3$$

Where W=weight in grams per meter of tape (21.6 grams for steel tape in use, 25 to 27 grams for invar tapes).

t=horizontal tension in grams=15000 grams in general.

l=length of span in meters.

54. The following publications of this Survey deal with tape measurements: Appendix 7, Report for 1893; Appendix 3, Report for 1901; Appendix 4, Report for 1907; Appendix 4, Report for 1910; Special Publications Nos. 19 and 58.

55. **Inclination correction tables for 25-meter tape lengths.**—Correction for inclination $=-(l-\sqrt{l^2-h^2})$ where l is inclined distance and h is difference of height. For l=25 meters and h in feet, the correction for inclination $=-.00186\ h^2-.000000069\ h^4- \ldots\ldots$ The second term may be neglected for differences of height of 5 feet or less.

For 50-meter spans take one-half the correction given in the table. For instance, for a span of 50 meters and a difference in elevation of the two ends of the span of 2 feet (0.6096 meter), the correction is 0.0037 meter.

Difference in elevation.		Correction.	Difference in elevation.		Correction.	Difference in elevation.		Correction.
Foot.	*Meter.*	*Meter.*	*Foot.*	*Meter.*	*Meter.*	*Feet.*	*Meter.*	*Meter.*
0.00	0.0000	−0.0000	0.50	0.1524	−0.0005	1.00	0.3048	−0.0019
.01	.0030	0	.51	.1554	5	.01	.3078	19
.02	.0061	0	.52	.1585	5	.02	.3109	19
.03	.0091	0	.53	.1615	5	.03	.3139	20
.04	.0122	0	.54	.1646	5	.04	.3170	20
.05	.0152	0	.55	.1676	6	.05	.3200	20
.06	.0183	0	.56	.1707	6	.06	.3231	21
.07	.0213	0	.57	.1737	6	.07	.3261	21
.08	.0244	0	.58	.1768	6	.08	.3292	22
.09	.0274	0	.59	.1798	6	.09	.3322	22
0.10	0.0305	0	0.60	0.1829	7	1.10	0.3353	22
.11	.0335	0	.61	.1859	7	.11	.3383	23
.12	.0366	0	.62	.1890	7	.12	.3414	23
.13	.0396	0	.63	.1920	7	.13	.3444	24
.14	.0427	0	.64	.1951	8	.14	.3475	24
.15	.0457	0	.65	.1981	8	.15	.3505	25
.16	.0488	0	.66	.2012	8	.16	.3536	25
.17	.0518	1	.67	.2042	8	.17	.3566	25
.18	.0549	1	.68	.2073	9	.18	.3597	26
.19	.0579	1	.69	.2103	9	.19	.3627	26
0.20	0.0610	1	0.70	0.2134	9	1.20	0.3658	27
.21	.0640	1	.71	.2164	9	.21	.3688	27
.22	.0671	1	.72	.2195	10	.22	.3719	28
.23	.0701	1	.73	.2225	10	.23	.3749	28
.24	.0732	1	.74	.2256	10	.24	.3780	29
.25	.0762	1	.75	.2286	10	.25	.3810	29
.26	.0792	1	.76	.2316	11	.26	.3840	29
.27	.0823	1	.77	.2347	11	.27	.3871	30
.28	.0853	1	.78	.2377	11	.28	.3901	31
.29	.0884	2	.79	.2408	12	.29	.3932	31
0.30	0.0914	2	0.80	0.2438	12	1.30	0.3962	31
.31	.0945	2	.81	.2469	12	.31	.3993	32
.32	.0975	2	.82	.2499	12	.32	.4023	32
.33	.1006	2	.83	.2530	13	.33	.4054	33
.34	.1036	2	.84	.2560	13	.34	.4084	33
.35	.1067	2	.85	.2591	13	.35	.4115	34
.36	.1097	2	.86	.2621	14	.36	.4145	34
.37	.1128	3	.87	.2652	14	.37	.4176	35
.38	.1158	3	.88	.2682	14	.38	.4206	35
.39	.1189	3	.89	.2713	15	.39	.4237	36
0.40	0.1219	3	0.90	0.2743	15	1.40	0.4267	36
.41	.1250	3	.91	.2774	15	.41	.4298	37
.42	.1280	3	.92	.2804	16	.42	.4328	37
.43	.1311	3	.93	.2835	16	.43	.4359	38
.44	.1341	4	.94	.2865	16	.44	.4389	38
.45	.1372	4	.95	.2896	17	.45	.4420	39
.46	.1402	4	.96	.2926	17	.46	.4450	40
.47	.1433	4	.97	.2957	18	.47	.4481	40
.48	.1463	4	.98	.2987	18	.48	.4511	41
.49	.1494	4	.99	.3018	18	.49	.4542	41

Difference in elevation.		Correction.	Difference in elevation.		Correction.	Difference in elevation.		Correction.
Feet.	*Meter.*	*Meter.*	*Feet.*	*Meter.*	*Meter.*	*Feet.*	*Meter.*	*Meter.*
1.50	0.4572	−0.0042	2.00	0.6096	−0.0074	2.50	0.7620	−0.0116
.51	.4602	43	.01	.6126	75	.51	.7650	117
.52	.4633	43	.02	.6157	76	.52	.7681	118
.53	.4663	44	.03	.6187	76	.53	.7711	119
.54	.4694	44	.04	.6218	77	.54	.7742	120
.55	.4724	45	.05	.6248	78	.55	.7772	121
.56	.4755	46	.06	.6279	79	.56	.7803	122
.57	.4785	46	.07	.6309	80	.57	.7833	123
.58	.4816	47	.08	.6340	80	.58	.7864	124
.59	.4846	47	.09	.6370	81	.59	.7894	125
1.60	0.4877	48	2.10	0.6401	82	2.60	0.7925	126
.61	.4907	48	.11	.6431	83	.61	.7955	127
.62	.4938	49	.12	.6462	84	.62	.7986	128
.63	.4968	50	.13	.6492	84	.63	.8016	129
.64	.4999	50	.14	.6523	85	.64	.8047	130
.65	.5029	51	.15	.6553	86	.65	.8077	131
.66	.5060	52	.16	.6584	87	.66	.8108	131
.67	.5090	52	.17	.6614	88	.67	.8138	132
.68	.5121	53	.18	.6645	88	.68	.8169	133
.69	.5151	53	.19	.6675	89	.69	.8199	134
1.70	0.5182	54	2.20	0.6706	90	2.70	0.8230	135
.71	.5212	55	.21	.6736	91	.71	.8260	136
.72	.5243	55	.22	.6767	92	.72	.8291	137
.73	.5273	56	.23	.6797	92	.73	.8321	138
.74	.5304	56	.24	.6828	93	.74	.8352	139
.75	.5334	57	.25	.6858	94	.75	.8382	141
.76	.5364	58	.26	.6888	95	.76	.8412	142
.77	.5395	58	.27	.6919	96	.77	.8443	143
.78	.5425	59	.28	.6949	96	.78	.8473	144
.79	.5456	59	.29	.6980	97	.79	.8504	145
1.80	0.5486	60	2.30	0.7010	98	2.80	0.8534	146
.81	.5517	61	.31	.7041	99	.81	.8565	147
.82	.5547	61	.32	.7071	100	.82	.8595	148
.83	.5578	62	.33	.7102	101	.83	.8626	149
.84	.5608	63	.34	.7132	102	.84	.8656	150
.85	.5639	64	.35	.7163	103	.85	.8687	151
.86	.5669	64	.36	.7193	103	.86	.8717	152
.87	.5700	65	.37	.7224	104	.87	.8748	153
.88	.5730	66	.38	.7254	105	.88	.8778	154
.89	.5761	66	.39	.7285	106	.89	.8809	155
1.90	0.5791	67	2.40	0.7315	107	2.90	0.8839	156
.91	.5822	68	.41	.7346	108	.91	.8870	157
.92	.5852	68	.42	.7376	109	.92	.8900	158
.93	.5883	69	.43	.7407	110	.93	.8931	159
.94	.5913	70	.44	.7437	111	.94	.8961	160
.95	.5944	71	.45	.7468	112	.95	.8992	162
.96	.5974	71	.46	.7498	112	.96	.9022	163
.97	.6005	72	.47	.7529	113	.97	.9053	164
.98	.6035	73	.48	.7559	114	.98	.9083	165
.99	.6066	73	.49	.7590	115	.99	.9114	166

Difference in elevation.		Correction.	Difference in elevation.		Correction.	Difference in elevation.		Correction.
Feet.	*Meters.*	*Meter.*	*Feet.*	*Meters.*	*Meter.*	*Feet.*	*Meters.*	*Meter.*
3.00	0.9144	−0.0167	3.50	1.0668	−0.0228	4.00	1.2192	−0.0297
.01	.9174	168	.51	.0699	229	.01	.2223	299
.02	.9205	169	.52	.0729	231	.02	.2253	300
.03	.9235	171	.53	.0759	232	.03	.2283	302
.04	.9266	172	.54	.0790	233	.04	.2314	303
.05	.9296	173	.55	.0820	235	.05	.2344	305
.06	.9327	174	.56	.0851	236	.06	.2375	306
.07	.9357	175	.57	.0881	237	.07	.2405	308
.08	.9388	177	.58	.0912	238	.08	.2436	309
.09	.9418	178	.59	.0942	240	.09	.2466	311
3.10	0.9449	179	3.60	1.0973	241	4.10	1.2497	312
.11	.9479	180	.61	.1003	242	.11	.2527	314
.12	.9510	181	.62	.1034	244	.12	.2558	315
.13	.9540	182	.63	.1064	245	.13	.2588	317
.14	.9571	183	.64	.1095	246	.14	.2619	318
.15	.9601	185	.65	.1125	248	.15	.2649	320
.16	.9632	186	.66	.1156	249	.16	.2680	322
.17	.9662	187	.67	.1186	250	.17	.2710	323
.18	.9693	188	.68	.1217	251	.18	.2741	325
.19	.9723	189	.69	.1247	253	.19	.2771	326
3.20	0.9754	190	3.70	1.1278	254	4.20	1.2802	328
.21	.9784	191	.71	.1308	255	.21	.2832	330
.22	.9815	192	.72	.1339	257	.22	.2863	331
.23	.9845	194	.73	.1369	258	.23	.2893	333
.24	.9876	195	.74	.1400	260	.24	.2924	334
.25	.9906	196	.75	.1430	261	.25	.2954	336
.26	.9936	197	.76	.1461	262	.26	.2985	338
.27	.9967	198	.77	.1491	264	.27	.3015	339
.28	.9997	200	.78	.1521	265	.28	.3045	341
.29	1.0028	201	.79	.1552	267	.29	.3076	342
3.30	1.0058	202	3.80	1.1582	268	4.30	1.3106	344
.31	.0089	203	.81	.1613	270	.31	.3137	346
.32	.0119	205	.82	.1643	271	.32	.3167	347
.33	.0150	206	.83	.1674	273	.33	.3198	349
.34	.0180	207	.84	.1704	274	.34	.3228	350
.35	.0211	209	.85	.1735	276	.35	.3259	352
.36	.0241	210	.86	.1765	277	.36	.3289	354
.37	.0272	211	.87	.1796	279	.37	.3320	355
.38	.0302	212	.88	.1826	280	.38	.3350	357
.39	.0333	214	.89	.1857	282	.39	.3381	358
3.40	1.0363	215	3.90	1.1887	283	4.40	1.3411	360
.41	.0394	216	.91	.1918	284	.41	.3442	362
.42	.0424	218	.92	.1948	286	.42	.3472	363
.43	.0455	219	.93	.1979	287	.43	.3503	365
.44	.0485	220	.94	.2009	289	.44	.3533	367
.45	.0516	222	.95	.2040	290	.45	.3564	369
.46	.0546	223	.96	.2070	291	.46	.3594	370
.47	.0577	224	.97	.2101	293	.47	.3625	372
.48	.0607	225	.98	.2131	294	.48	.3655	374
.49	.0638	227	.99	.2162	296	.49	.3686	375

Difference in elevation.		Correction.	Difference in elevation.		Correction.	Difference in elevation.		Correction.
Feet.	*Meters.*	*Meter.*	*Feet.*	*Meters.*	*Meter.*	*Feet.*	*Meters.*	*Meter.*
4.50	1.3716	−0.0377	5.00	1.5240	−0.0465	5.50	1.6764	−0.0563
.51	.3747	379	.01	.5271	467	.51	.6795	565
.52	.3777	380	.02	.5301	469	.52	.6825	567
.53	.3807	382	.03	.5331	471	.53	.6855	569
.54	.3838	384	.04	.5362	473	.54	.6886	571
.55	.3868	386	.05	.5392	475	.55	.6916	573
.56	.3899	387	.06	.5423	476	.56	.6947	575
.57	.3929	389	.07	.5453	478	.57	.6977	577
.58	.3960	391	.08	.5484	480	.58	.7008	579
.59	.3990	392	.09	.5514	482	.59	.7038	581
4.60	1.4021	394	5.10	1.5545	484	5.60	1.7069	583
.61	.4051	396	.11	.5575	486	.61	.7099	585
.62	.4082	397	.12	.5606	488	.62	.7130	587
.63	.4112	399	.13	.5636	490	.63	.7160	589
.64	.4143	401	.14	.5667	492	.64	.7191	591
.65	.4173	403	.15	.5697	494	.65	.7221	594
.66	.4204	404	.16	.5728	495	.66	.7252	596
.67	.4234	406	.17	.5758	497	.67	.7282	598
.68	.4265	408	.18	.5789	499	.68	.7313	600
.69	.4295	409	.19	.5819	501	.69	.7343	602
4.70	1.4326	411	5.20	1.5850	503	5.70	1.7374	604
.71	.4356	413	.21	.5880	505	.71	.7404	606
.72	.4387	415	.22	.5911	507	.72	.7435	608
.73	.4417	416	.23	.5941	509	.73	.7465	611
.74	.4448	418	.24	.5972	511	.74	.7496	613
.75	.4478	420	.25	.6002	513	.75	.7526	615
.76	.4509	422	.26	.6033	515	.76	.7557	617
.77	.4539	424	.27	.6063	517	.77	.7587	619
.78	.4569	425	.28	.6093	519	.78	.7617	622
.79	.4600	427	.29	.6124	521	.79	.7648	624
4.80	1.4630	429	5.30	1.6154	523	5.80	1.7678	626
.81	.4661	431	.31	.6185	525	.81	.7709	628
.82	.4691	433	.32	.6215	527	.82	.7739	630
.83	.4722	434	.33	.6246	529	.83	.7770	633
.84	.4752	436	.34	.6276	531	.84	.7800	635
.85	.4783	438	.35	.6307	533	.85	.7831	637
.86	.4813	440	.36	.6337	535	.86	.7861	639
.87	.4844	442	.37	.6368	537	.87	.7892	641
.88	.4874	443	.38	.6398	539	.88	.7922	644
.89	.4905	445	.39	.6429	541	.89	.7953	646
4.90	1.4935	447	5.40	1.6459	543	5.90	1.7983	648
.91	.4966	449	.41	.6490	545	.91	.8014	650
.92	.4996	451	.42	.6520	547	.92	.8044	652
.93	.5027	452	.43	.6551	549	.93	.8075	655
.94	.5057	454	.44	.6581	551	.94	.8105	657
.95	.5088	456	.45	.6612	553	.95	.8136	659
.96	.5118	458	.46	.6642	555	.96	.8166	661
.97	.5149	460	.47	.6673	557	.97	.8197	663
.98	.5179	461	.48	.6703	559	.98	.8227	666
.99	.5210	463	.49	.6734	561	.99	.8258	668

Difference in elevation.		Correction.	Difference in elevation.		Correction.	Difference in elevation.		Correction.
Feet.	*Meters.*	*Meter.*	*Feet.*	*Meters.*	*Meter.*	*Feet.*	*Meters.*	*Meter.*
6.00	1.8288	−0.0670	6.50	1.9812	−0.0786	7.00	2.1336	−0.0912
.01	.8319	672	.51	.9843	789	.01	.1367	915
.02	.8349	674	.52	.9873	791	.02	.1397	917
.03	.8379	677	.53	.9903	794	.03	.1427	920
.04	.8410	679	.54	.9934	796	.04	.1458	922
.05	.8440	681	.55	.9964	799	.05	.1488	925
.06	.8471	683	.56	.9995	801	.06	.1519	928
.07	.8501	685	.57	2.0025	804	.07	.1549	930
.08	.8532	688	.58	.0056	806	.08	.1580	933
.09	.8562	690	.59	.0086	809	.09	.1610	935
6.10	1.8593	692	6.60	2.0117	811	7.10	2.1641	938
.11	.8623	694	.61	.0147	814	.11	.1671	941
.12	.8654	697	.62	.0178	816	.12	.1702	943
.13	.8684	699	.63	.0208	819	.13	.1732	946
.14	.8715	701	.64	.0239	821	.14	.1763	949
.15	.8745	704	.65	.0269	824	.15	.1793	952
.16	.8776	706	.66	.0300	826	.16	.1824	954
.17	.8806	708	.67	.0330	829	.17	.1854	957
.18	.8837	710	.68	.0361	831	.18	.1885	960
.19	.8867	713	.69	.0391	834	.19	.1915	962
6.20	1.8898	715	6.70	2.0422	836	7.20	2.1946	965
.21	.8928	717	.71	.0452	839	.21	.1976	968
.22	.8959	720	.72	.0483	841	.22	.2007	970
.23	.8989	722	.73	.0513	844	.23	.2037	973
.24	.9020	725	.74	.0544	846	.24	.2068	976
.25	.9050	727	.75	.0574	849	.25	.2098	979
.26	.9081	729	.76	.0605	851	.26	.2129	981
.27	.9111	732	.77	.0635	854	.27	.2159	984
.28	.9141	734	.78	.0665	856	.28	.2189	987
.29	.9172	737	.79	.0696	859	.29	.2220	989
6.30	1.9202	739	6.80	2.0726	861	7.30	2.2250	992
.31	.9233	741	.81	.0757	864	.31	.2281	995
.32	.9263	744	.82	.0787	866	.32	.2311	998
.33	.9294	746	.83	.0818	869	.33	.2342	.1000
.34	.9324	748	.84	.0848	871	.34	.2372	.1003
.35	.9355	751	.85	.0879	874	.35	.2403	.1006
.36	.9385	753	.86	.0909	876	.36	.2433	.1009
.37	.9416	755	.87	.0940	879	.37	.2464	.1012
.38	.9446	757	.88	.0970	881	.38	.2494	.1014
.39	.9477	760	.89	.1001	884	.39	.2525	.1017
6.40	1.9507	762	6.90	2.1031	886	7.40	2.2555	.1020
.41	.9538	764	.91	.1062	889	.41	.2586	.1023
.42	.9568	767	.92	.1092	891	.42	.2616	.1026
.43	.9599	769	.93	.1123	894	.43	.2647	.1028
.44	.9629	772	.94	.1153	896	.44	.2677	.1031
.45	.9660	774	.95	.1184	899	.45	.2708	.1034
.46	.9690	776	.96	.1214	902	.46	.2738	.1037
.47	.9721	779	.97	.1245	904	.47	.2769	.1040
.48	.9751	781	.98	.1275	907	.48	.2799	.1042
.49	.9782	784	.99	.1306	909	.49	.2830	.1045

Difference in elevation.		Correction.	Difference in elevation.		Correction.	Difference in elevation.		Correction.
Feet.	*Meters.*	*Meter.*	*Feet.*	*Meters.*	*Meter.*	*Feet.*	*Meters.*	*Meter.*
7.50	2.2860	−0.1048	7.80	2.3774	−0.1133	8.10	2.4689	−0.1222
.51	.2891	.1051	.81	.3805	.1136	.11	.4719	.1225
.52	.2921	.1054	.82	.3835	.1139	.12	.4750	.1228
.53	.2951	.1056	.83	.3866	.1142	.13	.4780	.1231
.54	.2982	.1059	.84	.3896	.1145	.14	.4811	.1234
.55	.3012	.1062	.85	.3927	.1148	.15	.4841	.1237
.56	.3043	.1065	.86	.3957	.1150	.16	.4872	.1240
.57	.3073	.1068	.87	.3988	.1153	.17	.4902	.1243
.58	.3104	.1070	.88	.4018	.1156	.18	.4933	.1246
.59	.3134	.1073	.89	.4049	.1159	.19	.4963	.1249
7.60	2.3165	.1076	7.90	2.4079	.1162	8.20	2.4994	.1252
.61	.3195	.1078	.91	.4110	.1165	.21	.5024	.1255
.62	.3226	.1082	.92	.4140	.1168	.22	.5055	.1258
.63	.3256	.1084	.93	.4171	.1171	.23	.5085	.1261
.64	.3287	.1087	.94	.4201	.1174	.24	.5116	.1264
.65	.3317	.1090	.95	.4232	.1177	.25	.5146	.1268
.66	.3348	.1093	.96	.4262	.1180	.26	.5177	.1271
.67	.3378	.1096	.97	.4293	.1183	.27	.5207	.1274
.68	.3409	.1098	.98	.4323	.1186	.28	.5237	.1277
.69	.3439	.1101	.99	.4354	.1189	.29	.5268	.1280
7.70	2.3470	.1104	8.00	2.4384	.1192	8.30	2.5298	.1283
.71	.3500	.1107	.01	.4415	.1195	.31	.5329	.1286
.72	.3531	.1110	.02	.4445	.1198	.32	.5359	.1289
.73	.3561	.1113	.03	.4475	.1201	.33	.5390	.1292
.74	.3592	.1116	.04	.4506	.1204	.34	.5420	.1295
.75	.3622	.1119	.05	.4536	.1207	.35	.5451	.1299
.76	.3653	.1121	.06	.4567	.1210	.36	.5481	.1302
.77	.3683	.1124	.07	.4597	.1213	.37	.5512	.1305
.78	.3713	.1127	.08	.4628	.1216	.38	.5542	.1308
.79	.3744	.1130	.09	.4658	.1219	.39	.5573	.1311
						8.40	2.5603	.1314

56. Signals.—Various types of signals are used. A very satisfactory one is a single pole held in a vertical position by wire guys, with the foot of the pole resting on a low bench. The bench may be made of two stakes driven into the ground on either side of the station mark, with a piece of scantling placed across and nailed to them. A hole is bored into the crosspiece directly over the station mark. The foot of the pole should have a spike placed in its center, projecting about an inch, and this spike should be placed in the hole in the crosspiece of the bench when the pole is erected. There should be four wires to each set of guys, the number of sets depending upon the length of the pole. The pole is easily lowered when the station is occupied by loosening the guy or guys on only one side and letting the pole fall over. The guys on the other three sides are not disturbed from their anchors. To replace the pole it is only necessary to stand it up on the bench and fasten the loosened guy to its anchor. The centering of the pole.

or that part upon which observations are made, should be tested. It will usually be found that the centering has not been disturbed by replacing the pole. Single poles with wire guys are not satisfactory when placed in a pasture where there are cattle, as their rubbing against the pole and wires will throw the former out of plumb. The part of the center pole of a signal observed upon should be accurately centered over the station mark, or if eccentric, the eccentric distance and angle should be measured and recorded. Uncorrected eccentricity of signal is the most frequent source of error in triangulation. If it becomes necessary to elevate the instrument more than a few feet, a double structure, like that described in Appendix 4, Report for 1903, should be used. That description gives bills of lumber, plans, etc.

57. Signal lamps.—The use of acetylene signal lamps, for long lines or even for lines of only moderate length, is recommended, if the atmospheric conditions are not favorable for observations on poles or targets. Illustrations in Special Publication No. 11 show the large and small lamps which are issued to field parties by the office. The large lamp is shown also in Special Publications Nos. 14 and 19. Large electric signal lamps may be used where conditions are especially unfavorable.

58. Instructions to lightkeepers are given in detail in Special Publication No. 65. There are also given the code signals used between the observer and lightkeeper in precise triangulation and the continental Morse alphabet.

59. Horizontal angle observations—Standard of accuracy.—In selecting the instrument to be used, the methods of observation, the number of observations, the signals to be used, and the conditions under which to observe, proceed upon the assumption that what is desired is the maximum speed and minimum cost consistent with the requirement that the closing error of a single triangle in the main scheme shall seldom exceed 10 seconds, and that the average closing error shall be between 3 and 5 seconds. The observations connecting supplementary stations with the main scheme should be of this same degree of accuracy. This standard of accuracy, used in connection with other portions of these instructions defining the necessary strength of figures, frequency of bases, and accuracy of base measurements, will in general insure that the probable error of any base line (or line of precise or secondary triangulation used as a base), as computed from an adjacent base (or triangulation line used as a base), is about 1 part in 20 000, and that the actual discrepancy between such bases is always less than 1 part in 5000.

60. Selection of instrument.—Either a direction or a repeating instrument may be used in triangulation of this class. In selecting the size of an instrument to be used, two opposing factors must be taken into account. If small, light instruments are used, and if sun and wind shields are not used, then the weight of the outfit which it is necessary to take to a station will be light, and the cost in time and money to transport the observing party and its outfit will not be large. On the other hand, the larger and better the instrument, the more fully it is protected from the sun and wind, and the more stable the support provided for it, the smaller will be the number of observations necessary to secure the required degree of accuracy and the shorter will be the observing period at the station.

61. Observations in the main scheme with a direction instrument.—An 8-inch direction instrument (No. 140, for example) used on its tripod and protected from sun and wind simply by an umbrella will usually give the required accuracy with two measurements, a direct and reverse reading being considered one measurement. Any two positions of the circle may be used with this instrument for which the settings on the initial signal differ by approximately 90° 05′. The backward (additive) reading of the micrometer only should be taken in each position of each microscope. At least once a month, as a test for run, a few special readings both backward and forward should be taken on various graduations of the circle to determine the run of each micrometer and placed in the record. If the average value of the run for either micrometer is found to be greater than two divisions (four seconds), the micrometer should be adjusted for run. Under these conditions and with the specified positions of the circle the run will be eliminated from the results with sufficient accuracy by the process of taking means. For any other direction instrument the system of positions to be used may be selected with reference to the number of measurements found to be necessary. With any direction instrument when a broken series is observed the missing signals are to be observed later in connection with the chosen initial, or with some other one, and only one, of the signals already observed in that series. With this system of observing no local adjustment is necessary. Little time should be spent in waiting for a doubtful signal to show. If it is not showing within, say, one minute when wanted, pass to the next. A saving of time results from observing many or all of the signals in each series, provided there are no long waits for signals to show, but not otherwise. When the elevations of the stations differ greatly it is necessary to keep the horizontal axis of the instrument level in order to avoid large and troublesome errors. The magnitude of these errors for various conditions is shown in the table in paragraph 19. Any releveling should, of course, be done between positions.

Example of record is given below.

62. Horizontal directions.—

Station: Gunton. Date: April 17, 1902.
Observer: ——. Instrument: 8-inch theodolite No. 140.

Position.	Objects observed.	Time.	Tel. D. or R.	Mic.	Angle.	Backward.	Mean.	Mean D. and R.	Direction.	Remarks.
		h. m.			° ′	Div.	″	″	″	
I	Benvenue	2 56	D	A	0 00	07.0				
				B		04.5	[1] 11.5			
	Benvenue	3 06	R	A	180 00	05.0				
				B		11.0	16.0	13.8	00.0	
	White Stone Point		D	A	45 40	12.0				
				B		07.0	19.0			
	White Stone Point		R	A	225 40	08.5				
				B		16.5	25.0	22.0	08.2	
	Stevenson		D	A	76 35	26.5				
				B		23.0	49.5			
	Stevenson		R	A	256 35	24.0				
				B		29.5	53.5	51.5	37.7	
	Gut		D	A	87 05	25.5				
				B		24.5	50.0			
	Gut		R	A	267 05	23.5				
				B		26.0	49.5	49.8	36.0	
II	Benvenue	3 10	R	A	270 05	03.0				
				B		09.5	12.5			
	Benvenue	3 15	D	A	90 05	06.0				
				B		05.5	11.5	12.0	00.0	
	White Stone Point		R	A	315 45	05.0				
				B		06.0	11.0			
	White Stone Point		D	A	135 45	06.0				
				B		07.0	13.0	12.0	00.0	
	Stevenson		R	A	346 40	24.0				
				B		22.0	46.0			
	Stevenson		D	A	166 40	20.5				
				B		23.0	43.5	44.8	32.8	
	Gut		R	A	357 10	22.0				
				B		21.5	43.5			
	Gut		D	A	177 10	18.0				
				B		22.0	40.0	41.8	29.8	

[1] Each division of the micrometer corresponds to 2″ of arc, and therefore the "mean" for this instrument is the sum of the two readings.

63. Observations in the main scheme with a repeating instrument.—A 7-inch Berger repeating theodolite used on its own tripod and protected from sun and wind by an umbrella will give the required accuracy with from one to two sets of observations on each angle, each set of observations consisting of six repetitions on the angle, with the telescope in the direct position, and six repetitions on the explement of the angle, with the telescope in the reversed position. This is the type of repeating theodolite recommended for tertiary triangulation in any region in which the convenience of transportation of the instrument is an important consideration. When the elevations of the stations differ greatly it is necessary to keep the horizontal axis of the instrument level in order to avoid large and troublesome errors. (See table in paragraph 19.) Releveling may be done between sets or between the separate angle measures of a set; that is, when the lower clamp is loose. With any repeating theodolite, measure only the single angles between adjacent lines of the main scheme and the angle necessary to close the horizon. In the comparatively rare case in which the failure of adjacent signals to show at the same time prevents carrying out this program, make as near an approach to it as possible and then take the remaining signals in another series together with some one, and only one, of the signals observed in the first series, and measure in the new series only the single angles between adjacent signals and the angle necessary to close the horizon. With this scheme of observing no local adjustment is necessary, except to distribute each horizon closure uniformly among the angles measured in that series. If the region is one in which there is no great inconvenience in transporting a heavier instrument, and a 10-inch Gambey repeating theodolite or an equivalent instrument is used on triangulation of this class, it will probably be found that one set of observations consisting of three repetitions on the angle and three on its explement, will be sufficient to secure the required accuracy.

64. An example of a record is given below. From this the resulting directions should be written in the "List of directions" (Form 24A) without any other abstract. It will be noticed in the sample below that, in addition to the usual practice of reading one repetition on the first measurement of each angle, there is a reading for three repetitions in each case. The latter gives a value of the angle correct to within 10 seconds, which will check the reading of the minutes for the six repetitions. The reading of one repetition on one vernier does not give a sufficiently accurate check. Use the reading on three repetitions as a check only.

65. Horizontal angles.—

Station: Dab. Date: February 7, 1906.
Island: Luzon. Instrument: B. & B. 7-inch theodolite No. 134.
Observer: ———

Objects observed.	Time.	Tel. D. or R.	Repetitions.	Angle.	A.	B.	Mean of verniers.	Arc passed over.	Angle, mean D. and R.	
	a. m.			° ′	″	″	″	″	° ′ ″	″ ″ ″
Pet-Dog	8.00		0	0 00	00	00	00			
			1	88 59	50					
			3	266 55	20	20				
		D	6	173 58	40	40	40	40	88 59 46.7	
(Dog-Pet)		R	6	0 00	10	20	15	25	44.2	45.5—0.7=44.8
Dog-Bat			0	0 00	15	25	20			
			1	42 30	15					
			3	127 30	35	45				
		R	6	255 01	15	25	20	00	42 30 10.0	
		D	6	0 00	25	25	25	55	09.2	09.6—0.7=08.9
Bat-Kow			0	0 00	10	10	10			
			1	27 34	10					
			3	82 43	10	20				
		D	6	165 26	20	30	25	15	27 34 22.5	
		R	6	0 00	50	00	55	30	25.0	23.7—0.8=22.9
Kow-Bol			0	0 00	00	10	05			
			1	37 40	40					
			3	113 02	10	20				
		R	6	226 04	20	30	25	20	37 40 43.3	
		D	6	0 00	10	20	15	10	41.7	42.5—0.8=41.7
Bol-Pet			0	0 00	20	30	25			
			1	163 15	10					
			3	129 15	30	30				
		D	6	259 30	40	40	40	15	163 15 02.5	
		R	6	0 00	20	30	25	15	02.5	02.5—0.8=01.7
									360 00	03.8 00.0

66. Observations on intersection stations.—An intersection station is one which is not occupied and of which the position is determined by observations upon it from stations of the main scheme, or from supplementary stations. The direction method of observation should be used in observations upon intersection stations even if the theodolite is a repeater. Each series of observations on intersection stations should contain some one line, and only one, of the main scheme (or a line used in fixing the position of a supplementary station). Such a series of observations should commence with the selected line of the main scheme, with the telescope in the direct position, and with the circle reading approximately zero. The intersection stations should then be observed in order of azimuth and the first half of the series closed with a reading on the line of the main scheme. The telescope should then be reversed and the same process repeated in the reverse order, beginning and ending as before with the selected line of the main scheme. A second set of observations should be made on each intersection station (with the circle shifted in position, say, 100°) if this can be done without materially delaying the party. It is important to observe at least three lines to each intersection station in order to secure a check, but a possible intersection station should be observed upon even if only two lines to it can be secured.

67. Example of record is given below. From this the resulting directions should be written in the "List of directions" (Form 24A) without other abstract.

68. Horizontal angles—

Station: Rat.
Island: Negros.
Observer: ——

Date: January 10, 1902.
Instrument: 7-inch theodolite No. 157.

Objects observed.	Time.	Tel. D. or R.	Angle.		A.	B.	Mean of verniers.	Correction.	Direction.			Remarks.
	a. m.		°	′	″	″	″	″	°	′	″	
Tree	9.50	D	0	00	00	50		+ 5				
		R	180	00	10	00	00		0	00	00	
• Bell tower, Olon		D	21	18	30	20						
		R	201	18	40	30	30		21	18	35	
Oil		D	176	13	10	30						
		R					20	+10	176	13	30	
Frog		D	209	59	50	40						
		R	29	59	60	50	50	+ 5	209	59	55	
L. tang. Padang Id		D	232	18								
		R	52	18					232	18		
Peak 17		D	241	11	00	40						
		R	61	10	50	40	48	+ 5	241	10	53	
Tree		D	359	59	50	40						
	10.32	R	179	59	60	50	50		0	00	00	

69. Eccentric stations and signals.—Whenever a station is not occupied centrally the distance and direction between the eccentric station and the center of the station must be carefully measured. A sketch, showing the relation between the two stations and also to one line of the main scheme of the triangulation, must be entered in the record book and also on the list of directions form for the station. If the station is a lighthouse, the eccentric distance can be obtained by measuring the circumference of the tower from which the radius can be computed. The length of the radius added to the distance between the eccentric station and the nearest point of the tower gives the eccentric distance sought. The direction to the center may be obtained by observing upon each side of the tower and entering the results in the record as left and right tangents. The mean of these two directions is the direction to the center. The eccentric angle should, if practicable, be measured from the station used as the initial in the regular observations.

70. If the part of a signal upon which observations have been made is eccentric, the eccentric distance and direction must be measured and entered in the record and on the list of directions. The eccentric distance for a signal is usually small, and it is sufficient to state that the pole is off center ——— meters on line and in the direction to ——— station, a station of the main scheme or an intersection station. If the eccentric station is not in a line between the center and some other station, the eccentric distance can be given, and then it should be added that it is ——— meters to the north of the line to ——— station. In any event the eccentric distance and direction must be measured with the greatest care. Making the measurements twice will nearly always insure against mistakes.

71. **Observations on large objects.**—When sighting on a gas tank, standpipe, large chimney, or other object which has a large diameter, it is often best to observe on the two sides, right and left, and enter the observations in the record book as left and right tangents to the object. The mean of the two observations will give the direction to the center of the structure and should be used in the computations of the triangles.

72. **Observations on indefinite and temporary objects.**—Observations may sometimes be made upon indefinite objects, as, for example, mountain or hill tops which are comparatively flat or wooded, or upon points which are temporary in nature and not marked upon the ground, such as flags in trees, etc., which are to be used as hydrographic and topographic signals. The direction method of observation shall be used in all such cases, even if the instrument is a repeater. One series of observations, such as is described in paragraph 66, is all that is necessary in such cases. The two pointings, one direct and the other reversed, are needed to check the degrees and minutes of the direction. The indefinite objects may be observed in the same series with other intersection stations. Each pointing upon an indefinite object should be clearly marked "indefinite," and all topographic and

hydrographic points not permanently marked upon the ground should be marked in the record with a circle and a dot. For observations of these two classes a graphic treatment will frequently be all that is desired, and hence the necessity of distinguishing them from other points for which a complete computation must be made. In selecting indefinite points to be observed it should be borne in mind that an approximate determination of the position of a prominent mountain or hill too far inland to be included in the fringe of topography along the coast, or an island far out from the coast, is frequently of considerable geographic value.

73. Indefinite or other unoccupied stations which have been observed upon from two or more stations must have their identity established in the record either by means of sketches, estimated distances, or descriptive notes, so that they may be plotted or computed without probability of confusion. An object appearing in more than one list of directions must bear the same name or designation in each. Any characteristic features of hills, mountains, church spires, or other objects which would render them good landmarks must be clearly noted, as such notes are valuable in chart construction and in hydrographic work. The location of prominent objects and the determination of elevations of mountains are to be considered important parts of the work essential to the completeness of the survey. This work is to be done even when the objects and mountains are beyond the limits of the area to be surveyed. In the case of imperfectly known regions tangents should be taken to points and islands outside of the region to be surveyed.

74. **Value of intersection stations.**—In selecting intersection stations it should be kept in mind that the geographic value of a triangulation depends upon the number of points determined, the size of the area over which they are distributed, and the permanence with which they are marked. The geographic value of a triangulation is lost for a given area when stations can not be recovered within that area. The chance of permanency is made greater by increasing the number of stations as well as by thorough marking. For the reasons stated there should be determined as intersection stations many artificial objects of a permanent character such as lighthouses, church spires, cupolas, towers, chimneys, and standpipes. Make the description definite whenever practicable. Instead of describing the object as "church spire" with the name of the town, make its identity certain by giving street location or denomination of church. There should

also be determined well-defined natural objects, such as sharp mountain peaks, waterfalls which show from the sea, and pinnacle rocks along the coast. Occasionally intermediate stations should be established, permanently marked, and determined by intersections for the special use of topographic and hydrographic parties.

75. **Report on aids to navigation.**—At the end of each season the chief of party will make a list of the objects whose positions have been determined by triangulation and which may serve as aids to navigation. For purposes of identification each object will be described as to its size, shape, color, and its relative prominence as seen from the water. This list and a description of each object must be sent to the office with a transmitting letter for the files of the chart construction division. (See also paragraphs 73 and 196.)

76. **Marking stations.**—Every station, whether it is in the main scheme or is a supplementary or intersection station, which is not in itself a permanent mark, as are lighthouses, church spires, cupolas, towers, large chimneys, sharp peaks, etc., shall be marked in a permanent manner, except where the station is on a shifting sand dune.

77. At every station a standard metal triangulation mark should, if practicable, be set in rock or concrete. Where digging is feasible, there should be an underground mark which is separate from the surface mark. The use of a standard station mark in the underground mark is desirable. The station mark, if on bedrock, should be surrounded by a triangle or circle cut in the rock, which will make it possible to recover the station approximately if the metal disk should be removed through cupidity. Wooden stakes will be acceptable as marks only where the station is on shifting sand dunes, where a concrete or stone mark could not remain undisturbed.

78. When the triangulation is on a narrow river or other body of water where it is difficult to identify topographic features, it is advisable to stamp numbers, by means of dies, on the metal disk station marks. The numbering of the stations in any one region need have no relation to the numbering of stations in other places. The number placed on the mark should be entered in the description of the station, but in no case should a station be designated by number only. Each station should be given a name to facilitate the filing and indexing of its position and description in the office records. It is desirable to stamp the year in which the station is established on all metal disks.

79. See paragraph 88 under the heading "Standard notes for use in descriptions of stations."

80. **Reference marks.**—Two permanent reference marks and several witness marks should be established at each marked station. These marks should be referred to the station by theodolite angles and tape distances. The object of the reference marks is to serve in place of the station mark, if the latter should be destroyed, and also to serve as an aid in the recovery of the station mark. The reference marks should, therefore, be placed in secure positions, if practicable, and the directions and horizontal (not inclined) distances from the station to them should be measured with great care. If the station is on a shore which is liable to erosion, the reference marks should be placed some distance, say more than 20 meters, inland. If the station is in a field, the reference marks should be placed in a fence line, on the edge of a road, or in some other place where they are not likely to be disturbed. In each reference block of concrete or rock should be placed a standard metal reference mark which is similar to the station mark, except that it has an arrow in its center instead of a triangle, and contains the words "reference mark" instead of "triangulation station."

81. Where the shore and the area back of it are marshy, the station and reference marks may be made as follows: Drive a piece of scantling (preferably one 4 inches square) into the marsh and let its top project about 12 inches. Set over this projecting end a drain tile, the bottom of which is made to extend about 6 inches below the surface of the marsh. Surround the bottom of the tile and fill it with concrete, and set one of the standard marks in the top of the tile. As the wood is protected from the air it is believed that it will last many years. The fact that the mark projects from 1 to 2 feet will aid in its recovery.

82. **Witness marks.**—These are used primarily to recover the general locality of a station and also to find the station mark, whether surface or underground. They may, therefore, be indefinite, such as the mouth of a creek, a fence corner, corner of a barn or other building, triangles cut into the bark of trees, mounds of earth, etc. In general, the distances from the station, as measured over the surface of the ground, are sufficient in the descriptions rather than the horizontal distance. The distances and directions need be only moderately accurate, but they should be free from gross errors. The objects used as witness marks

should be as widely separated as practicable to insure greater permanency of at least part of them. When close together the same cause may destroy all of them. On prairie or other uncultivated land where there are no objects available for witness marks one or more such marks should be constructed. A very permanent and satisfactory mark is a mound formed by digging a circular trench, say 10 feet in diameter, and throwing the dirt from the trench to the center of the circle formed by it. The trench and mound will probably soon become sodded over and will be easily found until the land is plowed (possibly even after that time). Blazed trees are frequently used as witness marks. These are to be considered as only temporary marks. A good witness mark is a standard metal reference mark set firmly into a hole bored into a tree at the center of a triangular blaze. When the station is in woods it is advisable to have a witness mark on the road which runs nearest to the station, and preferably the mark should be at the point on the road from which the path or trail leads to the station. It is also desirable to have a witness mark established in a conspicuous place on the seashore in certain cases opposite triangulation stations which would otherwise be difficult to recover. The witness mark should, if practicable, be a concrete mark with the standard reference mark set into its top. The arrow should point in the general direction of the station. The description should give the approximate bearing and distance between the witness mark and the station. See paragraph 88 under the heading "Standard notes for use in descriptions of stations."

83. If a recovered station is marked badly or in any other manner than with a standard metal mark, the re-marking should provide one of these marks which can be set into a block of concrete or solid rock. Where it seems inadvisable to disturb the old center mark a standard reference mark should be established near the old mark. The distance between the two marks need be only a few feet. With a standard reference mark near by, the station can be more easily recovered and it is less likely to be wantonly destroyed.

84. Re-marking stations of the Engineer Corps, U. S. Army.—Wherever a station, only temporarily marked, of the Engineer Corps is connected with, it should be re-marked in a permanent manner. An especially inscribed disk mark for engineers' stations, which is furnished by the office, should be set into the concrete or stone used to mark the station, and reference and witness marks should be established. (See pars. 81 to 82.)

85. Descriptions of old stations.—If the existing description of an old station is not exact as to the present topography around the station or as to the marking, a new description should be prepared and made complete in itself. The new descriptions of the old stations should be made on Form 526, called recovery note, triangulation station (see sample on p. 51), and should be written with a typewriter if possible. One of these recovery notes should be filled out for every station visited whether the station was recovered or not. Do not report a station as lost unless a very thorough search has been made. In case the station mark found differs from the mark given in the description furnished by this office, full details should be stated in the recovery note.

86. Description of stations.—Descriptions shall be furnished of all marked stations. For each station which is in itself a mark, as are lighthouses, church spires, cupolas, towers, large chimneys, objects valuable for future hydrographic signals, sharp peaks, etc., either a description must be furnished or the records, list of directions, and lists of positions must be made to show clearly in connection with each point by special words or phrases, if necessary, the exact point of the structure or object to which the horizontal and vertical measures refer. Every land section corner connected with the triangulation must be fully described. The purpose of the description is to enable one who is unfamiliar with the locality to find the exact point determined as the station and to know positively that he has found it. Nothing should be put into the description that does not serve this purpose. A sketch is not necessary, for the description can express in words the essential facts which would be shown on the sketch. There is no objection to a sketch being made, but the written description must be complete without it.

87. Only one copy of the descriptions of stations need be sent to the office but these descriptions must be on form 525 (see sample description on p. 50) and should be written on the typewriter if possible. The essential information which should be contained in a description is as follows:

Locality (general and particular).

How marked.

Distances (by tape) and *directions* (by theodolite) from center of station to reference and witness marks; and, if necessary for the recovery of the station, *directions* or magnetic *bearings* to prominent objects in the vicinity, *tangents* to points, islands, etc. In any set of directions to prominent objects and to reference and witness marks, a main scheme or intersection station should be used as the initial.

Notes describing the marks which are given in paragraphs 92 to 95 may be referred to by number, thus lessening the amount of work necessary in writing the descriptions. Wherever an exceptional mode of marking is used, the marks must be described in full. The notes in paragraphs 92 to 95 cover the various methods of marking now in general use by parties of this Survey.

The height above the station mark of the top of the signal pole, and of any other part of the signal likely to be used in observing vertical angles, should be measured in meters and centimeters and so stated in the "Description of stations."

88. Standard notes for use in descriptions of stations.—The following notes on the marking of stations are made as general as possible in order that it may not be necessary in the field to describe small and unimportant variations. For instance, no dimensions are given for the different concrete blocks and bowlders, but it is understood that they will have a volume of at least 1 or 2 cubic feet as a general rule. Although it is not stated in the notes, the surface and reference marks should project a little above the ground, say from 1 to 6 inches. In the notes regarding the underground marks the distance of the mark below the surface of the ground is stated as 3 feet. This probably represents closely the average value. Unless the variation from this value exceeds 6 inches it need not be stated in the description. Whenever a type of marking is used which is not covered by these notes, the marks used should be described in the record.

89. The standard triangulation disk station mark referred to in the following notes consists of a disk and shank made of brass and cast in one piece. The disk is 90 millimeters in diameter, with a small hole at the center surrounded by a 20-millimeter equilateral triangle, and has the following inscription: "U. S. Coast and Geodetic Survey triangulation station. For information write to Superintendent, Washington, D. C. $250 fine or imprisonment for disturbing this mark." On marks established after the year 1920 the word Director will supersede the word Superintendent. The shank is 25 millimeters in diameter and 80 millimeters long, with a slit at the lower end into which a wedge is inserted, so that when it is driven into a drill hole in the rock it will bulge at the bottom and hold the mark securely in place. (See par. 91.)

90. The authority for the warning concerning punishment for disturbing the mark is contained in an act of Congress, approved

March 4, 1909, entitled "An act to codify, revise, and amend the penal laws of the United States," and reads as follows: "Whoever * * * shall willfully deface, change, or remove any monument or bench mark of any Government survey shall be fined not more than $250, or imprisoned not more than six months, or both." 35 Statute 1088, section 57. Many States have also enacted additional laws, among them being California, Connecticut, Georgia, Illinois, Indiana, Maine, Maryland, Massachusetts, Minnesota, Michigan, Missouri, Mississippi, New Hampshire, New Jersey, Ohio, Oregon, South Carolina, Tennessee, Vermont, Virginia, and West Virginia.

91. The standard disk reference mark referred to in the following notes is similar to the standard disk triangulation-station mark described above, except that the center of the disk is inscribed with an arrow instead of with the triangle and that the words "reference mark" replace the words "triangulation station" in the inscription. A short perpendicular groove across the shank of the arrow indicates the point to which the measurements are made. The mark is set so that the arrow points toward the station. Both station and reference marks should have stamped upon the top, by means of steel dies, the name of the station and the year of its original location.

92. Surface-station marks.—

Note 1.—A standard disk station mark set in the top of (*a*) a square block or post of concrete, (*b*) a concrete cylinder, (*c*) an irregular mass of concrete.

Note 2.—A standard disk station mark wedged in a drill hole in outcropping bedrock (*a*) and surrounded by a triangle chiseled in the rock, (*b*) and surrounded by a circle chiseled in the rock, (*c*) at the intersection of two lines chiseled in the rock.

Note 3.—A standard disk station mark set in concrete in a depression in outcropping bedrock.

Note 4.—A standard disk station mark wedged in a drill hole in a bowlder.

Note 5.—A standard disk station mark set in concrete in a depression in a bowlder.

Note 6.—A standard disk station mark set in concrete at the center of the top of a tile (*a*) which is embedded in the ground, (*b*) which is surrounded by a mass of concrete, (*c*) which is fastened by means of concrete to the upper end of a long wooden pile driven into the marsh, (*d*) which is set in a block of concrete and projects from 12 to 20 inches above the block.

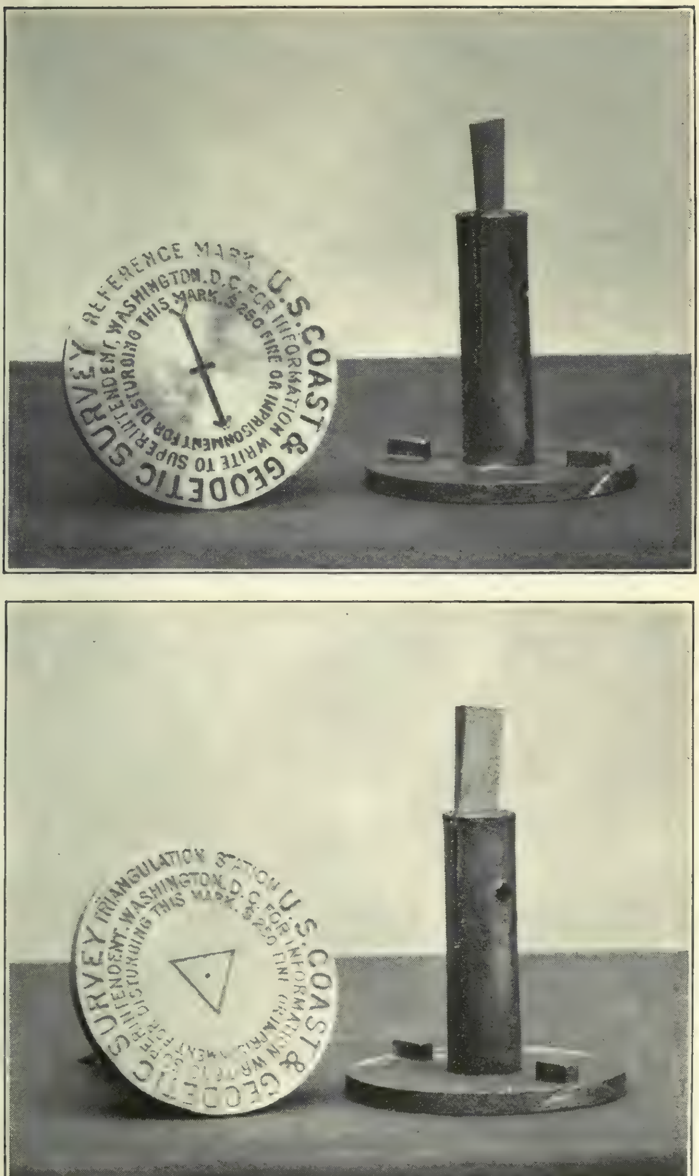

FIG. 15.—Standard station and reference marks used in marking triangulation stations.

93. Underground-station marks.—

Note 7.—A block of concrete 3 feet below the ground containing at the center of its upper surface (*a*) a standard disk station mark, (*b*) a copper bolt projecting slightly above the concrete, (*c*) an iron nail with the point projecting above the concrete, (*d*) a glass bottle with the neck projecting a little above the concrete, (*e*) an earthenware jug with the mouth projecting a little above the concrete.

Note 8.—In bedrock, (*a*) a standard disk station and mark wedged in a drill hole, (*b*) a standard disk station mark set in concrete in a depression, (*c*) a copper bolt set in cement in a drill hole or depression, (*d*) an iron spike set point up in cement in a drill hole or depression.

Note 9.—In a bowlder 3 feet below the ground, (*a*) a standard disk station mark wedged in a drill hole, (*b*) a standard disk station mark set in concrete in a depression, (*c*) a copper bolt set with cement in a drill hole or depression, (*d*) an iron spike set with cement in a drill hole or depression.

Note 10.—Embedded in earth 3 feet below the surface of the ground, (*a*) a bottle in an upright position, (*b*) an earthenware jug in an upright position, (*c*) a brick in a horizontal position with a drill hole in its upper surface.

94. Reference marks.—

Note 11.—A standard disk reference mark with the arrow pointing toward the station set at the center of the top of, (*a*) a square block or post of concrete, (*b*) a concrete cylinder, (*c*) an irregular mass of concrete.

Note 12.—A standard disk reference mark with the arrow pointing toward the station, (*a*) wedged in a drill hole in outcropping bedrock, (*b*) set in concrete in a depression in outcropping bedrock, (*c*) wedged in a drill hole in a bowlder, (*d*) set in concrete in a depression in a bowlder.

Note 13.—A standard disk reference mark with the arrow pointing toward the station set in concrete at the center of the top of a tile, (*a*) which is embedded in the ground, (*b*) which is surrounded by a mass of concrete, (*c*) which is fastened by means of concrete to the upper end of a long wooden pile driven into the marsh, (*d*) which is set in a block of concrete and projects from 12 to 20 inches above the block.

95. Witness marks.—

Note 14.—A conical mound of earth surrounded by a circular trench.

Note 15.—A tree marked with, (*a*) a triangular blaze with a nail at the center and each apex of the triangle, (*b*) a square blaze with a nail at the center and each corner of the square, (*c*) a blaze with a standard disk reference mark set at its center into the tree.

96. Sample descriptions.—

DESCRIPTION OF TRIANGULATION STATION.

DEPARTMENT OF COMMERCE,
U. S. COAST AND GEODETIC SURVEY.

Form 525.

Name of station: *Lopena.* State: *Texas.* County: *Willacy.*
Chief of party: *E. H. Pagenhart.* Year: *1913.* Locality: *Laguna Madre.*

Surface-station mark, Note, *1b.*
Underground-station mark, Note, *7c.*
Reference mark, Note, *11b.*
Reference mark, Note,
Witness mark, Note,
Witness mark, Note,
Height of signal above station mark, *1* meter.
Height of telescope above station mark, *1 1/2* meters.

Distances and directions to reference marks and prominent objects.

Object.	Distance.	Direction.	Azimuth.
		° ′ ″	° ′ ″
Acoca		*0 00*	
Windmill (northern one of two).	*1 mile*	*138 25*	
Windmill	*3/8 mile*	*247 25*	
Reference mark	*81.62 meters*	*351 41*	

Detailed description:
Near the southwestern end of a high sandy ridge partly covered with grass, on a large island known as Lopena Island on the western side of Laguna Madre. The ridge is near the western side of the island and about midway of its length north and south. The station is in range with the left tangent of the southernmost one of a group of four islands about ¼ miles distant in a south-southwest direction and the left tangent of an island west of the southern end of Lopena Island.

Described by *E. H. Pagenhart.* Marked by *G. D. Cowie.*

NOTE.—The initial direction must be to a main scheme station.

DESCRIPTION OF TRIANGULATION STATION.

DEPARTMENT OF COMMERCE,
U. S. COAST AND GEODETIC SURVEY.
Form 525.

Name of station: *Swan Point 3.* State: *Maryland.* County: *Queen Annes.*
Chief of party: *C. C. Yates.* Year: *1909.* Locality: *Chesapeake Bay.*

Surface-station mark, Note, *1a.*
Underground-station mark, Note, *7d.*
Reference mark, Note, *11a.*
Reference mark, Note,
Witness mark, Note,
Witness mark, Note,
Height of signal above station mark, *2* meters.
Height of telescope above station mark, *2½* meters.

Distances and directions to reference marks and prominent objects.

Object.	Distance.	Direction.	Azimuth.
		° ′ ″	° ′ ″
Love Point Light		*0 00*	
Chimney of cabin	*55 meters ±,*	*208 54*	
Gable of Rockhall wharfhouse.	*1 mile*	*264 07*	
Reference mark, a copper bolt in a block of concrete.	*21.43 meters*	*267 02*	
Reference mark (note 11a).	*13.26 meters*	*267 02*	
Chimney of house to right of Windmill Point.	*2 miles*	*292 12*	
Gable of barn	*2½ miles*	*308 49*	

Detailed description:

On Swan Point, a sand and marsh point on the eastern shore of Chesapeake Bay, about 5½ miles south-southwest of Tolchester Beach Wharf and 7 miles north of Love Point. The station is about 225 meters from the extremity of the point, about 1½ meters back from the shore line, and about 55 meters southwest of a fisherman's cabin.

Described by *C. C. Yates.* Marked by *J. J. Phelan.*

NOTE.—The initial direction must be to a main scheme station.

RECOVERY NOTE, TRIANGULATION STATION. R

DEPARTMENT OF COMMERCE,
U. S. COAST AND GEODETIC SURVEY.
Form 526.

Name of station: *Marysville Butte.* State: *California.* County: *Sutter.*
Established by: *W. Eimbeck.* Year: *1876.* Locality: *Sacramento Valley.*
Recovered by: *A. F. Rodgers.* Year: *1904.*

Detailed statement as to the fitness of the original description:

About 15 miles west of Marysville, on the southeastern summit of the south butte of the Marysville Buttes, about 6 meters northeast of the highest part of the summit, and near the steep cliff on the northern side. The station was marked originally by a copper bolt set in a drill hole in a depression in outcropping bedrock. When recovered in 1904 this mark was found in good condition. As an additional mark the depression was filled with concrete in which a standard disk station mark was placed directly above the copper bolt.

Distances and directions at stations.

	Distance.	*Direction.*
		° ′
Mount Helena		*0 00*
Reference mark No. 1 (note 12a)......meters	*2.915*	*53 04*
Reference mark No. 2 (copper bolt set in solid rock)......do	*2.470*	*196 45*
Reference mark No. 3 (same as No. 2)......do	*2.635*	*315 03*

NOTE.—One of these forms must be used for every station recovered.

97. Land section corners and other survey marks.—Whenever it is feasible to do so without incurring undue expense, the section corners established by the Land Survey, and survey marks of any kind found upon the ground, including township, county, State, and international boundary monuments, shall be connected with the trangulation, either by direct measurement of a distance and direction from a triangulation station or by treating them as intersection stations.

98. It will insure the permanence of a station if it is related by direct measures or otherwise to neighboring cadastral features, and a station located close to a line fence is less liable to disturbance than one situated out in an open field.

99. Poor seeing.—Observations either in the main scheme or on intersection stations in triangulation of this class may be taken under any atmospheric conditions when the object to be pointed upon is visible and there should be no delay to secure good seeing before observing. If the seeing is very poor, it may be necessary to increase the number of observations on angles in the main scheme in order to secure the required accuracy. The decision in regard to the necessity of each increase should be based upon the triangle closures which are secured with such poor seeing rather than upon the appearance of the signals or even upon the range of the observations.

100. Field computations.—The field computations for the main scheme and supplementary stations are to be carried to even seconds in the angles and azimuths, to hundredths of seconds in the latitudes and longitudes, and to five places in the logarithms. The field computations for intersection stations, and for indefinite objects should be carried out to a sufficient number of decimal places to give two uncertain figures in each result. In general it will be necessary to carry the angles to even seconds and the logarithms to five places. The computation of the horizontal measurements up to and including the lists of directions for all stations and objects and the computation of the triangle sides of the main scheme should be kept up as closely as possible as the work progresses, to enable the observer to know that the observations are of the required degree of accuracy and completeness. No least square adjustments are to be made in the field. All of the computation (taking of means, etc.) which is made in the record books and in the lists of directions, should be so thoroughly checked by some person, other than the one by whom it was originally done, as to render an examination in the office unnecessary. If there is no one in the party besides the observer who is competent to check the computations, then it will be acceptable for the observer to do the checking, but it should not be done immediately after the computing. The initials of the persons making and checking the computations in the record books and the lists of directions should be signed to the record as the computation and checking progresses. Pointings upon indefinite objects should be carefully examined, graphically or otherwise, the objects identified, and the identification clearly indicated in the records and computations. It is important to indicate clearly what lines are to objects on which no pointing was secured from a second station, as well as to indicate by common names or symbols what lines are to the same object. This must be done as the field work progresses.

101. In laying out the triangle side computation, the names of the stations should be written in the triangle in a clockwise direction, and the order of triangles should be such as to give two or more results for the side to be used as a base for going ahead.

102. For each quadrilateral figure the length of the base from which it is computed should be that resulting from the computation of the two strongest triangles (those used in computing R_1) in the preceding quadrilateral. The length computed through the two weakest triangles should be used only as a check. With well-shaped figures the two values for any one line will, in general, agree within 1 part in 5000, unless a mistake has been made.

103. In the position computation on Form 27 the position of a station should be computed from the two sides, radiating from the point, of one of the stronger triangles, used for carrying forward the lengths, and from the angles of that triangle. In any triangle *C B A*, figure 16, *C* being the new point whose position is desired, the line from *B* to *C* is computed on the left page of the form and from *A* to *C* on the right page. With the triangle side and position computation written as above (from left to right) the angles at *B* and *A* are always, respectively, + and −, and no sketch is necessary to write up the position computation. The

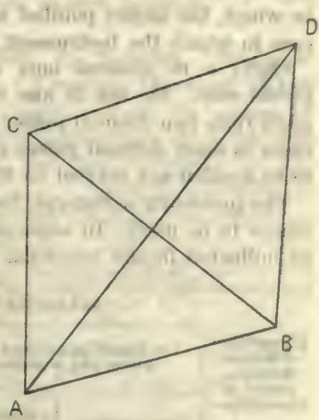

FIG. 16.

factors for the position computation in the latitudes from 0° to 72° are given in Special Publication No. 8. There are also given in the preface to that publication detailed directions, with sample forms, for making the position computation.

104. Where connection is made with a base the measured length is to be used in going ahead.

105. Reduction to center of observations at eccentric station.—Use Form 382. The instructions for computing the reduction to center are given on the back of the form, a copy of which is given below. A sketch showing the relative position of the center and eccentric station with directions to one or more stations must be entered in the record and on the list of directions.

The required reduction to center is, in seconds, $c=\frac{d \sin \alpha}{s \sin 1''}$, in which d is the distance from the eccentric station to the true station, and s is the length in meters of the line between the true stations involved, and, therefore, log s is taken directly from the computation of triangle sides. α is the direction of the distant station involved, reckoned in a clockwise direction as usual, but referred to the direction from the eccentric to the true station, or center, taken as zero. This definition of α is true for the case in which the object pointed upon is eccentric, as well as for the case in which the instrument is eccentric.

Carry α to minutes only and all logarithms to five decimal places only. Do not in any case carry the derived reductions to more than two decimal places. There is no advantage in carrying them to more decimal places than the directions to which they are to be applied are carried on Form 24A.

The preceding paragraph fixed the maximum number of decimal places to be used. In some cases a smaller number may be used as indicated in the following table:

If logarithm of shortest line concerned is more than—	And d is less than value stated below in meters—			
	Use logarithms to four decimal places and α to minutes.		Use logarithms to three decimal places and α to degrees.	
	Primary triangulation.	Secondary or tertiary triangulation.	Primary triangulation.	Secondary or tertiary triangulation.
2.5	....	0.6	....	0.02
3.0	....	2	....	0.06
3.5	0.6	6	0.02	0.2
4.0	2	20	0.06	0.6
4.5	6	....	0.2	2
5.0	20	....	0.6	6

REDUCTIONS FOR AN ECCENTRIC INSTRUMENT.

If the instrument is eccentric, the first column of this form should contain the names of the stations observed from that eccentric position of the instrument.

The values in the fifth column are derived by subtracting those in the fourth column from those in the third. The values in the fourth column may need to be derived by successive approximations from the triangle side computations if the eccentric reductions are large. The values in the sixth column are obtained from those in the fifth by adding log $\frac{d}{\sin 1''}$ derived as indicated in the heading of the form, if d is expressed in meters. If d is expressed in feet, to the other two logarithms add also 9.48402 to convert to meters. To obtain a direction as shown on Form 24 A, subtract the reduction c for the station which is the initial on Form 24 A from the reduction c for the required direction and apply the difference to the observed direction. Similarly, the correction to any angle is the difference of the reductions on this form to the two directions involved in that angle.

REDUCTIONS FOR AN ECCENTRIC OBJECT OBSERVED.

If the object observed is eccentric, the heading "Eccentric Station ——" should be changed to "Eccentric Observed Object at Station ——," the first column should contain the names of the stations from which this eccentric object was observed, and in each case α is the direction from the eccentric object to the distant station involved, reckoned in a clockwise direction as usual, but referred to the direction from the eccentric object to the true station, or center, taken as zero. (No distinction need be made between the direction from the eccentric object to the distant station and the direction from the true station to the distant station except when the eccentric reduction is more than one minute.) The remainder of the computation on this form is made in the manner indicated above with reference to an eccentric instrument. The reductions to directions are, however, to be applied to observed directions, at the stations named in the first column, to the eccentric object at the station named in the heading. The directions to which these reductions are to be applied are therefore found in various of the lists of directions on Form 24 A, not all in one list as is the case when the instrument is eccentric.

Compare the following example with that given on Form 24A.

REDUCTION TO CENTER.

Eccentric Station: Chase.

Log d = 1.04088
Colog sin 1″ = 5.31443

d = 10.987 meters.

Sum 6.35531

Stations.	α.		Log sin α.	Log s.	Log $\frac{\sin \alpha}{s}$.	Logarithms of reduction in seconds.	Reduction $=c$.
	°	′					″
Center	0	00					
Central	224	27	9.84528	4.40254	5.44274	1.79805	− 62.81
Little River	242	47	9.94904	4.51928	5.42976	1.78507	− 60.96
Lyons, salt works	249	02	9.97025	4.30616	5.66409	2.01940	−104.57
Bossing	179	18	8.08696	4.49198	3.59498	9.95029	+ 0.89

106. Spherical excess.—The spherical excess which is proportional to the area of the triangle becomes appreciable only when the sides are from 4 to 5 miles in length. One-third of the computed excess is deducted from each angle of the triangle, and the difference between the sum of the resulting angles of the triangle and 180° is the error of closure to be distributed. The formula for the spherical excess E is

$$E = mab \sin C.$$

in which a, b are the triangle sides and C the included angle. The values of m are tabulated for every 30′ of latitude, and are printed in Special Publication No. 8, page 16. A condensed table of log m to four decimal places for every 5° of latitude is given below. A rough approximation of the spherical excess of a triangle in seconds is obtained by multiplying its area in square miles by $1\frac{1}{3}$ and pointing off two decimal places.

107. Condensed table of log m.—

Latitude.	Log m.	Latitude.	Log m.	Latitude.	Log m.
°		°		°	
0	1.4070	25	1.4059	50	1.4035
5	69	30	55	55	30
10	68	35	50	60	25
15	66	40	45	65	21
20	63	45	40	70	17

108. Mathematical solution of the three-point problem.—If three points, forming a triangle of which the sides and angles are known or can be computed, be visible from a fourth point *P*, it is required to determine the position of *P*.

Set up the theodolite at *P* and measure the two angles subtended by any two of the given sides.

This problem is of use in cases where the regular triangulation having been completed, additional points are required for the topographic survey or are needed for special use. The angles should be carefully measured and in the computations the logarithms should be carried to the same number of places of decimals as in the regular triangle side computation.

Three cases of its application are given, depending upon the location of the point *P* with reference to the sides of the triangle. If *P* falls upon the prolongation of a side of the triangle the case resolves itself into the solution of a triangle with a side and all the angles given, while if *P* is situated on the circumference of the circle passing through the vertices of the triangle the problem is indeterminate.

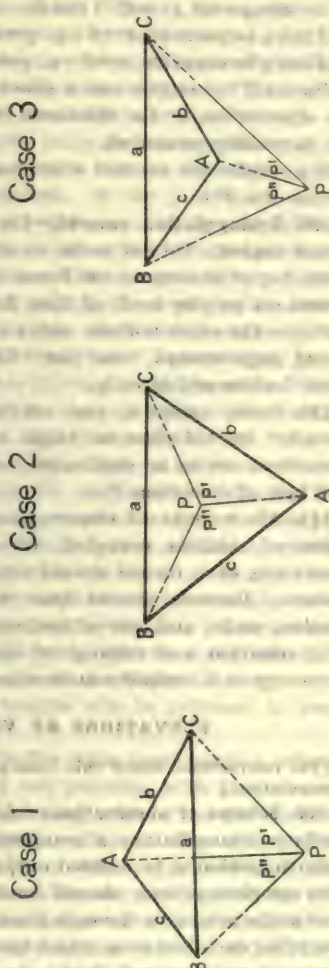

FIG. 17.

Given the sides, a, b, c, and the angle A.

Angles observed, $APC=P'$ $APB=P''$.

To find, $ABP=x$ and $ACP=y$.

In cases I and II, let $S=180°-\frac{1}{2}(A+P'+P'')=\frac{1}{2}(x+y)$.

In case III, $S=\frac{1}{2}(A-P'-P'')=\frac{1}{2}(x+y)$.

Let $\tan Z=\dfrac{c \sin P'}{b \sin P''}$

then,

$$\varepsilon = \tfrac{1}{2}(x - y)$$

$$\tan \varepsilon = \cot (z + 45^\circ) \tan S.$$

If $\tan \varepsilon$ be positive, $x = S + \varepsilon$, $y = S - \varepsilon$.

If $\tan \varepsilon$ be negative, $x = S - \varepsilon$, $y = S + \varepsilon$.

Since all the angles and a side in each triangle are now known, the other sides, or the distances from P to the three given points, can be readily computed.

The results are verified when both triangles give the same value for the line PA.

109. Triangulation records.—Do not duplicate volumes of horizontal angles. Do not make an abstract of angles. Make a complete list of directions on Form 24A, in accordance with the instructions on the back of that form. The local adjustment corrections (to close horizon only) are to be written in the "Horizontal angle record," and the "List of directions" is to be made from that record directly.

110. Base, azimuth, and vertical angle observations may be recorded in "Horizontal angle record." Base and azimuth observations are to be duplicated on computing paper and attached to "List of directions."

111. All records of observations should contain an alphabetic index of stations occupied. When stations are occupied more than once, each record should have a cross reference to page and volume. Records should also contain a preface giving briefly number, make, and size of instrument, with direction and manner of graduation and method of observation, and any information necessary to a complete understanding of the record.

ELEVATIONS BY VERTICAL ANGLES.

[The instructions under this head apply to both secondary and tertiary triangulation.]

112. Scheme of observations.—In connection with secondary and tertiary triangulation a complete scheme of vertical angle observations should be carried out, except in the cases stated below. This complete scheme should consist of a continuous series of vertical angle measures through the main scheme of the triangulation, observing each line over which horizontal angles are observed (the observations over each line to be made in both directions if both ends of the line are occupied), and should also include observations of vertical angles upon all supplementary and intersection stations corresponding to the horizontal angles measured upon such stations. Connections should be made with elevations accurately determined by precise leveling, wye leveling, or tidal observations as frequently as possible. When a triangulation is carried along a coast or tidal stream, at each station near the shore where it is convenient to do so, a connection should be made with mean sea level and the connection recorded. Tide gauge marks should be included where available, but otherwise an observed vertical angle to the water's edge and an approximate distance to the point sighted upon, with a note as to height of tide or the time, may serve the purpose. If the plane-table topography fixes the elevation in the region covered by the triangulation, that part of the observations of vertical angles upon supplementary and intersection stations which would merely furnish redeterminations of elevations fixed by the topographic survey may be omitted, but the observations of vertical angles in the main scheme and upon supplementary and intersection points beyond the limits of the plane-table surveys should be made. If the scheme of triangulation is along a coast or river, with no high ground visible from the stations, and if at each station it is not difficult to make a sea-level connection, then a series of vertical angles need not be carried through the main scheme. In this case only such vertical angles should be observed as are necessary to determine the elevations of the highest points of aids to navigation, such as lighthouses, standpipes, stacks, etc. If the elevations of such aids to navigation throughout the scheme are known to be fixed previously in elevation, no observations whatever need be made. This condition will probably seldom occur, and then only on the Atlantic and Gulf coasts of the United States.

113. Plane of reference.—All heights will be referred to mean sea level.

114. Method of observation.—In the main triangulation scheme, two measures, each consisting of one pointing with the telescope in the direct position and one pointing with it in the reversed position, on each day of occupation is sufficient. For observations on intersection stations and indefinite objects two measures, each consisting of one pointing in each of the two positions of the telescope, on only one day are all that are necessary. Such observations should be taken on each intersection station or indefinite object from all the stations from which horizontal angles are measured to that station or object.

115. As far as practicable, the observations for vertical angles should be made as near the middle of the day as possible, and in any event not before 10 o'clock in the morning nor later than one

hour before sundown. Early morning and late afternoon observations are of lower accuracy, owing to rapidly changing vertical refraction.

116. An essential for the accurate measurement of vertical angles, whether in triangulation or for astronomic positions, is that the vertical axis be truly vertical or that the effect of errors of verticality be eliminated by the method of observation. The instrument should of course be leveled and placed in adjustment before beginning observations, but thereafter error in verticality of axis will be eliminated by the following system of observing for each elevation to be determined:

117. Directions for observations.—(*a*) Point on object, bring horizontal thread to position by telescope-clamp slow-motion screw; (*b*) bring to the center of the vial the bubble attached to the verniers of the vertical circle by means of the vernier slow-motion screw; (*c*) read both verniers; (*d*) turn the instrument 180° in azimuth and transit the telescope. Repeat (*a*), (*b*), and (*c*) in same order. Do not change the relation between the axis of the bubble and the line joining the zeros of the verniers between the two pointings of a set. For all important objects determination of elevation should be obtained from at least three stations.

118. If the instrument used is a theodolite of 7-inch circle or smaller, it is usually best to bring the bubble to the center of the scale for each pointing in order to avoid having level corrections. With the larger instruments, especially designed for trigonometric leveling, the bubble is very sensitive, and it will be found best to make level readings for any position the bubble may be on the scale rather than attempt to center the bubble. If the vertical circle is fastened rigidly to the telescope of the theodolite, the bubble may be brought to the center by means of the foot screws (before making the pointing) or by the slow-motion screw of the frame supporting the bubble and verniers after making the second pointing. If the instrument is one by which the vertical angles are measured by the method of repetitions, then the bubble must be brought to the center or on the scale, for the second pointing, by the foot screws only.

119. Record.—Observations should be recorded in the usual Double Zenith Distance records except in work where very few stations are occupied for vertical angles, in which case they may be recorded in the Horizontal Angle record book and listed in the table of contents. The actual circle readings are always to be recorded.

120. The D. Z. D. record is arranged for use with repeating vertical circle; for observations as here proposed the columns headed "Rep's of DZD," "Level," "C," and "D" may be left blank.

121. In every case the record must show clearly the height of the instrument in meters and centimeters above the surface mark at the station occupied and the exact point observed on at each distant signal with its height above the surface mark; whenever the entire signal is visible the ground should be observed and so noted. In observing objects other than signals care should be taken to note in the record the exact point sighted upon in each case, as, for example, for mountain peaks, "ground" or "tops of trees"; for a church, "top of dome" or "top of tower," etc. When tops of trees are observed the estimated height above ground should be noted in the record and the ground should be observed if practicable.

122. In the case of mountains and hilltops a small sketch showing the relation of the point determined to the outline of the surrounding elevations will be useful in representing the object on the chart, as well as to the observer in identifying the object from another station.

123. Computation of elevations from observations of zenith distances made in connection with tertiary triangulation.—Abstract all zenith distances on Form 29, bringing together all observations upon the same object from a given station, and taking the mean. If the observations are taken on more than one day, give the mean result for each day the same weight, regardless of whether many or few observations were made on that day.

124. In the record book and on Form 29 carry all angles to seconds only.

125. The value in the column headed "Object above station" is zero if the object pointed upon is the final mark for elevation, as, for example, the top of a chimney, top of a spire, etc.

126. Use the column headed "Reduction to line joining stations" only when the observations are reciprocal—that is, are made in both directions over the line in question. The quantity in this column is an angle of which the value in seconds is $-\frac{t-o}{s \sin 1''}$, in which s is the horizontal distance between stations, t the elevation of the telescope above the station mark at the observer's station, and o the elevation of the object sighted on above the station mark at the distant station. This formula represents, therefore, a vertical eccentric reduction which is to be applied as a correction to the observed zenith distance to obtain the corrected zenith distance. Four places in the logarithms are all that are necessary in computing these values.

127. If the observations are made in one direction only over a line, the above vertical eccentric reduction is not needed. Instead, **the difference *t*—*o*, expressed in meters, is to be applied as a correction to the computed difference of elevation, as indicated on** Form 29B.

128. **For reciprocal observations** use Form 29A in computing differences of elevation. The lower part of the form, involving the weight p and the coefficient of refraction m, is not used in field computations. The formula for the difference of elevation between stations 1 and 2 is:

$$h_2 - h_1 = s \tan \tfrac{1}{2} (\zeta_2 - \zeta_1) \; [A \; B \; C].$$

In this formula h_1 is the elevation above mean sea level of station 1. which should be the station whose elevation is the more precisely known; h_2 is the elevation of station 2; s is the horizontal distance between the stations, reduced to sea level, log s being taken from the best available computation of triangle sides: ζ_2 is the mean corrected zenith distance of station 1, as observed from station 2; similarly, ζ_1 is the zenith distance of station 2 from station 1. The values of ζ_2 and ζ_1 are to be taken from computing Form 29. A, B, and C are correction factors whose values are nearly unity and whose logarithms may be found in Tables a, b, and c, on pages — and —. A is the correction factor for the elevation of station 1; its formula is

$$A = 1 + \frac{h_1}{\rho},$$

in which ρ is the radius of curvature of the arc between stations 1 and 2. B is the correction factor to the approximate difference of elevation, $s \tan \frac{1}{2} (\zeta_2 - \zeta_1)$. Its expression is:

$$B = 1 + \frac{s}{2\rho} \tan \tfrac{1}{2} (\zeta_2 - \zeta_1).$$

C is the correction factor for the distance between stations, its expression being

$$C = 1 + \frac{s^2}{12\rho^2}.$$

Further explanations in regard to A, B, and C will be found in connection with their respective tables.

129. Compute through the form by horizontal lines. In the form a brace groups those quantities which, added together, give the quantity on the line immediately below the brace. In field computations carry the angles to seconds, the logarithms to five places of decimals, and the differences of elevation to hundredths of meters. In field computations the lines marked "$\frac{1}{2}$ $(\zeta_2-\zeta_1)$ in secs." and "log ditto" may be omitted and log tan $\frac{1}{2}$ $(\zeta_2-\zeta_1)$ may be taken directly from Vega's or Shortrede's tables and entered in the line marked "T." Having found log $[s \tan \frac{1}{2} (\zeta_2-\zeta_1)]$, use it to take out log B from Table b. Add algebraically the logarithms of A, B, and C to log $[s \tan \frac{1}{2} (\zeta_2-\zeta_1)]$; the sum will be log (h_2-h_1), h_2-h_1 being expressed in the same unit as s, in this case the meter, which is the unit throughout the computation. To convert meters to feet, which should be used in topographic work, multiply the number of meters by 3.28083 (log 3.28083= 0.51598).

130. For nonreciprocal observations use Form 29B in computing differences of elevation. The computation of weights provided for at the bottom of the form may be omitted in a field computation. The same rules as to the number of figures, etc., will apply here as to the computation of reciprocal observations and the braces have the same meaning as in Form 29A. The formula for difference of elevation is similar to that for reciprocal elevations, but since only one zenith distance (ζ_1) is observed, the quantity $\frac{1}{2}$ $(\zeta_2-\zeta_1)$ must be replaced by $90°+k-\zeta_1$, the value in seconds of k being given by the equation $k=\frac{(0.5-m)\,s}{\rho \sin 1''}$. In this equation m is the coefficient of refraction, which varies with varying atmospheric conditions. In office computations the best available value of m will be used, but for field computations put

$$\log (0.5-m)=9.63246\text{–}10$$

which corresponds to m=0.071. Log ρ comes from the table in paragraph 138, the arguments of which are the mean azimuth and mean latitude (α and ϕ) of the line. These quantities need not be known closer than the nearest tenth of a degree. Having found k (to the nearest second only for field computations) the formula for the difference of elevation is given by

$$h_2-h_1=s \tan (90°+k-\zeta_1)\ [A\ B\ C].$$

The quantity ζ_1 is the mean observed zenith distance and comes from Form 29, as does also the quantity $t-o$ which is to be applied as a correction to h_2-h_1 as indicated in paragraph 127. No vertical eccentric angular reduction is to be applied to ζ_1. This is contrary to the practice on reciprocal zenith distances.

131. In the field computations the lines marked "$90°+k-\zeta_1$ in secs." and "log ditto" may be omitted and log tan $(90°+k-\zeta_1)$ taken directly from Vega's or Shortrede's tables and entered in the line marked "T." Log $[s \tan (90°+k-\zeta_1)]$ is used as the argument for log B. The arguments of log A and log C are h_1 and log s, respectively, as in the case of reciprocal observations. The logarithms of A, B, and C added algebraically to log $[s \tan (90°+k-\zeta_1)]$ give log (h_2-h_1).

132. Table *a* gives the values of log A, the correction factor for the elevation of the known station, by showing the limiting values of the elevation h_1, between which log A may be taken as 0, 1, 2, 3, etc., units of the fifth place of decimals. Log A is positive, except in the very rare case where h_1 corresponds to a point below mean sea level.

133. Table *a*.

h_1	Log A, units of fifth place of decimals.	h_1	Log A, units of fifth place of decimals.	h_1	Log A, units of fifth place of decimals.	h_1	Log A, units of fifth place of decimals.
Meters.		*Meters.*		*Meters.*		*Meters.*	
0		1541		3156		4770	
	0		11		22		33
73		1688		3303		4917	
	1		12		23		34
220		1835		3449		5064	
	2		13		24		35
367		1982		3596		5211	
	3		14		25		36
514		2128		3743		5357	
	4		15		26		37
661		2275		3890		5504	
	5		16		27		38
807		2422		4036		5651	
	6		17		28		39
954		2569		4183		5798	
	7		18		29		40
1101		2715		4330		5945	
	8		19		30		41
1248		2862		4477		6091	
	9		20		31		
1394		3009		4624			
	10		21		32		
1541		3156		4770			

134. Table *b* gives the values of log B, the correction factor for approximate difference of elevation, by showing the limiting values of log $[s \tan \frac{1}{2} (\zeta_2-\zeta_1)]$ or log $[s \tan (90°+k-\zeta_1)]$ between which log B may be taken as 0, 1, 2, 3, etc., units of the fifth place of decimals. Log B has the same sign as the angle $\frac{1}{2}(\zeta_2-\zeta_1)$ or $90°+k-\zeta_1$; for example, if log $[s \tan \frac{1}{2}(\zeta_2-\zeta_1)]$ lies between 3.565 and 3.598 and $\frac{1}{2}(\zeta_2-\zeta_1)$ is positive, log $B=+0.00013$, but if $\frac{1}{2}(\zeta_2-\zeta_1)$ is negative then log $B=-0.00013$, i. e., 9.99987—10, the former way of writing being usually more convenient in practice.

135. Table *b*.

Log [$s \tan \frac{1}{2}(\zeta_2-\zeta_1)$] or log [$s \tan (90°+k-\zeta_1)$]. ($s$ in meters.)	Log B, units of fifth place of decimals.	Log [$s \tan \frac{1}{2}(\zeta_2-\zeta_1)$] or log [$s \tan (90°+k-\zeta_1)$]. ($s$ in meters.)	Log B, units of fifth place of decimals.	Log [$s \tan \frac{1}{2}(\zeta_2-\zeta_1)$] or log [$s \tan (90°+k-\zeta_1)$]. ($s$ in meters).	Log B, units of fifth place of decimals.
−∞					
	0				
2.167		3.397		3.685	
	1		9		17
2.644		3.445		3.711	
	2		10		18
2.866		[illegible]		3.735	
	3		11		19
3.011		3.528		3.758	
	4		12		20
3.121		3.565		3.779	
	5		13		21
3.208		3.598		3.800	
	6		14		22
3.281		3.629		3.820	
	7		15		23
3.343		3.658		3.839	
	8		16		24
3.397		3.685		3.857	

136. Table *c* gives the value of log C, the correction factor for distance between stations, by showing the limiting values of log s between which log C may be taken as 0, 1, 2, 3, etc., units of the fifth place of decimals. Log C is always positive.

137. Table *c*.

Log s (s in meters).	Log C, units of fifth place of decimals.	Log s (s in meters).	Log C, units of fifth place of decimals.
0.000		5.297	
	0		4
4.875		5.352	
	1		5
5.113		5.395	
	2		6
5.224		5.432	
	3		7
5.297		5.463	

138. Table of logarithms of radii of curvature of the earth's surface in meters for various latitudes and azimuths, based upon Clarke's ellipsoid of rotation (1866).

Azimuth.	0° lat.	1° lat.	2° lat.	3° lat.	4° lat.	5° lat.	6° lat.
°							
Meridian.	6.80175	6.80175	6.80175	6.80176	6.80177	6.80178	6.80180
5	177	177	178	178	179	180	182
10	184	184	184	185	186	187	188
15	195	195	195	196	197	198	199
20	209	209	210	210	211	212	214
25	227	228	228	228	229	230	232
30	248	249	249	250	250	251	252
35	272	272	272	273	273	274	276
40	296	297	297	297	298	299	300
45	322	322	322	323	324	324	325
50	348	348	348	348	349	350	351
55	373	373	373	373	374	374	375
60	396	396	396	396	397	398	398
65	417	417	417	418	418	418	419
70	435	435	436	436	436	437	437
75	450	450	450	450	451	451	452
80	461	461	461	461	462	462	463
85	468	468	468	468	468	469	469
90	470	470	470	470	471	471	472

Azimuth.	6° lat.	7° lat.	8° lat.	9° lat.	10° lat.	11° lat.	12° lat.
°							
Meridian.	6.80180	6.80181	6.80183	6.80186	6.80188	6.80191	6.80194
5	182	184	186	188	190	193	196
10	188	190	192	194	197	200	202
15	199	201	203	205	207	210	213
20	214	215	217	219	222	224	227
25	232	233	235	237	239	242	244
30	252	254	256	257	260	262	264
35	276	277	278	280	282	284	287
40	300	301	303	304	306	308	310
45	325	326	328	329	331	333	335
50	351	352	353	354	356	358	359
55	375	376	377	379	380	382	383
60	398	399	400	401	403	404	406
65	419	420	421	422	423	424	426
70	437	438	439	440	441	442	443
75	452	452	453	454	455	456	457
80	463	463	464	465	466	467	468
85	469	470	470	471	472	473	474
90	472	472	473	474	474	475	476

Azimuth.	12° lat.	13° lat.	14° lat.	15° lat.	16° lat.	17° lat.	18° lat.
°							
Meridian.	6. 80194	6. 80197	6. 80201	6. 80204	6. 80208	6. 80213	6. 80217
5	196	199	203	206	210	215	219
10	202	206	209	213	217	221	225
15	213	216	219	223	227	231	235
20	227	230	233	236	240	244	248
25	244	247	250	254	257	261	265
30	264	267	270	273	276	280	284
35	287	289	292	295	298	301	305
40	310	313	315	318	321	324	327
45	335	337	339	342	344	347	350
50	359	361	364	366	368	371	373
55	383	385	387	389	391	394	396
60	406	407	409	411	413	415	417
65	426	427	429	430	432	434	436
70	443	444	446	447	449	451	453
75	457	458	460	461	463	464	466
80	468	469	470	471	473	474	476
85	474	475	476	478	479	480	482
90	476	477	478	480	481	482	484

Azimuth.	18° lat.	19° lat.	20° lat.	21° lat.	22° lat.	23° lat.	24° lat.
°							
Meridian.	6. 80217	6. 80222	6. 80226	6. 80232	6. 80237	6. 80242	6. 80248
5	219	224	228	234	239	244	250
10	225	230	234	239	244	250	255
15	235	239	244	249	254	259	264
20	248	252	257	262	266	271	277
25	265	269	273	277	282	287	292
30	284	287	292	296	300	305	309
35	305	308	312	316	320	324	329
40	327	330	334	338	341	345	350
45	350	353	357	360	364	367	371
50	373	376	379	382	386	389	392
55	396	398	401	404	407	410	413
60	417	419	422	424	427	430	432
65	436	438	440	443	445	448	450
70	453	454	456	459	461	463	465
75	466	468	470	472	473	476	478
80	476	478	479	481	483	485	487
85	482	483	485	487	489	490	492
90	484	485	487	489	490	492	494

Azimuth.	24° lat.	25° lat.	26° lat.	27° lat.	28° lat.	29° lat.	30° lat.
°							
Meridian.	6. 80248	6. 80254	6. 80260	6. 80266	6. 80272	6. 80279	6. 80285
5	250	256	262	268	274	280	287
10	255	261	267	273	279	285	292
15	264	270	276	282	288	294	300
20	277	282	288	293	299	305	311
25	292	297	302	308	313	319	325
30	309	314	319	324	330	335	340
35	329	333	338	343	348	353	358
40	350	354	358	362	367	372	377
45	371	375	379	383	387	391	396
50	392	396	399	403	407	411	415
55	413	416	420	423	426	430	434
60	432	435	438	442	445	448	451
65	450	453	455	458	461	464	467
70	465	468	470	473	475	478	481
75	478	480	482	484	487	489	492
80	487	489	491	493	495	498	500
85	492	494	496	498	501	503	505
90	494	496	498	500	502	504	507

Azimuth.	30° lat.	31° lat.	32° lat.	33° lat.	34° lat.	35° lat.	36° lat.
°							
Meridian.	6. 80285	6. 80292	6. 80299	6. 80306	6. 80313	6. 80320	6. 80327
5	287	294	300	307	314	322	329
10	292	298	305	312	319	326	333
15	300	306	313	320	326	333	340
20	311	317	324	330	337	343	350
25	325	331	337	343	349	355	362
30	340	346	352	358	364	370	376
35	358	363	369	374	380	385	391
40	377	382	386	392	397	402	407
45	396	400	405	410	414	419	424
50	415	419	423	428	432	436	441
55	434	437	441	445	449	453	457
60	451	455	458	462	465	469	472
65	467	470	473	476	480	483	486
70	481	484	486	489	492	495	498
75	492	494	497	500	502	505	508
80	500	502	505	507	510	512	515
85	505	507	510	512	514	517	519
90	507	509	511	514	516	518	521

Azimuth.	36° lat.	37° lat.	38° lat.	39° lat.	40° lat.	41° lat.	42° lat.
°							
Meridian.	6.80327	6.80335	6.80342	6.80350	6.80357	6.80365	6.80373
5	329	336	344	351	359	366	374
10	333	340	348	355	363	370	378
15	340	348	355	362	369	376	384
20	350	357	364	371	378	385	392
25	362	368	375	382	388	395	402
30	376	382	388	394	401	407	413
35	391	397	402	408	414	420	426
40	407	412	418	423	429	434	440
45	424	429	434	439	444	449	454
50	441	445	450	454	459	464	468
55	457	461	465	469	474	478	482
60	472	476	480	484	487	491	495
65	486	489	493	496	500	503	507
70	498	501	504	507	510	514	517
75	508	510	513	516	519	522	525
80	515	517	520	523	525	528	531
85	519	522	524	527	529	532	534
90	521	523	526	528	531	533	536

Azimuth.	42° lat.	43° lat.	44° lat.	45° lat.	46° lat.	47° lat.	48° lat.
°							
Meridian.	6.80373	6.80380	6.80388	6.80396	6.80404	6.80411	6.80419
5	374	382	389	397	404	412	420
10	378	385	393	400	408	415	423
15	384	391	398	406	413	420	428
20	392	399	406	413	420	427	434
25	402	408	415	422	429	436	442
30	413	420	426	433	439	446	452
35	426	432	438	444	450	456	462
40	440	446	451	457	462	468	474
45	454	459	464	470	475	480	485
50	468	473	478	482	487	492	496
55	482	486	490	495	499	503	508
60	495	499	502	506	510	514	518
65	507	510	514	517	520	524	528
70	517	520	523	526	529	532	536
75	525	528	531	534	536	539	542
80	531	534	536	539	542	544	547
85	534	537	540	542	545	548	550
90	536	538	541	544	546	549	551

Azimuth.	48° lat.	49° lat.	50° lat.	51° lat.	52° lat.	53° lat.	54° lat.
°							
Meridian.	6.80419	6.80426	6.80434	6.80442	6.80449	6.80457	6.80464
5	420	428	435	443	450	458	465
10	423	430	438	445	453	460	467
15	428	435	442	450	457	464	471
20	434	441	448	455	462	469	476
25	442	449	456	463	469	476	482
30	452	458	465	471	477	484	490
35	462	468	474	480	486	492	498
40	474	479	485	490	496	501	506
45	485	490	495	500	505	510	515
50	496	501	506	510	515	520	524
55	508	512	516	520	524	528	533
60	518	522	526	530	533	537	541
65	528	531	534	538	541	545	548
70	536	539	542	545	548	551	554
75	542	545	548	551	554	557	559
80	547	550	553	555	558	561	563
85	550	553	555	558	560	563	566
90	551	554	556	559	561	564	566

Azimuth.	54° lat.	55° lat.	56° lat.	57° lat.	58° lat.	59° lat.	60° lat.
°							
Meridian.	6.80464	6.80471	6.80479	6.80486	6.80493	6.80500	6.80506
5	465	472	479	486	493	500	507
10	467	474	481	488	495	502	509
15	471	478	485	492	498	505	511
20	476	483	489	496	502	509	515
25	482	489	495	501	508	514	520
30	490	496	502	508	514	519	525
35	498	503	509	515	520	525	531
40	506	512	517	522	527	532	537
45	515	520	525	530	534	539	543
50	524	528	533	537	542	546	550
55	533	537	541	545	548	552	556
60	541	544	548	552	555	558	562
65	548	551	555	558	561	564	567
70	554	557	560	563	566	569	572
75	559	562	565	568	570	573	575
80	563	566	568	571	573	576	578
85	566	568	570	573	575	578	580
90	566	569	571	574	576	578	580

Azimuth.	60° lat.	61° lat.	62° lat.	63° lat.	64° lat.	65° lat.	66° lat.
°							
Meridian.	6.80506	6.80513	6.80520	6.80526	6.80532	6.80538	6.80544
5	07	14	20	26	32	38	44
10	09	15	22	28	34	40	45
15	11	18	24	30	36	42	47
20	15	21	27	33	39	44	50
25	20	26	31	37	42	48	53
30	25	30	36	41	46	51	56
35	31	36	41	46	51	56	60
40	37	42	46	51	56	60	64
45	43	48	52	56	60	64	68
50	50	54	58	62	65	69	73
55	56	60	63	67	70	74	77
60	62	65	68	72	75	78	81
65	67	70	73	76	79	82	84
70	72	74	77	80	82	85	87
75	75	78	80	83	85	87	90
80	78	80	83	85	87	89	91
85	80	82	84	86	88	90	92
90	80	83	85	87	89	91	93

Azimuth.	66° lat.	67° lat.	68° lat.	69° lat.	70° lat.	71° lat.	72° lat.
°							
Meridian.	6.80544	6.80550	6.80555	6.80560	6.80565	6.80570	6.80575
5	44	50	55	61	66	70	75
10	45	51	56	62	66	71	76
15	47	53	58	63	68	72	77
20	50	55	60	65	70	74	78
25	53	58	62	67	72	76	80
30	56	61	65	70	74	78	82
35	60	64	69	73	77	81	84
40	64	68	72	76	80	83	87
45	68	72	76	79	83	86	89
50	73	76	79	83	86	89	92
55	77	80	83	86	89	91	94
60	81	84	86	89	91	94	96
65	84	87	89	92	94	96	6.80598
70	87	90	92	94	96	6.80598	6.80600
75	90	92	94	96	98	6.80600	01
80	91	93	95	97	6.80599	01	02
85	92	94	96	98	6.80600	01	03
90	93	95	97	98	00	02	03

GRAVITY.

139. A publication on modern methods for measuring the intensity of gravity is in course of preparation. When published it will contain detailed instructions for the determination of gravity.

TRAVERSE.

140. Instructions for precise and secondary traverse are given in Special Publication No. 58.

PRECISE LEVELING.

141. For general instructions for this work, see Special Publication No. 18, entitled, "Fourth General Adjustment of the Precise Level Net in the United States and the Resulting Standard Elevations" and also Special Publication No. 22, entitled, "Precise Leveling from Brigham, Utah, to San Francisco, California."

RECONNOISSANCE FOR TRIANGULATION.

142. The reconnoissance preliminary to precise triangulation is made under special instructions suited to the work to be undertaken. On tertiary triangulation the lines are usually of comparatively short length where the intervisibility of the points is easily tested, but for the occasional instances where such is not the case, the methods briefly indicated below may be employed.

Where the intervisibility of the points desired can not be determined by trial, or where it is necessary to estimate the heights of towers which will make them intervisible when the line is obstructed elsewhere than in the immediate vicinity of one or both of the points, the map method of reconnoissance may be used. The degree of precision obtained by this method will depend upon the accuracy of the map itself, which is usually indicated by its source, date, and method of compilation, as well as by internal evidence.

The difference between the apparent and true difference in elevation of two points is affected by two factors, the curvature of the earth's surface and the refraction of light by the earth's atmosphere. These factors are of opposite sign and of an approximately fixed relation to each other, so that the combined effect can be applied as a single factor. The effect of refraction is about one-seventh as much as the curvature; the formulas for the separate effect of each can be found in various works on geodetic surveying, but the formulas below give the approximate resultant:

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

or

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

143. Below is a table, condensed from the one given in Appendix 9, Report for 1882, which gives the distance K (in statute miles) at which a line from the height h (in feet) will touch the horizon, taking into account terrestrial refraction with a mean assumed coefficient of 0.070.

Correction for earth's curvature and refraction.

Dist.	Corr.	Dist.	Corr.	Dist.	Corr.
Miles.	*Feet.*	*Miles.*	*Feet.*	*Miles.*	*Feet.*
1	0.6	21	253.1	41	964.7
2	2.3	22	277.7	42	1012.2
3	5.2	23	303.6	43	1061.9
4	9.2	24	330.5	44	1111.0
5	14.4	25	358.0	45	1162.0
6	20.6	26	388.0	46	1214.2
7	28.1	27	418.3	47	1267.7
8	36.7	28	449.9	48	1322.1
9	46.4	29	482.6	49	1377.7
10	57.4	30	516.4	50	1434.6
11	69.4	31	551.4	51	1492.5
12	82.7	32	587.6	52	1551.6
13	97.0	33	624.9	53	1611.9
14	112.5	34	663.2	54	1673.3
15	129.1	35	703.0	55	1735.8
16	146.9	36	743.7	56	1799.6
17	165.8	37	785.6	57	1864.4
18	185.9	38	828.6	58	1930.4
19	207.2	39	872.8	59	1997.5
20	229.5	40	918.1	60	2065.8

To determine how much the line of sight between two stations will clear or fail to clear an intervening hill, either the table above may be used or the following formula employed:

$$h=h_1+(h_3-h_1)\frac{d_1}{d_1+d_2}-0.5803d_1d_2,$$

where

h =height of line at obstruction,
h_1=height of lower station,
h_2=height of intervening obstruction or hill,
h_3=height of higher station,
d_1=distance from lower station to intervening obstruction,
d_2=distance from intervening obstruction to higher station.

AZIMUTH.

144. **General remarks.**—Parties engaged in general coast surveys should make azimuth observations at one station for every 20 or

30 figures of the triangulation. The azimuth may be measured at any convenient station of the triangulation, but preferably at some station at which the deflection of the plumb line is not large in the prime-vertical, therefore avoiding, if possible, points having near-by mountain masses to the east or west.

Observation and computation of azimuth.—For examples of observations with the repeating theodolite and also with the direction theodolite, see Special Publication No. 14, entitled, "Determination of Time, Longitude, Latitude, and Azimuth" (5th edition).

Observations on the sun for azimuth.—It is occasionally desirable in reconnoissance for triangulation or in magnetic determinations to have an approximate azimuth. For methods of obtaining such an azimuth by observations on the sun, see Principal Facts of the Earth's Magnetism.

TOPOGRAPHY.

145. Use of the plane table.—Full details regarding topographic surveys with the plane table will be found in A Plane Table Manual, Appendix No. 7, Coast and Geodetic Survey Report for 1905, which may be obtained bound separately.

146. Control of topography.—The most satisfactory way of making detailed topographic surveys is to first complete and compute a systematic triangulation, and plot the points determined on a projection. This will not always be feasible in charting new regions, on account of both time and expense, and the topography will sometimes have to be executed at the same time as the triangulation.

147. Where topography is carried on simultaneously with triangulation and other work, if practicable, the triangulation will be kept sufficiently in advance so that the distances (not necessarily the geographic positions) may be computed and plotted on the sheet before filling in the topography. In all cases where this will cause too great a delay or is not practicable from other causes, the topographer must check the distances on his sheet by the computed distances as soon as they are available, and where there are important discrepancies must correct the error by examining the portion affected.

Upon combined operations in Alaska the specifications for the standard control of topography in Alaska shall be as follows:

In general, main-scheme triangulation stations for control of hydrographic and topographic work should be distributed along the coast at intervals not greater than about 5 miles. This triangulation should be of the tertiary grade. To supplement the main scheme, intersection stations of the triangulation, or stations located by plane-table triangulation, by transit and tape, or transit and stadia, should be distributed at intervals not greater than about 2 miles. In localities where triangulation is impracticable traverse with transit and tape may be used for control, provided that the accuracy of the traverse is equal to that of tertiary triangulation.

When the details of improvements along the water front, such as docks, prominent buildings, etc., are to be located, a control point should be established at a distance not greater than 500 meters from such improvements.

Control stations shall be marked and described in accordance with paragraphs 76–96. All triangulation signals must be cut in with the plane table and shown on the topographic sheet; those falling off the limits should have direction lines drawn on the sheet. All traverse lines run must, if practicable, be checked by closing circuits, and small errors adjusted; if large errors appear, the lines must be rerun. On a 1–20000 scale the closing error should not exceed 8 meters per mile of traverse, and an error of half that amount will usually be obtainable.

Unless otherwise specified, the standard of accuracy for the location of shore line in Alaska shall be equal to that for the Atlantic and Pacific coasts of the United States.

The position of any part of the well-defined and permanent shore line shall not be in error more than 10 meters, where the shore line is less than 1,000 meters from a triangulation or other control station; not more than 20 meters for distances between 1,000 and 4,000 meters from such a station; and not more than one-half of 1 per cent of the distance from a control station where the distance is greater than 4,000 meters from such a station.

The descriptive report for each sheet must give the closing errors of the traverses run and state how and between what points the discrepancy was distributed. If proper care is exercised, it will be possible to fit a projection to the plane table sheet by the triangulation points, so that there will be little or no error in the resulting chart.

148. The magnetic meridian should be drawn on the sheet in the field from at least one point, by means of the declinatoire. In regions of large local disturbance, additional determinations of the magnetic meridian should be made.

In order to utilize all the available force at the beginning of a season, it may be advantageous to make a plane table survey of a harbor and fill in the hydrography on this, the signals to be determined by triangulation later.

149. When former triangulation stations are searched for and not found, or when stations are recovered which are insufficiently marked or described, the deficiency in marking or description must be remedied and a report made to show existing conditions.

150. Scale.—For all general coast topography in new regions, unless otherwise specified, a scale of $\frac{1}{20000}$ will be used. Larger scales, as $\frac{1}{10000}$ (and in exceptional cases $\frac{1}{5000}$), are to be used for special harbor surveys where the amount of detail or the importance of the locality warrants, but smaller scales than $\frac{1}{20000}$ will not be used unless specially authorized.

151. Contour intervals for ordinary coast topography should be either 20, 50, or 100 feet; 40-foot intervals should not be used. The choice of intervals should depend on the nature of the country and the scale of the sheet. Only one specific interval should be used on a single sheet.

152. Contours.—Within the continental limits of the United States, the relief will be indicated by contours. In Alaska and the Philippine Islands "form lines" instead of "contours" will be used for this purpose, except in the case of a large scale survey. The term "contour" is generally understood to mean lines of equal elevation located by a sufficient number of determined points along its course, so that in open country on slopes of 5° or less no part of it shall be out of position more than one-half the horizontal distance between each successive contour.

In Alaska this standard of accuracy is not practicable as it is important for the benefit of the navigator to include a large area of rugged country back from the shore, so that its general configuration will be indicated and the peaks and hilltops charted to serve as landmarks.

For this purpose the relief will be shown by "form lines," the sketching of which will be controlled by as many points (reference points) of determined heights and location as can be secured from the shore as the survey proceeds along the coast.

In general, these reference points, together with the elevations of prominent summits, shall be distributed over the area so that there will be at least one reference point for every 4 square inches of field sheet, with such additional elevations as can be obtained without unduly delaying the progress of the work.

Form lines developing the slopes and summits of points and headlands which may be of use in determining a vessel's position from seaward should closely approximate the value of contours, as they are often used when the immediate shore line lies below the observer's horizon.

In order that the relative value of the form lines may be known, the position and height of each reference point shall be inked on the sheet.

153. Interior elevation.—Under the head of triangulation, provision is made for determining important elevations visible from the coast and beyond the limit of the plane table sheet. Information indicating the relation of these elevations to the surrounding country is of value, especially on small-scale general charts. While it is impossible to obtain correct detailed information without going over the country, yet it is suggested that by plotting on a small scale (as on a piece of a general chart) the points determined, a sketch may be made showing the trend of the ridges and the low areas as far as visible. This will to some extent avoid the false idea which is given of a mountainous country by showing on the chart only detached summits.

154. The plane of reference for elevations is mean sea level and must be used unless otherwise instructed. Elevations are to be stated in feet. All elevations given either by figures or contours should represent the elevation of the ground; when for any reason the elevation of the top of trees or vegetation is given, a note to that effect should be added, with an estimate of the height above ground in each case.

155. Elevations may be read from the hypsograph (see Appendix No. 4, Report for 1902), or they may be scaled from a graphic diagram. They can be obtained by using the "Table of factors for computing differences in elevation" and "Table of corrections for curvature and refraction," pages 338 and 339 of Plane Table Manual (also printed separately).

156. Laying out sheets.—Plane table sheets should, in general, be laid out to run parallel with the coast to cover as great a length of coast line as convenient, and to include the signals necessary for its control. Sheets containing small detached fragments of topography should be avoided as far as possible; this can sometimes be done by placing a subplan on an adjacent sheet. Where the topography permits, sheets should preferably be laid out with the two sides parallel to the meridian.

In order to improve the field sheets and field records pertaining to topographic and hydrographic surveys, it is directed that whenever drafting facilities are available for the field parties, projections shall be made in the field, thus obviating the errors due to the distortion of a projection constructed under climatic conditions which differ materially from that in the field.

157. Table of dimensions of standard topographic sheet, 30 inches by 52 inches, expressed in nautical and statute miles, for different scales:

Scale.	Nautical miles.		Statute miles.	
	Width.	Length.	Width.	Length.
$\frac{1}{5000}$	2.06	3.56	2.37	4.10
$\frac{1}{10000}$	4.11	7.13	4.74	8.21
$\frac{1}{20000}$	8.22	14.25	9.47	16.41
$\frac{1}{40000}$	16.45	28.51	18.94	32.83
$\frac{1}{100000}$	41.12	71.27	47.35	82.07

158. The features to be included in ordinary coast topography are the following:

159. The careful location of average high-water line and the low-water line so far as it may be determined or estimated without waiting for low tide.

160. Rivers and streams for a reasonable distance back from the coast, according to their importance; large streams should be surveyed to the limit of the detailed topography, while small and unimportant creeks need be shown only as far as rowboats can ascend; navigable streams should be surveyed to the head of tidewater or ship navigation.

161. Off-lying islets, reefs, and rocks, including elevations of all prominent rocks and islets. Off-lying reefs should be designated as bare, awash, or covered at high or low water, as the case may be.

162. Towns, settlements, roads, and important trails within a reasonable distance of the coast. The individual buildings in a town must not be shown except those of sufficient prominence to be useful as landmarks. When there is no street system and it is desired to indicate a settlement a group of small buildings can be used as a symbol.

163. Objects along the shore either natural or artificial that may be useful in future hydrographic work should be located with care and so named or described that they may be identified without difficulty. In coastal topography, even where the hydrographic survey follows closely, it is essential to mark permanently a sufficient number of points to make it unnecessary to redetermine them by theodolite or plane table should later hydrographic work become necessary. On a rugged, rocky coast this is easily accomplished by placing patches of cement on the rocks, having embedded therein a large nail or other object to make identification more certain. Under other topographic conditions different durable marks may be used to give to the survey a more permanent value. Descriptions of the marks and locations in duplicate must accompany the descriptive report of the sheet on which they are located.

164. The location and elevation of hills or mountains within the limits of the sheet, so far as may be obtained from the vicinity of the coast.

165. The nature of the coast line and of the low-water line, as sand, coral rock, mangrove, etc., must be indicated by symbols, and the general vegetation along the shore must be shown.

166. Features not fully surveyed, as the fast land back of the mangroves and large areas of swamp land, also the extension of a stream beyond the limits actually run, may be indicated by broken line or appropriate note.

167. **Use of sextant and theodolite in topography.**—While the plane table is the most valuable instrument for topography, the surveyor should not regard himself as restricted to its use. Where located signals are in sight and the shore is lined with swamp or mangrove, and in other situations presenting no suitable locations for the table, the sextant may be used to advantage in filling in topography by locating each principal feature by two or preferably three sextant angles, with additional angles to tangents of points and other objects. A continuous sketch should be made in a sketchbook, with the angles written opposite the corresponding points on the sketch. Cases may also arise where the topography may be obtained advantageously with a theodolite traverse line (the transit and stadia or chain method).

A rapid and sufficiently accurate method of mapping rivers which are comparatively unimportant yet navigable by small boats is by a modification of the stadia method, in which the distance readings are made on a stadia rod by a plane-table alidade, supported on a board nailed on top of a pole thrust into the river bottom at the side of the boat, the angles being measured by a sextant.

168. When any of these auxiliary methods are used the work should be plotted and combined by the topographer and added to the general topographic sheet, and the descriptive report should state what portions are so surveyed.

169. Stadia errors.—The source of the largest systematic errors in stadia measurements lies in the different refractive power of the air strata at the bottom of the rod as compared to those at the top. All stadia readings within 1 meter of the ground should be avoided, especially in hot climates, as readings above this limit are practically free from error. When necessary to use the full length of the stadia rod, attach an extension piece without any graduation.

170. Stadia rods should be carefully tested before beginning a season's work, even though it is practically certain that they were used with the same alidade and diaphragm on the previous season, or have come direct from the Washington office.

171. Approximate locations.—If from any triangulation or plane-table station breakers or other indications of off-lying dangers not previously located are noticed, directions should at once be determined, and also, if practicable, vertical angles. From the latter and the elevation of the instrument approximate distances may be computed, which will aid in identifying the objects from other stations. Another method quite useful in rapidly getting approximate locations of objects so as to permit of their future identification is to take cuts on them from a plane-table station and then from another station nearby. Of course such locations are to be confirmed by good intersections from other points.

172. Revision.—In revision of the shore line and adjacent areas where changes of moment have occurred it is more economical to make an entirely new outline survey rather than to select places where changes are thought probable and then to work each way from such spots to junctions with unchanged portions of the coast. This applies principally to stretches of coast where intermediate triangulation points are lacking.

When it is not deemed advisable to make an entirely new outline survey, bromide copies of the original topographic sheet will be furnished. From the bromide copy the chief of party will transfer in pencil to a plane-table sheet the data covering the area to be revised. This will permit erasing where objects shown on the bromide no longer exist or when changes have occurred since the original survey. The new topography will then be inked and the sheet forwarded to the office in the usual form of a completed topographic sheet.

173. In the revision the following features heretofore shown on the original sheets and the charts are not deemed of importance to navigation and will be disregarded, viz:

Individual buildings.

(*Exceptions:* Those of large size close to water front or a detached group of small ones along shore which would serve as a landmark; also individual buildings back from the water front which are conspicuous and will serve as navigational aids, such as church spires, factory chimneys, water towers, etc., and the principal building of the life-saving stations. These navigational aids and life-saving stations should be well determined and listed in the descriptive report.)

Woods.

(*Exceptions:* Where they will be of navigational importance, such as a conspicuous clump of trees or where the growth along shore is an exceptional and distinguishing feature.)

Minor roads.

(*Exceptions:* Those leading up from the water.

All fences.

In the case of the water front of cities and large towns the details of the wharf line and adjoining streets should be carefully located and drawn, using all available accurate information. Back of this the street system will be compiled in the office from local maps obtained by the field party. Such maps should have sufficient points and an azimuth in common with the plane-table sheet to insure location and orientation. In general, the inclusion of three streets back from the water will be sufficient for the chart.

174. Plans of towns and local maps, if available, should be obtained. These must be inspected in the field and marked to distinguish between details that exist and those that are projected only. They will be used in the office for filling in details, especially of towns, but not for the positions of important objects which must be determined by the topographer. Copies of maps of value obtained should be forwarded to the office with the topographic sheet.

175. Symbols and lettering.—The standard topographic symbols are to be followed.

176. The high-water line, being one of the most important features on the sheet, should be drawn with sufficient strength to make it clearly distinguishable. The use of a full line for defining the limits of vegetation outside of the high-water line or the limits between marsh and fast land should be avoided.

177. Time need not be taken for the elaborate covering of a sheet with topographic vegetation symbols, but limits may be shown with words in the center to show the area covered. Words may be used to indicate vegetation features for which there is no special symbol.

178. The field topographic sheet is a survey record; it should show all useful information plainly, neatly, and correctly, but time that can be more usefully employed should not be expended in endeavoring to make it a handsome drawing.

179. Valuable information, useful notes, etc., should not be omitted for fear of marring the appearance of the sheet; nor should the topographer hesitate to place the necessary information on the sheet because he is not expert at lettering.

180. In lettering topographic and hydrographic sheets, names applying to the land should be in vertical letters, the names applying to the water, including objects covered at high water, should be in slanting letters. All geographic names are to be in black ink, and names solely for surveying use, as of signals and stations, are to be in red ink.

181. Care must be taken not to confuse the symbols for sunken rocks (a simple cross), rocks awash (three lines crossing), and rocks above high tide (heavy dot or shape). Brief notes are desirable clearly indicating the nature of important reefs and rocks, as "awash at low water," "awash at high water," "coral heads bare at low water," "breakers at low water," etc.

182. The following remarks apply particularly to Philippine topographic sheets. The cocoanut palm being usually a distinctive feature on the coast, should be shown by the special symbol. Mangrove growing in the water should be limited by a very light line to preserve the detail and correct position, and yet to represent it differently from the strong black line used for the high-water line. Sometimes where there is mangrove the solid shore may not be seen, and it may not be practicable to locate it. Its approximate position should be shown by broken lines sketched on the sheet. The ordinary coral-reef symbol should be used only to represent the limit of reefs bare or awash at low water, and should not be used to represent reefs covered to some depth at low tide. When not developed by the soundings the limits of submerged reefs should be indicated by the sunken-rock symbol. Rice paddies may be represented conventionally by small irregular quadrilaterals bounded by slightly irregular lines and a little grassing.

183. Inking of sheets should be done by the topographer himself or by a member of the party under his supervision, and as soon as practicable after the field work is completed on each sheet. Intervals of delay in field operations may be utilized advantageously for this purpose. The inking of a sheet can not be considered as finished until all essential notes and names are inked.

184. Accuracy, neatness, and clearness are necessary in inking sheets; beyond this fine drafting is not essential.

185. When for any reason an uninked sheet is transmitted to the office, the greatest care must be exercised by the chief of party that every feature, fact, and name is clearly and distinctly shown. The topographer must also make it a point to see and verify the sheet at some time after it is inked, examining every detail.

186. It is particularly important in such case that small detached rocks along the shore, and other features that might be mistaken for accidental markings, should be made clear, and in general such objects should be inked by the topographer.

187. The elevations of summits should be distinctly marked on the sheet, and care must be taken that they are not rubbed or lost before inking. Red ink is to be used for numerical elevations.

188. Triangulation stations should be marked by small black circles inclosed in red triangles, with names in red ink, but in no case should this symbol be permitted to obscure an essential topographic feature; for instance, in case of an offshore rock or islet used as a triangulation station, the rock or islet should not be obscured by the station symbol, but the latter may be omitted if necessary and an explanatory note may be added as to the station.

189. Plane-table positions should be marked on the sheet with small red circles when the positions are recoverable and likely to be of future value; otherwise such positions should not be inked.

190. Titles should not be inked on original sheets in the field, but should be furnished on Form 537a and pinned to the sheet. The information must include general locality, special locality, names of chief or party and of officers making survey, date (months and year), and scale, together with a list of all data forwarded with the sheet. In the Philippines the stamped title form should be filled in with ink on the sheet, or on a slip pinned to the sheet.

191. In preparing and inking original sheets, north shall be taken as the top, and titles, names, numbers, and symbols shall be put on normal to the meridian regardless of the direction of the borders of the sheet, except where it is desirable that names be lettered to conform to geographic features. In such cases the names shall be inked so as to be read when looking north. Names should by their direction and proximity clearly indicate the object designated.

192. Photographs or tracings of sheets.—When there is reason to believe that the mode of forwarding a sheet is not secure, it should, if practicable, be photographed, or if photographic facilities are not available, an outline tracing of the more important features of the original sheet may be made. Otherwise, no tracing of an original sheet should be made in the field. Bromide enlargements from photographs of sheets should not be made except at Washington, unless specially ordered.

193. When sheets are photographed the plates must be preserved until the sheets have been received at the office. Prints should not be made unless the sheets are lost.

194. List of plane-table positions.—Before transmitting topographic sheets to the office, chiefs of parties will prepare a list of the prominent objects on the sheets that have been determined by the planetable, namely, spires, chimneys, cupolas, flagstaffs, trees, etc., and such natural objects as sharp, well-defined mountain peaks, rock cliffs, and other objects that might be recovered and utilized, and particularly such objects as will be useful in hydrographic work; and indicate the position of each object listed by scaling the D. M. and D. P. from the sheet in the following form, giving the height, if determined:

Plane-table positions.

Object and description.	Latitude.		D. M.	Longitude.		D. P.	Height.	Remarks.
	°	′	*Meters.*	°	′	*Meters.*	*Feet.*	
Cupola, Harrison's house	42	21	356	72	40	508	146	Top.
Cupola, Blackwell's barn	42	22	845	72	39	724	138	Weather vane.
Chimney, square house, Smith's.	42	25	632	72	37	395	157	Top.
North chimney, Rodger's house.	42	26	981	72	38	1,023	125	Top.
Episcopal Church spire	42	25	63	72	40	875	250	Top of cross.
Murray Mountain	42	27	426	72	46	125	3,256	The north peak.

195. This list should be attached to the descriptive report. The exact position of the objects referred to should, of course, be distinctly indicated on the sheet. Where space permits, the more important objects, and especially those landmarks which should appear on the chart, should be named directly on the sheet itself, either close to the object or by reference letter and note elsewhere on the sheet. Brief legends descriptive of important landmarks may also, where practicable, be conveniently placed on the sheet.

196. **Landmarks for charts.**—A list of the objects which are of sufficient prominence for use on the charts must be furnished. The selection, determination, and description of these points is of primary importance. When placed upon the published charts with brief descriptive legends they are little less than indispensable for—

(*a*) Alongshore navigation, especially at difficult entrances or those subject to frequent and considerable changes;

(*b*) The original location and determination of aids to navigation and subsequent verification of their positions;

(*c*) Hydrographic examination of features subject to change, to serve as the base for more complete surveys, such as entrance approaches, bars, and channels. Also the verification of reported shoals or other features incorrectly or incompletely charted.

197. In relinquishing charge of a topographic sheet, the chief of party will inspect and approve each sheet before it is transferred to the office or to another chief of party for completion. When circumstances are such that a departure from this rule is unavoidable or when any part of the provisions of the instructions for completing these sheets are omitted, an explanation shall be forwarded promptly to the office for approval; a full explanation of the circumstances must also be entered in the descriptive report accompanying each sheet.

HYDROGRAPHY.

198. **Data to start survey.**—When the information is available from previous work, and the locality of the work and conditions are such as to require it, the following will be furnished with the instructions from the office, and the chief of party should at once examine the information to see that it is complete and understood: Projections on which have been plotted triangulation points, shore line, and all objects or features located by plane table or otherwise which may be useful in the hydrography; list of geo-

graphic positions; descriptions of stations; tidal plane of reference; description and relation of tidal bench marks; copies of previous charts or surveys; information as to dangers reported or other special features to be examined, and, in the case of continuous surveys along the coast in a new region, a copy of the progress sketch of the previous season.

In regions where survey work has not previously been done the triangulation may have to be accomplished and the tide plane determined by the party charged with the hydrography, and the projection will then be made in the field. In some cases it may be desirable to carry on the hydrography simultaneously with the triangulation or topography in order to save time or utilize the services of all of the party at the beginning of a season. In such cases preliminary locations of the signals should be plotted graphically on the boat sheet, but all the work must be planned with the view of ultimate control by the triangulation, and the more important stations should be carefully marked.

199. The lists of geographic positions and descriptions of stations furnished to field parties must be returned to the office upon the completion of the work. When former stations are recovered that are found to be insufficiently marked or described, or the marks partially effaced, or the witness marks gone, the defects should be remedied and an amended description forwarded (see pars. 84–96). Stations should not be reported as lost unless an exhaustive search has been made. When building signals over stations care should be taken not to disturb the station marks.

200. Shore line.—When there is reason to suppose that the shore line has changed materially since the previous survey the important features should, if practicable, be located in connection with the hydrography, either with the plane table or by determining prominent points by sextant angles (preferably three at each point) and sketching in the intermediate shore line. Shore line so located should be drawn in broken line. The same course should be followed when the hydrography precedes the topography and it is impracticable at the time to obtain the complete topographic information desirable.

201. Scale.—Unless otherwise directed, inshore hydrography should be plotted on scale not less than $\frac{1}{20000}$, and must be done in sufficient detail to fully develop recommended sailing lines, approaches, channels, and anchorage areas and remove doubt as to dangers. Anchorages, harbors, and channels may sometimes require scales of $\frac{1}{10000}$ or even $\frac{1}{5000}$. Offshore hydrography may usually be plotted conveniently and economically on smaller scales, as $\frac{1}{40000}$, $\frac{1}{60000}$, $\frac{1}{80000}$, or $\frac{1}{100000}$. Where there are no dangers or details either of the last two may be sufficient for charting purposes.

202. **Location of signals.**—It is desirable that in advance of the hydrographic development a reconnoissance be made, the best locations for signals chosen, and the whole work systematically planned.

203. If the hydrographic work is to be based on triangulation and topographic points previously determined, these should be first recovered, as far as practicable, and if necessary additional points located from them.

204. For triangulation methods, instruments, and records which should be used for the extension of the triangulation beyond the limits already executed and to supply the place of points lost, see paragraphs 12–111. The sextant should not be used for this purpose nor for the location of important hydrographic signals or of permanent objects, such as lighthouses, beacons, buildings, and other useful landmarks.

205. When in the course of the hydrographic work it is desirable to locate new signals by sextant, three angles should be taken, if practicable.

206. In some cases it may be necessary to locate a subordinate signal or object by angles from several positions of the boat, the latter determined from other signals. Where recourse to this device is necessary at least three positions should be used as a check.

207. The officer in charge should make sure while yet on the ground that the position of every signal or object used in the hydrography is determined with sufficient accuracy for the scale of the projection, and this must be tested by actually plotting or computing in the field.

208. Great care must be taken that ample information for the correct plotting of every hydrographic signal accompanies the record. A list of such as depend on plane-table locations and a list of such as depend on sextant angles should be given in the "Description of stations" and in the "Descriptive report."

209. In connection with the triangulation and plane-table work along the coast in a new region special attention must be given to determining suitable objects for hydrographic work, each of which should be described and marked when necessary, so as to be available for future use. (See paragraphs 73–75 and 194–196.)

210. A signal erected exactly over an old station should bear the name of that station. If for any reason a signal is located near, but not exactly at a previous station, it must have a dis-

tinguishing name, or may be given the old name followed by "No. 2" or the year.

211. Names of signals.—For convenience short words of not more than three or four letters should be used for names of hydrographic signals. Avoid using in the same locality two names that resemble each other in sound.

212. List of permanent positions determined.—Before transmitting hydrographic records or sheets to the office chiefs of parties will prepare a list of prominent objects or positions of a permanent character that may be useful in future work that have been determined in connection with the hydrographic work. Indicate the position of each object listed by scaling the D. M. and D. P. from the sheet, in the form given under "Plane-table positions" (paragraph 194). This list should be attached to the "Descriptive report."

213. Character of signals.—It will materially facilitate hydrographic work to have a sufficient number of conspicuous signals which may be readily picked up by the sextant observers. For convenience as well as economy natural objects, such as bowlders, cliffs, and lone trees, and artificial objects, such as towers, flagstaffs, lighthouses, gables of buildings, etc., should be used as signals when available. It is considered that the success of a party engaged on offshore hydrography depends largely on the type of tall signal and signal buoy allowing of the longest range of visibility. Specifications for the tall type signal and different classes of signal buoys may be had upon application.

214. A good form of hydrographic signal is a tripod with slats across two of its sides, or a pole with banners of cloth stretched between cross pieces so that the banners will show in different directions. Driftwood, small trees, and other material on the ground and in the Tropics bamboo poles fastened with wire or rattan, may be used economically. Signals near each other or similarly situated should be varied in form or color to avoid likelihood of confusion. The directions from which they will be viewed should, of course, be considered in building signals. Natural as well as artificial objects may readily be made conspicuous by whitewash. Against a dark background white signals show best; against the sky black is preferable. For general use white is the better color, and cloth the better material, other conditions being equal.

215. A tripod made of lengths of iron pipe, wired together through crosses at the top, makes a simple signal that will stand in a moderate depth of water, and if wrapped with cloth and with flags set in top may be seen at a long distance. In exposed situations in the water such signals may be made more secure by pumping the legs into the bottom by means of a water jet; long poles and saplings have also in this manner been pumped in on ocean bars and have withstood storms.

216. Indefinite objects, such as tops of round hills and centers of islands, should never be used for critical or inshore hydrography, but for offshore hydrography it is sometimes necessary to use the summits of mountains which have been determined by triangulation; of course, for this purpose, definite and conspicuous points are to be selected as far as practicable.

217. When sounding from boats, it may sometimes be desirable to use the foremast of the vessel as a signal; in such case the vessel should be anchored with a short scope, and her position determined whenever there is any change, due to change in the direction of the wind or tidal current. The angles determining the positions and the time they were taken must be noted, and this information should also be put in the record book of the sounding party.

218. Plan of development.—The plan of development should be carefully considered in advance, so as to cover properly the whole area, with suitable allowance for the relative importance of the different parts; the closeness of development should vary from a maximum in channels and anchorages having depth near the draft of the vessels to be accommodated to a minimum on extensive flats of much less depth and in clear areas of much greater depth. Careful attention must also be given to the development of shallow channels and waters that are likely to be used by light-draft vessels, such as motor boats. The soundings upon the chart in addition to indicating to the mariner dangers, channels, and anchorages, also enable him by casts of the lead to recognize his position, and this requires a development of the material and relief of the bottom within the limits of ordinary sounding depths.

219. In working on the general scale along a coast in new regions, closer development should be made of all parts where vessels are likely to be compelled to approach land, as in possible anchorages or off promontories, even though present conditions do not warrant special large-scale surveys. The lines should also be closer off projecting points of land or reefs. In regions where continual changes are going on the development need not be so detailed as in regions where changes do not take place.

220. The order of the development of the hydrography should depend on an economical management of the party. Much valuable time may be lost in sending boats to sound a long distance from the ship or headquarters, and whenever circumstances permit the anchorage or the shore quarters should be shifted to keep near the working ground.

221. Systems of sounding lines.—Systems of parallel lines cover an area most evenly and economically, and zigzag lines, except as provided for to supplement wire-drag work, should, in general, not be used. The development should usually be by straight lines perpendicular to the general trend of the coast, though the direction will depend somewhat on currents, wind, and vessel.

When there is a strong irregular current in a thoroughfare or river, lines run normal to the channel, owing to the nonuniform progress of the boat over the bottom, will not afford reliable means for plotting soundings unless position angles are observed frequently. Under such circumstances the greater part of the development should be made by lines run with or against the current. For a certain mileage of sounding lines, a system of close parallel lines will develop a given area more thoroughly than if the same mileage was laid out in two systems, at right angles, of wider-spaced lines. However, cross lines furnish a valuable check on the accuracy of the work, and it is therefore recommended that for inshore hydrography the first system of parallel lines be crossed by lines approximately perpendicular and spaced several times as far apart as the first system. Outside of the 10-fathom curve, such cross lines will be run as will insure that no important changes of depth remain undeveloped. When, however, a system of lines extends seaward for a considerable distance beyond where it can be checked by observations on fixed objects, a few cross lines should be run to enable the draftsman to detect gross errors. In many localities the submarine relief is characterized by a succession of more or less continuous ridges which trend in a common direction, such as the submerged glaciated areas in Maine and Alaska, the fringing coral reefs of the Florida Peninsula, and the common sand waves and banks of rivers and coastal waters.

Where such areas are surveyed and developed by means of the hand lead, the trend of the ridges should be ascertained by means of a general system of lines and final development completed with lines run at an angle with the direction of the axes of the ridges. Lines making a more or less acute angle with the axis of the feature are necessary also in the development of steep slopes, narrow channels, and crests of bars.

222. The spacing of lines will have to depend largely on the character and relief of the bottom and the importance of the region. In general coast work with flat and sandy bottom and without indication of danger, inshore lines may be spaced 200 to 400 meters apart, but this interval should be diminished for steep slopes, broken, uneven, or rocky bottom such as are found in the Philippines and Alaska. In important anchorages and channels lines as close as 50 meters may be required. Between the 10 and 100 fathom curves about four, or even less, lines to the mile should be sufficient in regions like the South Atlantic and Gulf coasts where there are no indications of dangers. In general the minimum requirements will be included in the instructions, and the chief of party should not hesitate to increase the number of lines for the development of the area, as the survey may require, reporting the necessary change of details to the office. All areas with depths up to 100 fathoms, including detached lumps outside the 100-fathom curve, should be developed sufficiently for the purposes of navigation. On an abrupt coast, outside of the 100-fathom curve, lines from 5 to 10 miles apart should be run offshore at least to the limits of visibility of the mountain peaks, or the 1,000-fathom curve.

223. For the sake of economy care must be taken not to extend the close inshore system of development into open and deep areas where it is unnecessary, as a serious loss of time and energy may result. The system of lines must be varied to suit the conditions. Ordinarily the close inshore work will be done with launch or boat, and the more open offshore work with ship, the latter system slightly overlapping the limit of the former.

224. Sounding interval.—The interval between soundings should depend on the nature of the bottom and the depth of the water. In depths of critical importance to navigation it should be made as short as is consistent with good work, and it should always be less than the interval between lines. Generally in moderate depths of water more soundings will be taken than can be plotted on the sheet.

225. Time interval.—The time interval should usually be uniform, the recorder indicating the time by the order "sound" to the leadsman. For very irregular bottom the time soundings should be abandoned and the leadsman should sound as rapidly as possible. Under normal conditions and with a single leadsman the following time intervals have been found to meet the requirements:

Depths under 2 fathoms	15-second interval.
Depths from 2 to 4 fathoms	20-second interval.
Depths from 4 to 7 fathoms	30-second interval.
Depths from 7 to 10 fathoms	40-second interval.
Depths from 10 to 15 fathoms	1-minute interval.

226. Sounding speed.—The speed of the boat should be varied as may be necessary for efficient and economical work. It may be increased in very shoal water when soundings can be made rapidly, and also in deeper open water where a close interval is unnecessary. But it should never be so great as to interfere with getting correct soundings. It is impossible to obtain up-and-down casts when the vessel is running at high speed. About 5 knots should be considered as the maximum speed through the water for sounding with a hand lead under favorable conditions.

227. Precautions in case of danger indications.—When the bottom is rocky, or when detached rocks are known or suspected to exist, the precautions in sounding should be much increased.

228. In all cases of shoals, suspicious soundings, and indications of dangers, whatever additional work is necessary to develop the bottom thoroughly and to determine the least depth of water must be done regardless of any prearranged system of lines. It must not be assumed that the regular lines of soundings show the least depth. A sounding showing even very little less than the average depth should be regarded as the indication of a possible shoal, much more so when two such shoaler soundings are found on contiguous lines, and in such case very careful investigation should be made of the vicinity to obtain the least depth.

229. Depth curves.—A valuable test of the completeness of the data from a hydrographic survey is to draw the curves for all depths. The data are adequate when no doubt exists of the location of any portion of a curve.

230. Additional development.—All channels, sailing lines, and anchorages should be sounded thoroughly and dragged if necessary; additional lines in the direction of the axis of the channel or of the sailing lines should be run if they are not parallel with the system of sounding lines adopted for the general development. Sailing lines should not be recommended without actual test by running lines of soundings over them.

231. Ranges for running lines.—Sounding lines are ordinarily run on compass courses. Ranges of natural objects on shore should be picked up when practicable and will be especially useful when there is any wind or current. Usually, however, it will not be desirable to delay the work to select ranges or for the purpose of getting the boat in the exact position to start a proposed line, and this must not be done unless there is special reason for it. When essential to select a range, the angle between some signal and the line proposed to be run may be taken off the sheet with a protractor, and with the sextant set to this angle search made for suitable objects ashore in the direction of the line.

232. Running lines by compass.—A proposed system of parallel lines spaced as directed should be laid out in pencil on the boat sheet. In following a course indicated by a pencil line, when a position plots off to one side, position angles should be taken at the moment of changing course. No time should be wasted, however, in attempting to follow closely the pencil lines on the boat sheet.

233. In close development with parallel lines, soundings should not be taken between the last position on one line and the first position on the next line.

234. In cases of exposed shoals with breakers it may be impracticable to do more than run a line just outside of the breakers and to note the distance of the sounding boat off the breakers at numerous points.

235. Special development of reefs, shoals, bars, and channels.—In surveying a reef with a single high point or surface a buoy is generally placed on the highest point and radial lines run from this; but this may give an imperfect idea of the shape of the reef, as the lines diverge rapidly from each other. New lines should be introduced, therefore, between the first radial lines as they recede from the buoy, or preferably the area in question should be developed by a system of close parallel lines and cross lines. On shoals or rocks that are bare at some stage of the tide the depth should be obtained if practicable.

236. If the reef has more than one high point, several buoys placed upon them will give the means of laying out upon a diagram and of executing by sounding a regular plan of work which will show the peculiarities of the reef, increasing the soundings where the slopes are steep or the irregularities great. It is very desirable to visit rocks and shoals at extreme low water, when an examination may show how near the surface any portion approaches.

237. In the development of areas remote from shore signals, water signals (or buoys with signal superstructures) must be established so that details may be studied in their true relative position and results made conclusive; these water signals must be connected with the remote shore signals. (See par. 275.)

238. In harbors lines should be run to the outer face of quays and wharves to show that water can be taken to them.

239. When convenient, shoals and flats bare at low water may be sounded over at or near high water. When reduced for tide these soundings will show the height above the plane of reference. These heights will be plotted on the sheet as "minus soundings," that is, the heights in figures will be plotted with the minus sign before each. In general, whenever a sounding is less than the amount of the tide reduction at the same moment, the difference should be plotted as a minus sounding. All minus soundings are, of course, to be included within the low-water line.

240. Locating reefs in heavy weather.—On a field of work exposed to the sea, reefs and shoals may be discovered, located, or verified during heavy weather by occupying two or more stations, and with an instrument cutting in the breakers, or by cutting them in from a vessel. The depths can be ascertained during fair weather.

241. When the survey of a shoal or rock is finished, care must be taken to note upon the spot all useful ranges, bearings, and marks which lead over it or close to it on every side.

242. Examination for adequate development.—The development of channels having moderate depths in the fairway, and that of bars, if there are any, which obstruct the fairway, is of the utmost importance and should receive the close personal attention of the chief of party. After the lines are plotted and the curves drawn in he should carefully trace out each channel and assure himself that no soundings are wanting to show exactly how much water can be carried throughout its whole extent, and extra lines should be run where there is the least room for doubt. Should he find indications of a bar, a further examination must be made to develop its form and extent and to make sure of having found the least depths upon it.

243. Dragging for dangers should be resorted to in cases of important channels and anchorages where obstructions have been reported and not found or where the nature of the bottom and surroundings indicates a likelihood of dangers which might be missed in the ordinary sounding lines. Even in the closest development with the sounding lead pinnacle rocks may be missed, and a thorough sweeping of a doubtful area is necessary to prove that it is clear. Experience indicates that this precaution is well warranted in important areas.

The wire drag is the only sure and effective means for this purpose. It is described in the Coast and Geodetic Survey Special Publication No. 56, with general directions for its use.

In plotting a large area of drag work the method described in Special Publication No. 56 should be followed. For small areas the positions may be plotted on the regular hydrographic sheet, but the connecting lines should not be drawn, as this will interfere with the legibility of the soundings when plotted. A piece of vellum should be used to show the details.

A drag made of pipe and intended for use with a surveying vessel is described in Appendix No. 6, Coast and Geodetic Survey Report for 1903. For surveying operations this apparatus has been superseded by the wire drag.

Where special apparatus is not available a drag of some sort should be improvised to search for an important reported obstruction which can not be found by the lead. Two pulling boats may be used, and the principle of the wire drag should be followed in keeping the drag taut by means of weights at each end and the boats towing on courses somewhat divergent. Wire should preferably be used, or, in its absence, rope or light chain, or an iron pipe or bar suspended horizontally may be towed beneath a launch or between two boats.

244. The length of drag will depend on the nature of the work and the amount and quantity of material available. With standard equipment lengths of drag under 3,000 feet are rarely used except in channels with less width than this. The following table gives information relative to drag lengths in ordinary use:

Length of drag.	Length of section.	Effective width.	Conditions.
	Feet.	*Feet.*	
Less than 3,000 feet	300	....	Narrow channels.
3,000 feet	300	2,700	Very broken bottom.
4,000 feet	400	3,600	Broken bottom.
5,000 feet	500	4,500	Fairly clear bottom.
6,000 feet and over	600	....	Deep water.

Lengths of drag for deep-water work are commonly 9,000, 12,000, and 15,000 feet, depending on the area to be covered and the current velocity.

245. Drag depths shall be referred to the plane of mean low water unless otherwise instructed. It is considered that an examination to a depth of 50 feet at mean low water is sufficient to insure safe navigation for surface vessels, while an examination to 100 feet is necessary to safeguard submarine navigation. Therefore, unless otherwise instructed, the following will be the standard drag depths: Deep-water areas to 100 feet or over; areas with depths between 50 and 100 feet to within 10 or 20 feet from the bottom; and areas with depths less than 50 feet to within about 3 feet from the bottom.

When the drag is towed through the water the bottom wire will usually lift slightly. The amount of this lift, which is rarely over 2 feet, shall be determined by tests usually conducted from the tender. For this purpose a tester should be used which may consist of a ½-inch metal rod about 3 feet long attached to one end of a small chain. This rod and chain is graduated in the same manner as a lead line, the chain being used to insure an invariable length. The tender should stop a short distance ahead of the drag opposite the point to be tested and lower the tester to a depth about equal to the upright length. When the wire strikes the rod the tester is lifted until it clears the wire and the difference between the upright length and the reading of the tester when it clears gives the lift.

To obtain the upright setting for a certain effective depth add to this depth the lift correction and the height of the tide above mean low water as shown by predictions. While predicted tides are used for setting the drag, the final reduction is to be made by using observed values obtained during the course of the work on a near-by gauge.

In channels and in deep water the drag is usually set to one depth throughout, and for the latter work it is customary to avoid depth changes by setting the drag for the maximum height of tide that will occur during the day. In shoal water fairly long drags can be used by setting the drag at different depths to conform to the bottom contour as shown by soundings. In this class of work frequent depth changes are necessary, in order to allow for rise and fall of the tide, to conform to changing bottom contours and to avoid shoals previously discovered. In this class of work it is not good practice to have the difference in length between adjoining uprights greater than one-fortieth of the distance between them.

246. In dragging areas where soundings of previous surveys are widely spaced and where additional information relative to the depths is required soundings taken at stated intervals at each alternate buoy during the progress of the drag will give a staggered line of soundings over the entire path. The soundings are plotted at the position of the buoy by using the time interval on the normal path of the buoy. When the position of the drag varies from its normal curve the position of the buoy at which the sounding is taken should be fixed in order to plot its position on the curve of the drag. This method of sounding should be used only when specially instructed.

247. All operations and angles in wire-drag work are to be recorded for final preservation and for later work on the smooth sheet. A separate smooth sounding record and a wire-drag record are to be kept for each sheet. The end launch officer records, for future comparison, each angle that he signals, together with the time. Each tender records all data obtained on shoals; depth changes, giving the time that the change started and ended, the new depth and the buoys involved in the change; drag tests, etc. All data in regard to shoals are to be copied from the tender records into the smooth sounding record on the guide launch, while other information is transferred to the wire-drag record. Soundings taken during the progress of wire-drag work shall be recorded in a separate sounding volume. When cuts or bearings are taken from the end or guiding launch to locate the position of a sounding at an intermediate buoy they shall be recorded in the same volume with the sounding.

On the first page of each record are to be entered the names of objects used for control and the manner in which their locations are obtained, together with the shore names assigned to them for convenience in recording. On the second page the party organization shall be given, with the name and duties of each member. Rubber stamps are provided for insertion of data at the beginning and end of each day. A stamp may be obtained for insertion of initial lengths of upright at the beginning of the day and whenever a depth change is made during the day. At each position the time, position angles, buoy angles, distance angle, signaled angle, and distance shall be entered in the order named. A buoy angle is to be considered as plus if the buoy is to the right of the object, and minus if to the left. When the drag catches on a shoal, an excellent check on the shoal position is obtained by observing and recording a bearing to the indicated position, with a note as to the number of the buoy nearest the shoal.

Successive days are to be lettered in order and corresponding days in the wire-drag and sounding records are to be given the same letter. Explanatory notes should be entered, when necessary, in the wire-drag record, and every care taken to make it a clear and complete record of each day's work.

For long-drag work positions are to be recorded on the end launch and later transferred to the right-hand angle column of the guide-launch record.

248. To reduce the records, the upright length is to be entered in the proper column at the top of each page and where it is changed by a depth change. The correction, as shown by tests, is entered and subtracted from the upright length to obtain the drag depth. If there is a correction for swell it shall be noted by the officer in charge and added to the correction. For deep drag work a factor of safety may be introduced, at the discretion of the chief of party, by adding a foot or two to the lift shown by tests. Tidal reducers are to be entered in the same manner as for ordinary hydrographic work and applied to the drag depth to give the effective depth. If the tidal change occurs between two positions, it is shown at the preceding position if it decreases the effective depth, and at the succeeding position if the contrary is true. All distances must be checked by recomputation.

249. At the end of each day in the record an effective depth diagram will be entered. This diagram, which is simply a summary of all effective depths obtained during the day is to be entered in the following form:

Position		Remarks
	43 45	
1	N ---- 6 ---- F	**B**
	34 →	
2.8–6.4	2 ------------ F	
	44 35	
8	N ---- 2 ---- F	**Tide.**

The first entry shows the initial effective depths, the letter B indicating that the line begins. On an inclined section between two different upright lengths, the lesser depth is to be considered as extending horizontally to the first upright set at a greater depth. Thus at the beginning of the day buoy No. 5 is set at 43 feet and buoy No. 6 at 45 feet making the path of buoy No. 6 the dividing line between depths. The second entry shows a depth change of 34 feet made from buoy 3 to buoy F in the direction of the arrow. As the depth is decreased the change extends automatically to buoy 2 as soon as buoy 3 is changed. The fractional position numbers show that the change started between positions 2 and 3 at a time when buoy No. 3 had traversed 0.8 of the distance between the two positions, and that it ended when buoy F had traversed 0.4 of the distance between positions 6 and 7. At position No. 8 an increase of 1 foot in the effective depths, due to tidal decrease, is indicated.

250. When the drag parts, care should be taken to eliminate uncertainty by the rejection of a sufficient number of positions.

251. For plotting, the smooth sheet is protected by tracing cloth held securely in place, with small holes cut through over each control object position on the sheet. A number of boat positions are plotted, after which the buoy positions are plotted and pricked through on the smooth sheet. The successive buoy positions are connected by straight lines, using a pencil hard enough to indent the smooth sheet. Care must be taken to plot the buoy positions within a reasonable time after the boat positions, lest the tracing change its position with relation to the sheet. The tracing is then removed while the path lines are drawn in pencil on the smooth sheet. Every fifth position is indicated by its number and the letter of the alphabet assigned to the day, using ink of one certain color. These numbers should be entered only on the guide-launch side of the strip. The curved line of the drag is drawn at the end of each strip, using the buoy spacer. The positions of all shoals discovered during the day are plotted, either immediately before or after plotting the day's work, and numbered as for the drag positions. When a drag strip ends on a shoal, care must be taken to extend the line of the drag back of the shoal.

After the various strips are plotted in pencil they are subdivided to show effective depths. For changes due to tide the line of the drag is drawn with the spacer at the proper point. Depth changes are shown by connecting, with a line, the position of the first buoy involved at the time the change started and the similar position of the last buoy changed. If the change affects less than half the drag, the two positions are connected by a straight line. If more than half the drag is changed, it is best to locate the middle buoy involved at the time it was changed, assuming a uniform rate of change, and to connect the three points with a smooth curve. With a drag set at different depths, the dividing lines are obtained by plotting the positions of the dividing buoys at each drag position and connecting succeeding buoy positions with straight lines.

After a strip is subdivided each subdivision is outlined with colored ink in accordance with the following color schemes, and with the rule that deeper areas are completely surrounded with a line of the proper color, while areas of less depth are surrounded by the proper color, except where they adjoin an area of greater depth:

19 feet and under	Brown.
20 to 29 feet	Yellow.
30 to 39 feet	Blue.
40 to 59 feet	Red.
60 to 79 feet	Purple.
80 feet and over	Orange.

Each area has one or more light lines extending across it, with a space for a numeral representing the difference between the effective depth and the color base. Thus an area dragged to 94 feet will be surrounded with an orange-colored line and contain the numeral 14. When the strips are inked, corresponding positions of *N* and *F* are indicated by short lines drawn from each toward the other. Each fifth position is indicated by slightly longer lines.

In shoal localities, where an area may be covered several times by drags set at different depths, the subdivision described above may be simplified by tracing each strip as it is plotted, subdividing the strip on the tracing and then transferring the subdivisions to the smooth sheet.

252. All records of dragging operations should be kept in wire-drag record books, and the work clearly explained.

253. Position angles.—For locating position of sounding boat the two methods generally used are by theodolite angles on the boat from two stations ashore, and by sextant angles from the boat on three shore signals, or a combination of the two. The former is the most precise, but is not well adapted to surveys of extended areas.

254. The second method is employed in nearly all the coast work, the principles involved being the same as in the location of a plane table in topographic work by the three-point problem. The strength of a determination of position depends directly on the relative positions of the three fixed points and the position sought. There are usually a number of objects from which to select in taking the sextant angles, and good judgment is required in making this selection; some positions of the objects with respect to the observer give strong conditions and some very weak conditions for the angles.

255. Strength of position angles.—A single angle between two fixed points gives as a locus of the vertex part of the circumference of a circle through the two fixed points in which the given angle may be inscribed. Two angles measured between three fixed points determine the position as at the intersection of three such loci passing through each two of the points, respectively. The strength of the position depends in part on the angle at which these circles intersect; as they approach tangency the position becomes weak, until the limiting case is reached, when the position is on the circumference of the circle passing through the three fixed points. In this case the three position circles coincide and the position is indeterminate and can be plotted only as somewhere on the circle.

256. Whenever the distance between any two of the fixed points is small as compared with the distance from them to the observer, the corresponding position circle will be poorly determined and the position will be weak.

257. Based on the two preceding paragraphs, the following should be observed in selecting objects for angles:

258. Avoid any selection in which the boat's position is on or near the circle passing through the three fixed points. This is commonly called a "revolver" and is to be constantly guarded against. In case there is no choice of signals and a "revolver" is expected, as may sometimes occur inshore near the end of a line, a third angle should, if practicable, be taken to a point of land or other defined object.

259. Avoid a selection in which two of the fixed points are close together as compared with their distance from the observer.

260. A strong position will be obtained with the three objects nearly in line or with the central object nearer than the others and no angle less than 30°.

261. Small angles should generally be avoided, as they give weak positions in most cases and also are apt to be inconvenient to plot.

262. There is one case, however, in which a small angle will give a strong position, and that is when two of the objects are nearly in line and not close together and the third object is so located as to give a good angle of intersection with them. The limiting case is where the position sought is in range with two of the objects. Only a single angle need then be observed, but a second angle on a fourth object may be taken as a check. A range should be taken when there is opportunity, but the range points should not be relatively close together.

263. As slight errors in angles affect a position more with distant signals than when near objects are observed, preference should always be given to the latter, other conditions being favorable. The uncertainties of plotting due to paper and instruments also make it preferable to use near objects. Thus for inshore hydrography it is desirable that signals on the adjacent shore be used, and not very distant signals, as for instance, those on the opposite side of a bay.

264. When the central object is very close and the other two objects distant, the whole angle between the latter should be observed if practicable, or the two separate angles should be taken from the same spot, to avoid the error in position that will otherwise result from angles taken by observers at points slightly apart, if the two angles are not taken at the same instant.

265. If practicable, avoid angles between signals having considerable difference of elevation, when either is near the observer.

266. If in running the sounding line both angles change slowly, the position will be weak. In plotting it should be noted that the position is strong if a slight movment of the center of the protractor throws the arms away from one or more points, and that the position is weak if such movement does not appreciably disturb the relation of the arms to the three points.

267. The time interval between positions will depend on the scale and the character of the hydrography, but on large scale work should seldom exceed three or four minutes. For convenience in plotting and spacing soundings, positions should ordinarily be taken on the full minute, and when possible at uniform intervals. Position angles should, however, be observed when there are sudden changes of depth and at all changes of course and of speed.

268. Where the change of course is considerable, positions should be taken both at the time the change is made and as soon as the boat is on the new course, and in such case the track of the sounding boat should be plotted as a curve and not as a sharp angle.

269. In addition to the position at the beginning of the line, position angles should again be observed when the boat gains full headway (to be noted in the record) in order to avoid the serious errors in spacing soundings on the plotted sheet as a result of the variable speed of the boat. The same holds true when the speed is slowed down on the approach to shoal water at the end of a line; that is, position angles should be taken when the boat is slowed down as well as at the end of the line. The irregular and improbable depth curves sometimes seen on plotted sheets near the shore are generally due to a failure to take account of the changes in speed of the boat near the beginning and end of sounding lines.

270. Positions may conveniently be recorded in the following form, the signals being named from right to left:

4	Bet	70° 40′
	Cat	
	Dog	41° 14′

271. The position number is to be placed immediately to the left of the time at which position was taken, being careful that there is no uncertainty as to which time is referred to. It is important that the time recorded should be that at which the position and sounding were actually taken; discrepancies in the hydrography will result from lack of care in this respect.

272. A range is indicated by zeros with a line drawn through them, thus:

4	Bet	61° 27′
	Cat	
	Dog	~~00~~

273. Buoys and other aids to navigation within the field of work should be determined by special sextant angles. If found to be out of position or unfavorably located, this should be promptly reported, as well as any recommendations as to desirable positions for aids to navigation. (See par. 401.)

274. The method of locating positions by two theodolites ashore should be used when extreme accuracy is demanded, as in harbor improvement surveys. Although not often employed in general coast work, it may be convenient in some cases. For instance, the signal at the masthead of a vessel may sometimes be distinguished at a greater distance offshore than the shore stations can be seen from the vessel. The two theodolities are set up at suitably situated triangulation stations. All the directions are referred to a known direction as zero, which it will be convenient in plotting to have to the left of any position of the vessel, when the theodolite is graduated clockwise. This zero should be verified, say at the beginning of each page of the record, by recording a pointing on the reference object.

275. A time ball or flag is shown from the vessel each time a position is required, and the instant it is dropped the direction of the foremast of the vessel will be observed at each station, and the time recorded at the two stations and on board. Or observations made by a prearranged time schedule, in which case occasional signals should be made, if possible, for the comparison of clocks. The clocks should be set to agree and compared at the end of the day.

276. Positions for offshore hydrography.—In developing offshore areas along the Atlantic and Gulf coasts, survey buoys are placed two or three miles beyond the limit of visibility of the tall signals on the coast. The positions of these buoys are determined by intersecting cuts taken from the Survey vessels while at anchor at various points within the range of visibility of both shore signals and the buoys whose positions are to be determined. With this control the fixed positions on sounding lines are carried from 5 to 7 miles beyond the limit of visibility of the shore stations. For the survey of an important bank offshore out of sight of objects on land, a sextant triangulation should be carried out from the shore to locate several buoys or beacons placed on the bank to serve as signals during the hydrographic development. For the intermediate stations between shore and bank sailboats may prove convenient, as they can be readily shifted from point to point in a scheme which requires several figures to make the connection. If, owing to rough seas or other causes, this method is found impracticable, the use of two ship logs and a record of the engine revolutions, previously standardized, and the compass to determine a position on the bank by the adjustment of outward runs from a known position combined with that of return runs to a similar position in sight of land is recommended. The relative positions of the control signals on the bank can then be determined by courses and log distances, as well as sextant angles. When the signals are short distances apart, a run between any two by compass and log should be immediately repeated in the reverse direction to eliminate the effect of current and other sources of error. For long distances the two runs should begin and end respectively with the same phase of tide. The record should be complete as to the compass deviations, log corrections, currents, wind, and apparent drift. The sounding lines should be plotted and adjusted by the field party. In all coast hydrography where the lines run offshore out of sight of signals, current observations shall be made while on the sounding lines, about once every two hours or at intervals of not over 10 miles. Each course is to be corrected for leeway. Having an annemometer available, a table should be prepared giving a factor for the wind at each 45° from ahead or astern on either side of the vessel. When possible, astronomic observations at the current stations shall be taken for ship's position in addition to all of the dead reckoning data obtained, making also full use of wireless time comparisons. Complete adjustment of the positions must be shown.

277. A reconnoissance of a bank offshore, where signals can not be seen from a boat, may be made by anchoring the ship and sounding with a boat, obtaining the distance from the ship by measuring the vertical angle from the water line to the masthead and taking bearings on the boat with the ship's compass. The height of the mast above the water furnishes a vertical base for plotting the distance of the boat.

278. **Soundings with lead and line.**—The leadsman should be trained to estimate the probable depth for the next sounding in order that he may pay out an adequate amount of spare line; too much may be more objectionable than too little. The effort should be to have the lead draw the line taut as it reaches the bottom; also to have the lead reach the bottom as the leadsman gets over it, or just before the line becomes plumb. The leadsman should then quickly lift the lead off the bottom, and as it touches again read the depth. This is an important precaution for the purpose of straightening the line and keeping the lead vertical. When there is a swell or the surface of the water is agitated the leadsman must be careful to make an allowance for the height of the waves, so that the reading of the lead line will give the depth from the mean surface.

(*a*) The following sounding leads and hand lines are in general use:

For hand lead in depths up to 8 fathoms, a 6 to 8 pound lead is used.

For hand lead in depths over 8 fathoms, a 10 to 12 pound lead is used.

For all hand lines No. 7 or No. 8 Silver Lake sash cord or Sampson spot cord is used.

For trolley soundings in depths up to 20 fathoms, a 20-pound lead with No. 9 cord is used.

For trolley soundings in depths over 20 fathoms a 30-pound lead with No. 12 cord is used. (See pars. 354 and 360.)

For the sounding machine in depths up to 500 fathoms leads from 30 to 40 pounds are used with stranded wire. In greater depths a shot of 30 to 60 pounds is used with piano wire.

Where subsurface currents exist an extra heavy lead should be used to permit a straight stretch of the leadline from bottom to surface.

279. Soundings with vessel underway.—When working in moderate depths (from 20 to 60 fathoms), and yet beyond those in which it is practicable to sound with a hand lead (over 20 fathoms), there is considerable saving of time and of wear on machinery by using methods which permit the soundings to be taken without stopping the vessel.

280. Trolley rig.—A satisfactory and often-used method is that of dropping the lead near the bow and reading the depth as the lead line comes vertical under the leadsman stationed on the quarter-deck. With a sounding lead of from 20 to 30 pounds weight up-and-down soundings can thus be obtained rapidly in depths up to 50 fathoms, with speeds up to 4½ knots, without stopping. Various methods are used for carrying the lead forward and automatically releasing it. A trolley wire may be rigged along one side of the vessel, with a grade downward toward the bow. The lead is suspended from a traveler hung from two grooved wheels which carries it forward until a projecting bolt on the traveler strikes a rubber surface on a boom, pushing back the catch holding the lead and releasing it. The lead drops to the bottom, and the traveler is hauled aft again. Another device is described and illustrated in Wharton's Hydrographical Surveying.

281. Deflection scale.—A system of sounding underway with sounding machine and wire (piano wire, No. 21 B. & S.) has been used in moderate depths (under 10 fathoms). An iron weight of 30 to 60 pounds, attached to sounding wire, is employed, the amount of wire out read on a registering sheave, and the angle of deflection from the vertical of the wire noted on a horizontal scale projecting from the deck. Soundings are made rapidly without stopping, the weight being lifted only a short distance off the bottom and not brought to the surface. The weight dragging near the bottom will develop the presence of shoal spots between the soundings. An occasional sample of bottom may be brought to the surface. The correction for deflection of the wire is $-l(1-\cos\alpha)$ where l is the inclined length of wire and α is the angle of deflection from the vertical, supposing the wire to be straight. This method of sounding has been used to advantage only in moderate depths (10 to 30 fathoms) and at moderate speeds (4 to 6 knots). In greater depths (over 40 fathoms) the angle of deflection will become too great, and the curvature of the wire will introduce difficulties in the correction.

282. A modification of this method has been used in depths from 30 to 50 fathoms. Soundings were taken when the headway of the

vessel was reduced sufficiently to keep the correction for inclination of wire small. As soon as the angle is reduced to the desired limit it is read, the lead is dropped, and the instant it strikes bottom the registry dial is read and the reading recorded. The advantage of this over up-and-down soundings is that less reversing of machinery is required, and that the vessel, retaining some headway, is under better control and the proposed sounding lines can be more easily followed.

283. In machine sounding in moderate depths where vertical casts are obtained there may be some saving in simply lifting the lead a short distance off the bottom and going ahead without reeling in, except where a sample of bottom is desired. In using the heavier sounding leads for trolley rig, a proportionately heavier grade of sounding line should be used, as a pendant between the lead and 20-fathom mark, as noted in paragraph 278 (*a*). Over an extended area with depths greater than 20 fathoms a section of wire of that length may be used to eliminate a portion of the stretch incident to the use of a long hemp or cotton line.

284. Pressure tubes.—Pressure tubes are designed for use in sounding when a vessel is under way in depths up to about 90 fathoms. Pressure tubes with appliances employing the overflow device, and others with springs and pistons, are also used. Pressure tubes, while satisfying the requirements of navigation, should not be used in depths less than 20 fathoms or when very accurate hydrographic survey work is required on account of errors due to temperature and other causes. On off-shore work where sounding tubes are used in the course of a sounding line, every fifth sounding should be checked by a vertical measurement of the depth with wire and registering sheave.

285. Sounding machines.—The Cosmos hand-sounding machine may be used successfully for soundings to depths of 500 fathoms, using No. 24 standard Brown & Sharpe gauge and about a 35-pound lead. When sounding in greater depths, steel wire should be employed. Other small sounding machines may be used when available, such as the Kelvin navigational machine or the Tanner machines. In all cases it is preferable to use a separate registering sheave, such as the Tanner, for reading the length of wire out, instead of the dial on the reeling drum, which is subject to correction, depending on the amount of wire on the drum. In using the Sigsbee sounding machine the scale attached to the upright carrying the leading sheave will show the strain on the wire when heaving in. A 90-pound strain is the approximate limit in using the 21 Brown & Sharpe gauge wire. When sounding in depths over 1000 fathoms the speed in paying out and reeling in should not exceed 100 fathoms per minute.

(*a*) In splicing stranded wire, a lay of 16 inches with neat tucks at each end will suffice.

For piano wire, a splice 3 inches long will suffice. In making the splice, caution should be observed not to give the lay at the cross or middle of the splice so short a nip that it will afterwards be straightened out under strong tension. The splice to be wiped with solder, giving a long taper to each end.

To cover the splice completely with solder, which must be done, several layers of felt, ticking, or moleskin cloth with tallow coating in the palm of the hand will serve to wipe the splice as the solder is dropped or poured over it. In this operation care must be taken that the soldering iron, ladle, or flame from the blow torch does not come in contact with the wire.

In preparing the splice for soldering a flux of muriatic acid with zinc dissolved in it till it will take no more should be used before the solder is dropped or poured on.

Pure tallow, sperm candle or sweet oil only should be used in greasing the wiping cloth.

An electrician's soldering torch with soldering wire facilitates the operation. Stranded wire No. 24 B. & S. gauge is furnished in sealed tins containing 300 fathom lengths. Piano steel wire No. 21 B. & S. gauge is furnished in sealed tins containing 2000 fathom lengths.

(*b*) The ordinary sounding-record books may be used for work with these machines; the time required to reach bottom should be recorded for the deeper soundings as a useful check. For description of the Sigsbee deep-sea sounding machine and explanation of its use, reference should be made to Tanner's Deep-Sea Exploration (U. S. Commission of Fish and Fisheries, 1897) and to Sigsbee's Deep-Sea Sounding and Dredging (Coast and Geodetic Survey, 1880).

286. Sounding records.—All sounding records must be complete and intelligible, and the chief of party must personally see that the record is being kept in a systematic and careful manner. Give description of sounding apparatus (whether hand or machine), and state size and kind of line or wire, whether registering sheave is used, etc. Many things which are perfectly clear to an observer, having the work fresh in his memory, may not be so to a stranger; hence the necessity of making complete notes with each day's work and recording everything essential to a complete understanding of the record. All uncertainties and doubtful places should be carefully investigated before leaving the field.

(*a*) Sounding-record volumes must, as far as practicable, be kept separate for each hydrographic sheet and numbered in separate series. It is inconvenient in plotting and filing records to have in one volume soundings that go on different sheets; to avoid this, where projections are not furnished, the scheme of sheets should be planned in advance as far as circumstances will permit. Boat sheets should conform to the limits of the smooth sheets.

A special form of record, "Soundings with wire," is now available and should be used for deep-sea sounding.

287. Identification letters and numbers.—In order to aid in the identification of sounding records, hydrographic projections sent from the office will be designated by a temporary number, and those made in the field should be assigned a letter, and these field numbers or letters, marked plainly in pencil, should form a part of all sounding records, descriptive reports, etc., pertaining to each sheet, respectively. At Manila, Philippine sheet numbers will be assigned to each field party at the beginning of the season, and the records and reports must be systematically marked in ink with the corresponding sheet numbers.

288. Information notes.—At the beginning of each day's work enter in the sounding book the time the party left the vessel, or the vessel left the anchorage; the distance to the field; the fact that the sextants, clock, and lead lines have been examined and were correct, or the corrections, if any; describe sounding apparatus used—if machine give weight and form of sinker and kind and size of wire used, also any departure from ordinary methods; the names of the observers, recorder, and leadsmen, and should any of these be relieved during the day a note should be made in the column of remarks at the time it occurs. If there are two observers, state which takes the right and which the left angle, also the one in charge. Should there be any correction or fact recorded later, which should be known before commencing the plotting of the day's work, a note calling attention to it should be inserted at the beginning of the day's record, also the name and location of the tide gauge or staff to be used in reducing the soundings.

289. At the close of the day's work note again the examination of sextants, clock, and lead lines, and their corrections, if any, the time of returning to the vessel, and the distance from the working ground.

290. In the division of work between the two observers it will be well for one to supervise the steering of the boat and the plotting and the other to watch the correctness of the leadsman and the recorder.

291. Standard time is to be used in all records and so noted in the column "Time" at the beginning of each day.

292. Any information that will be of value in plotting the sheet or in explaining the hydrography should be noted in the remark column, as, for instance, the force and direction of the wind, the state of the sea whether rough or smooth, the force and direction of the current, the bearing and estimated distance of any object passed by the boat and which is or should be plotted on the projection, and the time of crossing the range of two well-defined objects. The time of changes in wind or current should be noted, as well as eddies, tide rips and their trend, whirlpools, etc. When, owing to surf or other dangers, a sounding line can not be run to the shore, explanation should be given in the record, with estimate of distance to the shore or danger.

293. Special care should be taken that sounding records are complete in the following respects:

(*a*) In remark column the relation of beginning and end of line to some object should be given approximately, as "line begins about 300 meters 30° from ⚠ Tree;" "line ends 25 meters from reef, 0° ⊙ Run." Also, for every line beginning or ending near the shore, the estimated distance in meters to the shore, reef, or breakers must be stated, and for every important object passed on a sounding line, as rock awash, breakers, buoy, etc., the estimated distance and bearing must be noted, or when not otherwise determined an additional sextant angle should be taken to it from two or more positions.

(*b*) The course should be noted at beginning of each line, and when changed the time of change and direction of the course should be indicated, as C. C. to 56°.

In the new form of sounding record the ship's or boat's head as read by compass should be entered in the first column on the right-hand page, and the course intended to be made good should be written in the remark column as an indication of leeway.

In offshore work, the course, corrected for variation and deviation, should be entered in the remark column, and the ship's deviation card should be entered on page 1.

(*c*) A reference mark should be made against every sounding or time to which any note refers.

(*d*) When stops are made, the "ahead" time should be noted, as well as any change of speed.

294. Courses, bearings, and directions should be stated in degrees (from 0°, at north, through east, south, and west to 360°) and not in points, and degrees should be used instead of points for *all* purposes on board vessels of the Survey. Whenever there is a possibility of confusion, a statement should be made as to whether the course is magnetic or true.

295. Name and location of tide gauge to be used in reduction should be entered at the heading of each day's work.

296. The second page of a volume of soundings should contain an index of signals determined and an index of currents noted; also a special reference to any other important information contained in that volume, giving in each case the page reference.

297. Duplication.—Sounding records should not be duplicated, except when specially directed, or when there is considered to be an unusual risk in forwarding records. A good security against loss will be to forward the sheet and records at different times; the records to be sent by registered mail.

298. Soundings will in general be recorded in fathoms and integral feet; only in such cases as in developments less than 40 feet at critical or controlling points, in channels, across bars, and in fairways, need fractions of feet be recorded, or, in other words, this will depend upon the locality and depth of water.

299. "No bottom" soundings are not satisfactory, and where practicable the depth should be obtained. They are quite objectionable in harbor surveys.

300. Character of bottom.—The sounding record should show the character of the bottom at the top of each page and at each change reported by the leadsman, by the usual abbreviation used on the charts, which are as follows: M, mud; S, sand; G gravel; Sh, shells; P, pebbles; Sp, specks; Cl, clay; St, stones; Co, coral; Oz, ooze; bk, black; wh, white; rd, red; yl, yellow; gy, gray; bu, blue; dk, dark; lt, light; gn, green; br, brown; hrd, hard; sft, soft; fne, fine; crs, coarse; rky, rocky; stk, sticky; brk, broken; lrg, large; sml, small; stf, stiff. The occurrence of grass, kelp, hyacinth, or other growth should be noted; also where kelp is towed under, and at what stage of the tide it is covered.

301. It is particularly important that information as to the bottom be given for harbors and anchorages. The information given by the sounding lead may be somewhat superficial, and when convenient a useful check is furnished by the actual experience in anchoring and the material brought up by the anchor, which should be noted.

302. In the record of soundings, one line should be omitted after the sounding on which a position was taken, and about four lines between the end of one line of soundings and the beginning of the next line.

303. The times of soundings and positions should be carefully recorded, as they are used in spacing the soundings. The time the boat starts or stops is required, although the angles may be taken earlier or later. When under way, if no sounding is taken on the position, leave that part of the line blank in the record.

304. Corrections.—Erasures should not be made in records. Mistakes discovered may be crossed out and corrected by writing above or to one side, with explanation, if any. Full explanation must be written in the record if any work is rejected, using blue or red pencil.

305. The recorder should promptly call attention to any unusual sounding; if it is confirmed it should be marked O. K.

306. The success of the hydrographic work depends directly on the correctness and clearness of the record; the recorder must make sure that he hears and records every fact properly and that the record is complete, and must not hesitate to ask for repetition when necessary. He should call back the figures as entered.

307. To save space in plotting upon the sheet, each day's work is known by a letter. The vessel and each boat should have a separate series, distinguishing them by using capitals of one color for the vessel and lower-case letters of another color for each boat, these distinctions to be preserved in the books, on the sheets, and in the table of statistics. For convenience of reference the letters used in each book should be given on the outside of the covers in the proper colors.

308. When the alphabet has been exhausted for day letters, use double letters or primes, as AA or A′. Red, blue, and green are the best colors to use; black should not be used, as this would obscure the soundings.

309. When a sounding machine of any kind is used the record should clearly state the kind of machine, manner of making sounding, and correction to machine or registering dial, and how correction was obtained. (See also par. 288.)

310. Reduction of sounding.—The plane of reference having been established and related to the graduation of the staff, the reducers, or tide corrections, to be applied to the soundings are derived by taking the difference between the tide-gauge reading at the time of sounding and the tide-gauge reading of the plane of reference. If the tide-gauge reading at the time of sounding is greater than the reading of the plane of reference the correction to be applied to the sounding will be minus. If less the correction will be plus.

311. The reducers, or tide corrections, for open ocean areas or for depths over 7 fathoms, will be entered in the sounding record in integral feet. On bars at entrances and over inside water areas for depths less than 7 fathoms and more than 3 fathoms the reducers will be entered to the nearest half foot, and for depths of 3 fathoms or less to the nearest tenth of a foot. The correction for the lead line, also to tenths of feet, must be applied at the same time as the tide reduction, but the lead-line correction may be omitted if not exceeding one-half of 1 per cent of the depth. The reduced soundings will be entered in integral feet in the column headed "Reduced soundings field" (see pars. 335–337) except in developments in less than 40 feet depth, at critical points (see par. 298) the reduction shall be made so as to take account of the fraction of a foot. In verifying the reduction of soundings discrepancies of two or three tenths of a foot may be disregarded.

Lead-line correction.—The correction for lead line or sounding apparatus, when necessary, will be entered in the sounding record in feet and tenths for depths of 7 fathoms and less, and in integral feet for depths over 7 fathoms, using the minus sign for corrections to be subtracted and the plus sign for corrections to be added to the soundings. When integral feet are used, a fraction of 0.8 foot or more in a positive correction, and a fraction of 0.3 foot or more in a negative correction will be counted as an extra foot, but the smaller fractions will be neglected in each case. The correction for lead line or sounding apparatus may be omitted if not exceeding one-half of 1 per cent of the depth.

312. The record must show, by initials at the end, by whom reducers were entered and soundings reduced, and by whom each of these operations was checked. It can not be too strongly impressed upon the commanding officer and chief of party and their subordinates as well that good results in hydrographic surveying can not be expected unless attention is paid to details. It is, therefore, the duty of the officers engaged upon Survey work to see that the records conform in all respects to these instructions.

313. Planes of reference.—The planes of reference adopted for the reduction of soundings and the publication of the charts of the Coast and Geodetic Survey are as follows:

314. For the Atlantic and Gulf coasts of the United States and Porto Rico, the mean of the low waters.

315. For the Pacific coast of the United States, Alaska, the Hawaiian Islands, and the Philippine Islands, the mean of the lower low waters (except for Wrangell Strait, Alaska, 3 feet lower than the mean of the lower low waters).

316. For the derivation of the above planes, see under "Tidal observations."

317. Plotting hydrographic sheets.—On boat sheet, smooth sheet, or tracing of either, positions should be plotted, and sufficient soundings should be plotted in pencil to keep track of the work and to make sure that the area is properly covered. All soundings showing unusual or dangerous depths at critical places should be plotted so that immediate examination can be made, before leaving the locality, of doubtful points and spots that give indication of danger to navigation. Approximate plane for tidal reduction should be used where tide observations are available, getting the plane by comparison with predictions. Where observations are not available use predictions in the form of tide curve prepared at the office on the tide-predicting machine in the form of a tide roll or marigram. This is recommended for preliminary hydrographic plotting and for wire-drag work. Approximate depths should be plotted on the boat sheet only.

318. Field parties must plot all sounding lines on the smooth hydrographic sheets, plotting the positions in ink and indicating them by pen dots instead of small circles. See paragraph 327 and the following paragraph for instructions. The protractor, particularly if it is a metal one, should seldom be permitted to touch the face of the smooth sheet. Before beginning the protracting, stretch a piece of tracing vellum over the entire sheet and cut circular holes one-fourth inch in diameter over each signal. Letter the names of the signals legibly on the tracing. In pricking the plotted positions apply sufficient pressure to mark through the vellum onto the smooth sheet. After plotting a few positions lift up the vellum enough to expose the area just protracted, and number the positions and connect them with hard-pencil lines. After the sounding lines are fixed on the sheet and there is opportunity for further office work, due to unfavorable weather for field work or other causes, the soundings should be entered in pencil after they have been reduced

for tide as noted in the preceding paragraph. It is important that in so far as practicable the hydrographic sheets should be completed in the field. In no case should the soundings be inked in by the field party.

319. Necessary details on completed sheet.—Every original hydrographic sheet when sent in from the field must contain the following:

(*a*) Projection in black ink, fine full lines, the latitudes and longitudes on each end of each parallel and meridian; a note at bottom giving the latitude and longitude, with seconds in meters, of some one triangulation station.

(*b*) Triangulation, plane table, and such other points as may have been determined or established by the hydrographic party must be plotted, each with its distinctive symbol and name. The standard symbol of triangulation point is a black circle 2 millimeters in diameter with red circumscribed triangle, the name of the point lettered in black. The symbol of plane-table position is a red circle 3 millimeters in diameter with name lettered in red. The symbol of hydrographic signal is the same as for plane-table symbol except that blue ink is used. The positions of all signals should be accentuated by fine black dots in the needle holes to assist plotting. Large buildings and prominent landmarks determined in connection with the hydrography should be indicated on the hydrographic sheet and designated by appropriate legend; if necessary, a reference letter may be used and the legend placed where there is more room. (See also par. 196.)

(*c*) The shore line must be drawn on the sheet in a continuous black line if it has been surveyed by a plane table; if sketched in by a hydrographic party, it is to be indicated by a broken line. The high-water line and all information outside of it should be transferred from the topographic sheet; the low-water line and other features outside of high-water line should, however, be left in pencil until the hydrography is plotted, when the information should be combined, in general giving greater weight to low-water line as developed by the soundings. The low-water line should be indicated by dotted line, as far as determined. The area between high and low water should not be sanded.

(*d*) The soundings on the finished sheet should be plotted in pencil by the field party with the positions, letters, and numbers in colored ink. Minus soundings, which represent the heights above the plane of reference of areas bare at low water, should be given with the minus sign and inclosed within the dotted low-water line.

(*e*) Rocks, reefs, coral, and shell banks, sunken or awash, must be marked with the proper symbols. Where the least depth over a submerged rock is obtained, the depth should be shown, with the word "Rock" or "Rk." Do not use symbol for sunken rock in such case.

(*f*) The positions of all buoys, light vessels, etc., must be given with their proper symbols, and depths at same determined.

(*g*) Bottom characteristics should be noted on the sheet at moderate intervals, to give information contained in the record. The standard abbreviations are to be used. (See par. 300.)

(*h*) The limits of grass, kelp, etc., and the conditions of tide or current when these show must be indicated. If the bottom is grassy, it must be so written. Kelp must be marked with its proper sign.

(*i*) The names of islands, points, rocks, reefs, shoals, banks, channels, creeks, etc., must be given on the sheet. Care must be taken to obtain these names correctly. Names should, as far as practicable, be placed on the land area, leaving the water area clear. Lettering should not be allowed to obscure soundings.

(*j*) All ranges, bearings for dangers, etc., and sailing lines on courses or ranges should be given and drawn as follows: The range in black lines broken with long dashes; the bearings in black dotted lines; and the sailing lines in black lines broken with short dashes, with the positions of the objects for ranges and bearings determined, marked, and named, and the names of the objects and the purpose of the range or bearing written along its line.

(*k*) Current stations and tidal stations must be plotted in position.

(*l*) Titles should not be inked on original sheets by the field party, but must be furnished on Form 537 and pinned to the sheet. The information for the title must include the general locality, special locality, names of persons actually in charge of sounding, and of chief of party, vessel, dates of beginning and ending, and scale, together with a list of all data forwarded with the sheet. The title of a hydrographic sheet must clearly indicate the limits of the hydrography, and the same title must be given on the record books pertaining to it.

320. Table of statistics.—A table of statistics should be made as the sheet is plotted and transmitted with the sheet. This table may be written on computing paper and should be in the following form:

Statistics sheet No. ______.

Date, 1903.	Letter.	Volume.	Positions.	Soundings.	Miles, statute.	Vessels.
January 28	a	1	164	1,309	24.8	Launch.
Total	......	......	7,488	53,981	950.8	

There must be a note stating the unit for soundings (fathoms or feet) and the plane of reference. Also a tidal note giving the location of the gauge, and if there was more than one tide gauge, for what parts of the sheet each was used; also the following information:

Plane of reference, reading on gauge.
Lowest tide observed, reading on gauge.
Highest tide observed, reading on gauge.

321. Depth curves.—The depth curves must be drawn on the sheet, and each curve should include the outer soundings of the depth represented by the curve. When curves run so close together as to confuse the sheet, the less important, or those representing greater depths, may be dropped. Curves must not be completely drawn where the information is insufficient, but parts of curves or curves with broken line may be put in.

The field party should leave the curves in pencil. When the sheet is verified at the office the curves will be inked with full colored lines, in general according to the following scheme:

Zero or mean sea-level curve__________________________Yellow.
6-foot or 1-fathom curve__________________________Green.
12-foot or 2-fathom curve__________________________Red.
18-foot or 3-fathom curve__________________________Blue.
24-foot or 4-fathom curve__________________________Yellow.
30-foot or 5-fathom curve__________________________Red.
36-foot or 6-fathom curve__________________________Green.
60-foot or 10-fathom curve__________________________Yellow.
120-foot or 20-fathom curve__________________________Blue.
300-foot or 50-fathom curve__________________________Red.
600-foot or 100-fathom curve__________________________Green.
1,200-foot or 200-fathom curve__________________________Yellow.
6,000-foot or 1,000-fathom curve__________________________Blue.

(The 24 and 36 foot curve will be omitted except in special cases.)

Depth curves are of much value in interpreting and examining the results of the field work. The depth curves will often indicate areas of shoaler depths requiring further examination. Also abnormal and improbable curves are a strong evidence of probable uncertainties or inaccuracies in the hydrographic survey. Depth curves correspond to contours on land, and in nature are therefore generally of graceful sweeping form, free from sudden changes in direction and from corners; ordinarily they can not cross or abruptly run into each other; on approaching they tend toward parallelism; any departure from probable natural conditions is an indication of error either in field work or in plotting, or it may be an indication of shoaling that will require further examination. A study of the characteristic bottom forms in any region is of value in the interpretation of hydrography, as such forms are apt to repeat themselves under similar conditions.

In relinquishing charge of hydrographic sheets and accompanying records the chief of party will inspect each record and sheet and approve each sheet before it is transferred to the office or to another officer for completion. When circumstances are such that a departure from this rule is unavoidable or when any part of the provisions of the instructions for completing these records and sheets are omitted, an explanation shall be forwarded promptly to the office for approval and so noted in the description report accompanying each sheet.

322. Comparison with previous surveys.—In plotting comparison should be made with the results of all previous surveys and with charts covering the same region, if available, especially as to all dangers or less depths shown on previous surveys. Develop previous dangers and verify their location and extent.

323. All remarks, comments, etc., in sounding records should be carefully noted in plotting; abrupt changes in depth should be verified by checking tide reduction, etc.; boat sheets and descriptive reports should be examined and compared to see that all essential information is on the smooth sheet.

324. Character of drafting.—The drafting work on the finished hydrographic sheet requires accuracy, neatness, and legibility, and of course good judgment and knowledge of the work, but it does not require expert penmanship.

325. Marking positions.—As each position is plotted on the sheet a point should be pricked through to show its exact position, and this point should be marked with a light dot of colored ink (small circles should not be made). The successive positions on the lines will be connected by lines drawn with a hard pencil.

326. Each position must be numbered and the number placed just below and to the right or left of the position; the position numbers must be small and so placed as not to interfere with the soundings.

327. The letter of the day's work must be placed at the beginning and end of each line, at about every fifth position on the line, and at the point of any decided change of direction in line.

328. The color of the position, day letter, and position number must be the same as the color given the vessel or boat in the sounding record.

329. Style of numerals.—Vertical block numerals (no hair lines) have been adopted for soundings on hydrographic sheets. The penciling, as well as the inking, should follow this style, using a pencil hard enough to avoid smudging, but not so hard that it will unduly cut into the paper.

330. Distinctness of important features.—It is important in plotting hydrographic sheets that the more important features, such as rocks and least depths on shoals, shall be perfectly clear and distinct, and great care must be taken not to obscure them by attempting to plot all of the numerous soundings that may have been taken for the development of such a feature. If for any reason an important feature is not clear on the finished sheet, or is so shown that there is a likelihood of its being overlooked, a note should be added calling attention to it.

331. Selection of soundings.—Where the number of soundings taken is greater than can be plotted on the sheet, as many soundings should be plotted as is consistent with clearness; those showing the least depths on shoals, greatest and least depths in channels, and changes of slope must be shown, the selection being such that a cross section could be drawn from it showing all important features; in no case should a mere mechanical selection be made, as, for instance, every third or every fourth sounding.

332. Enlarged scale for complicated areas.—It is sometimes difficult to properly plot the soundings to show the development of a complicated area on the scale of the general hydrographic sheet. In such cases an enlargement of the plotted positions should be made and the soundings plotted on the enlargement, which may appear on the sheet as a subplan. The enlargement should be to some even decimal scale, and the scale should be stated on the plan. The curves at the margin of the subplan should be reduced and transferred to the main sheet to make sure that the work is consistent.

333. Overlap of sheets.—For adjacent hydrographic sheets the curves and soundings should be common for a narrow strip, and this overlap should be in accord on the two sheets.

334. Dangers and stage of tide.—Definite information should be given on the sheet as to dangers which show at various stages of the tide, as so many feet above low water, awash at low water, awash at high water, breaks at half tide, breaks in heavy weather only, and the like. "Awash" should always be qualified by the stage of tide at which it occurs, and the mere use of the symbol for rock awash will not be sufficient for any important danger. (See par. 235.)

335. Tide rips should be indicated on the sheet by words, qualified as heavy, moderate, or light.

336. Depth units.—The unit to be used in plotting the soundings will depend upon the locality, the character of the body of water, and the closeness of detail to be shown. Extensive inclosed waters and inside routes frequently have but from 2 to 5 feet of water or even less, and of course should be plotted in feet and fractions (see par. 337) at critical points. Sheets in generally deep water will be plotted in fathoms and sixths of fathoms to a depth of $6\frac{5}{6}$ fathoms, $\frac{3}{6}$ being plotted as $\frac{1}{2}$; in fathoms and quarter fathoms from 7 to $8\frac{3}{4}$ fathoms, $\frac{2}{4}$ being plotted as $\frac{1}{2}$; and for greater depths fractions will be omitted. But one depth unit must be used for the whole area of any sheet.

337. On sheets plotted in feet no fraction of feet will be shown (fractions of less than 0.8 being omitted, and those of 0.8 or more being written as the next whole foot), except that in critical places (under 40 feet in depth) on navigable bars, in channels, and shallow inclosed waters and inside routes fractions ($\frac{1}{4}$, $\frac{1}{2}$, and $\frac{3}{4}$) shall be shown where important; but on outlying dangers all fractions shall be omitted and the next lower foot shall be given.

338. In converting fractions the following will in general be observed: When plotting in even feet omit all fractions of less than 0.8, and those of 0.8 or more write as the next whole foot; when plotting in quarters take $0.1=0$, $0.2=\frac{1}{4}$, $0.3=\frac{1}{4}$, $0.4=\frac{1}{2}$, $0.5=\frac{1}{2}$, $0.6=\frac{1}{2}$, $0.7=\frac{3}{4}$, $0.8=\frac{3}{4}$, $0.9=1$; when plotting in halves, take 0.1 to 0.3 as 0, 0.4 to 0.7 as $\frac{1}{2}$, and 0.8 to 1 as 1; when converting from feet to fathoms and quarters, take less than 1 foot as 0, 1 foot and less than 2.5 feet as $\frac{1}{4}$ fathom, 2.5 feet and less than 4 feet as $\frac{1}{2}$ fathom, 4 feet and less than 5.5 feet as $\frac{3}{4}$ fathom, and

5.5 feet and over as 1 fathom; when converting from feet to fathoms, for less than 4.9 feet drop the fraction, for 5 feet and over take the next whole fathom.

339. Defining reef limits.—The limits of reefs as located by the hydrography should be fully marked on the sheets in the field. The danger limit of rocky bottom having some depth of water, but which can not be investigated in detail, should be indicated by the sunken rock symbol. The coral-reef symbol should be used to indicate the extent of coral reefs either bare or awash at low water.

340. Errors and omissions.—Where from any reason but a single angle is available (as when a mistake has been made in reading one angle) a line of position may be plotted by setting the angle on a protractor and plotting several points in the vicinity of the work. The boat must have been at some place on the line drawn through these points, and its location can be fixed by the intersection of this line with the course made good, or by plotting on it the distance from either the preceding or succeeding position according to the time interval. If two angles have been observed, but without a common object, the two lines of positions may be plotted separately and their intersection will be the position of the boat.

Mistakes in angles or record may sometimes be detected by estimating the position from time and course and testing the angles with the protractor. No arbitrary deviation from the record should be made, however, unless it is reasonable and supported by other evidence. Such cases, or rejection of any portion of the record, should be noted in the column of remarks with reason therefor, and this statement must be signed and all defects corrected before leaving the working ground.

341. North the top of sheet.—In plotting and inking original sheets, north shall be taken as the top, and names, soundings, and signals shall be put on normal to the meridian, regardless of the direction of the borders of the sheet, except where it is desirable that names be lettered to conform to geographic features. In such cases the names shall be inked so as to be read when looking north. Names should by their direction and proximity clearly indicate the object designated.

342. Very large sheets should be avoided in plotting hydrography, being inconvenient to handle both in office and field. The standard size of topographic sheet is 30 by 52 inches. Somewhat larger sheets may sometimes be necessary for hydrography, but they should not exceed 42 by 60 inches.

343. For smooth hydrographic sheets, Whatman's paper is furnished mounted, of size 30 by 52 inches. When larger sheets are required backed drawing paper of the best available quality should be used.

344. A multiplicity of sheets should be avoided as far as practicable by completing each sheet in its entirety. Fragmentary sheets for small pieces of work should be avoided; such information can often be placed as a subplan on another sheet covering the vicinity, separated by a border and with subtitle.

345. For boat sheets a good quality of mounted paper should be used, and a paper with brownish tint has been found very satisfactory.

346. Thin transparent celluloid has been used advantageously for boat sheets; one side of this material should have a dull finish so that it may be written upon with a pencil. The celluloid is laid over the smooth sheet and the signals marked. In the boat the celluloid is used over a sheet of paper.

347. The boat sheet, if one is used, should always be forwarded to the office, to assist in the final verification.

348. The distances that will be included on a sheet of given size and scale may readily be obtained from the following table of scale equivalents, by dividing the length or width of the sheet by the length of 1 mile on the given scale. For instance, a sheet 42 inches by 60 inches on scale $\frac{1}{20000}$ will include an area 11.5 by 16.5 nautical miles.

Scale.	Nautical mile.		Statute mile.	
	Inches.	Centimeters.	Inches.	Centimeters.
$\frac{1}{5000}$	14.593	37.06	12.672	32.19
$\frac{1}{10000}$	7.296	18.53	6.336	16.09
$\frac{1}{15000}$	4.864	12.36	4.224	10.73
$\frac{1}{20000}$	3.648	9.27	3.168	8.05
$\frac{1}{30000}$	2.432	6.18	2.112	5.36
$\frac{1}{40000}$	1.824	4.63	1.584	4.02
$\frac{1}{50000}$	1.459	3.71	1.267	3.22
$\frac{1}{60000}$	1.216	3.09	1.056	2.68
$\frac{1}{80000}$	0.912	2.32	0.792	2.01
$\frac{1}{100000}$	0.730	1.85	0.634	1.61
$\frac{1}{200000}$	0.365	0.93	0.317	0.80
$\frac{1}{400000}$	0.182	0.46	0.158	0.40
$\frac{1}{1000000}$	0.073	0.18	0.063	0.16

349. Manipulation of protractor.—In plotting positions it is well for the sake of rapidity to have a uniform practice in placing the protractor. It is usually preferable to place the central arm on the central object, with the right and left arms about equally distant from the corresponding objects; keeping the central object on, push the instrument up, reducing the distances on either side equally until all three arms are on. Handled in this manner the clamped arms of the protractor are not touched by the hands. The protractor should be examined occasionally to see that it is in good adjustment and has no lost motion in any of its parts. A protractor may be tested by measuring with it several angles which have been accurately constructed geometrically on drawing paper.

350. For plotting angles where the three-arm protractor can not advantageously be used, either because the angles can not be set off or the positions fall under the frame, the Court celluloid protractor should be used. This is more convenient than using tracing paper.

351. Spacing soundings.—In plotting soundings the space between the plotted positions should be divided (using the convenient standard spacing dividers) according to elapsed time and the soundings placed at positions indicated by their times. Where there is any distinction the more reliable system of lines should be plotted first. The center of a numeral, or group of numerals, representing a sounding is the position of the sounding.

352. In starting a sounding line from a position determined when the boat is at rest, another position should be determined after an interval of one minute or when the boat has attained the sounding speed. Where considerable change of course is made and soundings are continued with the vessel or boat under way, allowance must be made in plotting for the curve made in turning and the fact that there is an appreciable interval before the vessel is on the new course. In such a case a position should be determined just before changing the course and another as soon as the boat is on her new course.

353. Sheets should be carefully examined for differences in depths when sounding lines cross one another.

Discrepancies at crossings should be recognized as evidence of some fault in apparatus, method, or record which requires a study to discover its source and indicate the most probable correction, and possibly a reexamination in the field. The following typical errors are likely to produce large discrepancies and which are most readily detected by such a study. Careless protracting or spacing of soundings; errors in applying lead-line correction; confusion of numbers, such as 7 for 11; miscalled sounding; reversed angles, left for right or right for left; misreading sextant 5 or 10°; confusion of signals; sextant badly out of adjustment; erroneous tide reduction.

The following are typical of errors which will require a more careful analysis of all available data: Spacing of soundings when affected by unrecorded variations of speed and course; unrecorded errors in length of lead line; large clock errors; plane of reference, when the soundings of one line at a crossing depend on a tide gauge blocked by shoals from the free accesss of the tide; tide gauge too distant, or othewise not well located in relation to the hydrography; abrupt changes of slope, especially those due to the existence of ridges formed by wave action on bars; difference in state of the sea, when the soundings of one line are more affected by rough water than those of another; soundings affected by the existence of a bight in the lead line when running with or against wind, sea, or current; very soft or ooze bottom; a condition which permits of a considerable latitude of judgment as to what is the bottom.

Most of the errors in the first list will have the effect of displacing the sounding line from its true location, and a study of the data should bring out the fact that the divergence was inconsistent with the record, and lead to the discovery of the error.

Unrecorded variations of speed most frequently occur at the start or finish of a line—a comparison of time intervals and distances between positions should indicate the trouble. A faulty plane of reference will produce discrepancies where lines of soundings reduced by it cross other lines of soundings reduced from a different gauge.

Curves of equal depth afford useful evidence of the source of several discrepancies, among which is that of a tide gauge poorly located with reference to the hydrography. Under this condition curves located by means of adjoining parallel sounding lines, run at different stages of the tide, will have a jagged unnatural appearance.

The existence of sand ridges on a bar should be apparent from an inspection of the whole area of the bar. A slight difference in the position of the vessel at a crossing might result in a sounding being taken on the crest of a ridge and one on the side or bottom of the steep inward slope. The possibility of an underwater bight in the lead line should be capable of inference from the notes in the record. And here it is pertinent to once more stress the importance of full notes in the record. It should be obvious from the foregoing how necessasry they are in clearing up discrepancies.

Sufficient notes may save from rejection an apparently unreliable sheet.

If the study does not result in an actual correction of one of the lines, yet it may plainly show good reasons for the rejection of one of the lines and, in consequence, warrant the adoption of the other. When the data do not afford a reasonable explanation of the difference, and the latter amounts to as much as 5 per cent of the depth in critical parts of the water area, the work should be revised in the field.

354. Lead-line corrections.—To avoid large corrections to soundings it is desirable and convenient to have the lead line as nearly correct as practicable. The following method has been found to give a fairly constant lead line: First, each lead line should have its own sized lead and not be subject to different tensions from leads of different weights; second, before marking, let the line, with lead attached, drag after the vessel for several hours a day for two or three days, and afterwards keep the line soaked in salt water; third, mark the fathoms with line under a tension equal to the weight of the lead, laying off the marks with a steel tape; the intermediate marks can be put in with line extended on the deck, averaging the spaces.

355. Verification.—The lead line must be verified by the officer in charge at the beginning and end of each day's work, and the corrections in feet and tenths recorded in the sounding record or a statement entered that lead line is correct. In verifying the line care should be taken to apply a pull equal to that of the lead in water.

356. Permanent marks may be placed on a deck or a wharf with copper tacks, and the verification of lead line can then be quickly accomplished.

357. The record in the sounding book of the comparison of lead lines should be so explicit as to avoid any possibility of error in applying the correction to soundings, and the following form is recommended:

Mark on lead line = M.	True length on tape or standard = L.	Correction to soundings = L − M.
1 fm.	5.8 ft.	−0.2 ft.
2 fm.	11.9 ft.	−0.1 ft.
3 fm.	18.1 ft.	+0.1 ft.

358. The minus sign indicates that the lead line is too short, so that the depths obtained with it appear too large and the correction to the soundings is subtractive. The plus sign indicates that the lead line is too long, so that the depths obtained with it appear too small and the correction to the soundings is additive.

359. The lead-line correction may be neglected if not exceeding one-half of 1 per cent.

360. Lead lines are marked as follows:

1 fathom.—A piece of leather with one strip.
2 fathoms.—A piece of leather with two strips.
3 fathoms.—A piece of leather with three strips.
4 fathoms.—A piece of leather with four strips.
5 fathoms.—White rag.
6 fathoms.—A piece of leather with one strip.
7 fathoms.—Red rag.
8 fathoms.—A piece of leather with three strips.
9 fathoms.—A piece of leather with four strips.
10 fathoms.—A piece of leather with a hole in it.
11 fathoms.—A piece of leather with one strip.
12 fathoms.—A piece of leather with two strips.
13 fathoms.—Blue rag.
14 fathoms.—A piece of leather with four strips.
15 fathoms.—Same as 5.
16 fathoms.—A piece of leather with one strip.
17 fathoms.—Same as 7.
18 fathoms.—A piece of leather with three strips.
19 fathoms.—A piece of leather with four strips.
20 fathoms.—Two knots.

361. Up to 5 fathoms the line should be marked with small white cord for every foot, the half-fathom mark being distinguished by a cord with a knot, and this designation for half fathoms should continue to 10 fathoms.

362. Sounding poles instead of lines may be used in shoal depths.

363. Sextant glasses.—A sufficient supply of spare sextant glasses should be kept on hand. When the glasses become unserviceable they should be returned to the office. Sextant glasses are expensive, and precaution should be taken against their being lost, broken, or scratched.

364. In case of emergency sextant glasses may be resilvered in the field by the following method: The necessary requisites are tin foil and mercury. Lay the tin foil, which should exceed the surface of the glass by a quarter of an inch on each side, on a smooth pad of paper; rub it smooth with the finger; add a drop of mercury about the size of a small shot, which rub gently over the tin foil until it spreads itself and shows a silvered surface; gently add sufficient mercury to cover the leaf, so that its surface is fluid. Prepare a slip of clean tissue paper the size of the tin foil. Brush the surface of the mercury gently to free it from dross. Take the glass, previously well cleaned, in the left hand and the paper in the right. Lay the paper on the mercury and the glass on it. Pressing gently on the glass withdraw the paper. Turn the glass on its face and leave it on an inclined plane to allow the mercury to flow off, which is accelerated by laying a strip of tin foil as a conductor to its lower edge. The edges may be removed after 12 hours, and in 24 hours give it a coat of varnish made from alcohol and red sealing wax. Spare sextant glasses are now furnished with each sextant.

365. The mercury-tin amalgam, while less readily affected chemically, is more liable to mechanical injury than silver, and caution is therefore necessary in handling the sextant glasses.

366. Dangers previously reported.—Existing charts and publications must be carefully compared with the development of the field work. Should a rock or shoal previously indicated on a chart or mentioned in a publication not be found during the progress of the work, the locality must be so carefully searched and the records must be so complete as to show beyond doubt that the rock or shoal does not exist. It must be specially mentioned in the descriptive report, and in this report must be given, if possible, the evidence of anyone who may be deemed an authority in the matter. No rock or shoal which has found a place on the publications is removed unless it is proved beyond any doubt that such rock or shoal no longer exists.

367. Information must be obtained from all available sources. Pilots, fishermen, shipmasters, boatmen, and others living in the vicinity or acquainted with the locality, must be consulted, and every place credited with a rock or shoal, even if only by rumor, must be examined. (See par. 374.)

368. Blank areas on charts.—Surveying vessels when proceeding to or from the field of work should take opportunity, when it will not materially delay more important duties or interfere with their instructions, to obtain occasional soundings in areas on the charts where no information is at present given, particularly in the ordinary tracks of vessels.

369. Ranges for compass deviations.—Report should be made of ranges of prominent and easily distinguished objects that would be suitable and useful for the purposes of determining the compass deviations of vessels in the vicinity of important harbors or anchorages.

370. Information affecting navigation, reports of dangers, and changes in aids to navigation.—All persons in the service of the Coast and Geodetic Survey should communicate to the Director any valuable information obtained affecting the interests of navigation along the coasts. Special reports should promptly be made of any information of the following classes, giving in each case the authority and such recommendations as may seem desirable: rocks, reefs, shoals, or sunken wrecks (with depth of water over same), either not shown or incorrectly shown; aids to navigation differing in any respect from the data given on the charts or in the light or buoy lists; important errors or omissions on charts or in Coast Pilots or sailing directions; changes in depths or directions of channels, changes in coast line, currents, etc. (See also par. 401.)

371. Determination of aids to navigation.—All aids to navigation in the area of the field of work, not already located, should be determined. Even outside of the limits of proposed work, when practicable, lights and buoys established by proper authority should be determined in position and described when they are not shown on the charts or have not previously been determined by this Survey.

372. Vessels en route from one port to another, when weather and other circumstances will permit, should verify the positions of lightships and seacoast buoys. The positions of all buoys and lightships on the field of work should be accurately determined.

373. Care of property.—Reasonable and proper care should at all times be taken of property, boats, and vessels employed in the survey work.

COAST PILOT.

374. The following outlines briefly the topics on which information shall be sought for publication in the Coast Pilot. It is a general guide for those whose special assignment is coast-pilot work. All officers, when in a position to do so, shall collect such information and forward coast-pilot notes as herein directed, which shall include all the data obtained on any or all of the subjects mentioned.

(*a*) The Coast Pilot aims to supply all information not furnished on charts or in other readily available forms, which may be of use to the navigator of any craft whatsoever, regardless of draft, size, or service.

(*b*) Inquiries shall be made of local authorities, commercial organizations, yacht clubs, and others interested, for the purpose of ascertaining their needs so far as they can be supplied by this service, or through reference to other bureaus.

(*c*) Relations shall be established, when possible, whereby the Survey will be advised at all times of any matters which should receive consideration in the office or attention in the field.

(*d*) Preparation for this work shall be made by collecting all data in the office or elsewhere available bearing upon the region which is the subject of investigation, such as reports of aids and dangers uncharted or incorrectly charted; examine previous publications and note omitted, incomplete, or erroneous information; make study of United States Army Engineers' blue prints of surveys of improved areas in order to determine necessity for extension of their surveys to cover indicated changes beyond the limits of their work; note localities requiring examination on account of the incompleteness of surveys or increased importance of locality; ascertain from the office in what localities our data on tides and currents are incomplete and should be supplemented in the field; consult Senate and House documents on examinations, surveys, reports, and improvements in regions under consideration.

Bromides of original sheets may be required where a chart is inadequate by reason of scale or lack of detail for purposes of field examination.

(*e*) In the field, data will be collected from all available sources; offices of the United States Army Engineers should be visited to obtain results of their surveys and examinations, program of proposed operations, and information on subjects useful to the Survey.

(*f*) Application for similar information shall be made, personally if possible, to municipal engineers in charge of water fronts, engineer departments of railways controlling deep-water terminals, State authorities or others engaged in the development or operation of waterways, mariners and other individuals interested in shipping.

(*g*) Travel to and from the field of work and movements by members of the party while on the working ground shall be by steamer as far as possible in order to collect data from local masters and pilots making the runs. On the working ground, visits should be made to lightships, tenders, and stations of the Bureau of Lighthouses, and officers and employees interviewed. No general rules can be laid down, but the following points will be suggestive so far as applicable to any particular region. The amount of detail to be given requires much judgment, as over-minute details tend to obscure the most useful facts. Obviously certain classes of information may be useful as in a new country previously unsurveyed which may not be necessary to give in connection with a well-known coast.

375. General description of the coast, following the geographic sequence of the published Coast Pilots, and including the aspect or appearance of the coast on making the land; describing prominent objects, as, on a bold coast, the headlands, peaks, etc., with their form, color, and height; or, on a flat coast, the water tanks, spires, beacons, etc. Especially describe the first landfall and objects useful as guides to navigation.

376. Outlying dangers and islands, the limits of tide rips and breakers, and their relation to wind and tide.

377. Landmarks.—Description of all prominent landmarks likely to be useful to navigation or to future surveying operations. If mountains, state whether summits are often clouded. Give measured or estimated heights of mountains, hills, cliffs, islets, or rocks referred to. Describe ranges in use by pilots and means of identifying them. Suggestions should be made as to other ranges that would be useful or as to artificial marks that it would be desirable to erect. (See par. 194, "Topography.")

378. Directions for passing the outlying dangers.

379. Refuge.—In case of stress of weather the best anchorage or the nearest harbor of refuge to run for; or in extreme cases of damage the best place to beach a ship. Locate and describe life-saving stations and houses of refuge. Give character of beach and behavior of vessel in breakers.

380. Pilots.—Information as to their station or cruising ground, any special regulations or signals, their charges, the possibility of obtaining tugs, etc.; anchorage while awaiting pilot or tug.

381. Approaches.—General remarks, usual course from alongshore or from sea, dependence on lead, approaching in thick weather.

382. Bars.—Describe principal marks and aids. Give directions for approach, with description of outlying and other dangers and how to avoid them. Least depth and width at best place for crossing bar; most favorable time to enter. Does bar break in ordinary or only in heavy weather? How far out do breakers extend?

Give velocity and direction of wind and stage of tide producing these conditions. Can entrance be made while bar is breaking; and, if so, for what draft? Give character of bottom, and usual allowance made for squat, pitch, and tides under different conditions on the bar. To what change in depth and position is the bar channel or approaches subject; if any, give magnitude and direction of change. (See Currents.)

383. Channels.—Give minimum available depth throughout and where necessary the minimum width. Give character of bottom and describe all aids and natural objects. Are channel banks defined by grass or other growth, color of shoals, or in any other readily recognizable manner?

State maximum draft possible and greatest draft entering or leaving. Where maximum draft differs from minimum depth in channel state reasons for same, as swell, squat, tide, and rocky or soft bottom. Note depth and character of approaches to wharves, piers, dry docks, marine railways, and coal stations. Manner of approaching them and why. Are channels permanent, subject to considerable or frequent change, under improvement, or maintained?

384. Description of the shore, with characteristics (as height, color, wooded, cultivated, bold, sandy) of each important headland, point, island, and rock.

385. Inshore dangers.—Extent and nature, least depth over them; whether visible; if breaking, at what stage of tide; how much, if any, is bare at low water; marks or ranges for clearing them by day or night. In regions where dangerous shoal areas or pinnacles are marked by kelp or other growth state the ordinary significance of such growths, at what stage of tide they show at surface, and when, if ever, they are towed under.

In regions where bowlders, ledge, coral heads, or similar dangers probably exist it is very desirable to examine the suspected areas at extreme low water, at which time important features may show above or near the surface.

In the examination of entrances and approaches for off-lying dangers, advantage should be taken of heavy weather to locate any shoals marked by breakers. The existence of rocks or other shoals in localities of considerable current is often indicated by rips and swirls; such disturbances should be noted at strength of current and investigated.

386. Ports.—Commercial importance, character, and magnitude of trade, chief exports and imports, facilities for coaling and watering vessels, supplies and provisions obtainable, facilities for repairs to hulls and machinery, marine railways or dry docks (length, draft forward and aft, and tonnage hauled), wharves, piers, and docks, and depth of water and character of bottom alongside and in approaches, whether public or private, and rules for use, harbor regulations, means of communication.

Locate and describe customary anchorage, customhouse and landing, time ball, station for reporting vessels, storm warning and small craft warning display stations, quarantine stations, hospitals for mariners; and obtain copies of all published pilot, harbor, and anchorage rules and regulations where possible. Note harbor improvements in progress or projected.

387. Sailing directions for approaching, entering, and leaving channels and harbors; such directions should be actually tried under different conditions and verified before they are adopted or recommended for use.

Verify ranges and determine and describe any natural ranges or leading marks, defining sailing lines, points of change of course, dangers, and other features.

Check bearings or obtain azimuth of dredged channel axes. Wherever possible locate aids by means of ranges, bearings, or angles for use as checks on their position. Add any useful details not given in light list, reliability of lights and buoys, visibility of lights and audibility of fog signals. Note localities of unusual sound reflection. Locate and describe marks and aids, whether natural objects or others, used in connection with works of improvement which may serve as navigational guides. Locate and describe fish weirs, oyster stakes, and similar constructions, also day marks and lights maintained on them. Give rules and regulations relating to them.

388. Aids.—Lights, lighthouses, buoys, beacons, and other aids shall be verified on the ground for location, description, depth alongside, and in relation to the features they are intended to mark. Note buoys which tow under or do not watch properly. Where the distinctive characteristic of an aid is its color state whether it is generally clearly distinguishable.

389. Currents, tidal or nontidal.—General conclusions from observations or other information. Give velocity, direction, duration, and relation of time of slack to that of high water or low water. Note set with reference to axis of channel and openings through bridges and at other contractions of the fairway, across bars and in entrances; approaching docks and piers; occurrence of rips, swirls, and eddies. Effect of wind and freshets on currents, and if flood current is ever entirely overcome. Describe fully all abnormalities in currents or marked variations from usual phenomena. The notes shall cover the entire field of operations, both inshore and offshore, and include all horizontal movements of surface waters, whether tidal or nontidal, or both. Where the currents are due to winds or other meteorologic cause or are greatly modified in velocity, direction, and duration thereby, the variations produced shall be determined and their relation to the conditions that produce them shall be developed if possible, such as velocity and direction of wind.

390. Tides.—Collect all available data bearing upon tides, excessive or abnormal rise and fall, duration of stand, and time of high and low water. Where gauges are in operation make special effort to obtain records of such conditions; whether due to wind, flood, or other causes. Note rate of progress of the tidal wave and the variation of amplitude along its course.

In shoal areas, especially inclosed waters, give variation of surface level due to storms and, if possible, develop relation of velocity and direction of wind to locality and magnitude of resulting changes in surface elevation.

391. Bridges, contractions, and obstructions.—Note kind of bridge, horizontal and vertical clearance at high water of openings through fixed spans, draws when closed, and at other contractions; also depth in openings. Length, beam, and draft accommodated by locks and similar structures. Vertical clearance of aerial cables and trolley wires. Which side of draw or opening of bridge should be used, and if only one, state for what reason. Obtain copies of rules and regulations governing the operation of bridges and locks and signals in use.

392. Ice.—Season during which it is encountered. Its form of occurrence; movements under influence of winds and currents; extent to which it affects navigation. Season of navigation as affected by ice, flood, fog, low water, storms, and in addition in the case of canals and other artificial waterways give period of navigation fixed by law or regulation.

393. Rivers.—Give draft and class of vessels which can enter; point to which tide reaches; depth on bars and permanency of channel; strength of current; effect of freshets; distance to head of navigation for steamers and other craft.

394. Canals.—Describe location and approaches, give total length of each lock, capacity of locks, controlling vertical clearance under overhead structures, passing points, tie-up points, local contractions, variations of surface elevation, period open to navigation, rules, signals, and regulations governing operation.

395. Anchorages, with descriptions relative to their capacity, holding ground, amount of protection, and circumstances of weather under which tested. Character of bottom, marks, and rules and regulations for use, if any.

396. Landing places, especially on a coast exposed to swell.

397. Watering places for vessels—Rivers, streams, or springs.— At ports state whether water is piped to wharves or supplied by water boats, and charges; convenience for watering ships. Give distance upstream that salt water extends at different seasons or under other varying conditions; state also when overboard water is sufficiently fresh for drinking or boiler purposes.

398. Weather.—Under this head state briefly only new and important facts, as prevailing winds and their seasons, directions from which gales come and how they affect anchorage, land and sea breezes, rainy seasons, fogs, and freshets, and seasons or conditions when prevalent.

399. Wrecks, where usually occurring; tendency of wrecks to break up or remain in position. Information bearing upon the occurrence of wrecks is exceedingly desirable. It is of first importance that inquiries be made and investigations instituted for the purpose of developing the various causes contributing in any way to marine disasters, such as little known currents, additional aids required, misleading or deceptive bottom relief in approaches, shifting shoals and channels, imperfect or inadequate charts.

400. Change of coast line or depths.—Mention any reliable evidence as to recession or growth of shore line or change of depths. Note any important facts regarding changes observed. Give evidence, if any, of subsidence or emergence of shores. Locate and outline limits of dumping ground for dredged or other materials. Give location of submarine cables and water mains. Define limits and give regulations for forbidden anchorages. Report all obstructions and temporarily obstructive operations. Note especially localities where changes of any sort affecting navigation are likely to occur and report those which should receive frequent attention in order to keep publications up to date.

401. Information of importance affecting navigation, such as rocks, reefs, shoals, sunken wrecks, aids omitted or incorrectly charted, errors or omissions on charts or in Coast Pilots, changes in depth, channels, coast line, and currents shall be forwarded to the Director without delay for insertion in the Notice to Mariners or other immediate publication. Where aids are involved a report shall be forwarded, without recommendation, to the lighthouse inspector and a copy sent to the Director. Suggestions or recommendations in regard to aids shall be sent only to the Director.

(*a*) To avoid delay, inspectors and chiefs of parties on the Pacific coast and Alaska are authorized, whenever the Survey develops rocks or other important information that should reach the public promptly, to issue a notice furnishing such information. A copy of such notice, with full details, will be mailed to the Washington office at once.

402. Inside route pilot.—(*a*) Special effort shall be made to collect information which will contribute toward the completeness of our publications covering the inside routes through inland waters and all entrances and inlets affording access to such routes and with special reference to the needs of motor boats.

(*b*) Note extent of routes and period of navigation; draft that can be accommodated at low water and at high water; width of opening and vertical clearance under both fixed spans and drawbridges; rules and regulations for operation of drawbridges; draft in canals; length and width of locks; obstructions; tolls; period of navigation; attended or unattended bridges; rules, regulations, and signals.

(*c*) Navigability of tributary rivers, creeks, and other waterways, and distance from mouth to falls, rapids, dams, or other head of navigation, including depths and distances to various points.

(*d*) At points where boats must wait for the tide the time of local high water referred to some known point should be given. Character of bottom shall be determined generally, especially at local shoalings such as cross-overs, bars, oyster reefs, etc. Outline and describe snag infested and stump infested areas.

(*e*) The extent to which the tide affects the inland waters and variation of surface due to winds and floods should be noted. Localities of strong currents should be mentioned with at least approximate velocities and relation of time of occurrence to that of local or other high or low waters. Note points where navigation depends upon freshet conditions or high water due to rain.

(*f*) Locate and describe, in relation to the channels or other features they are intended to mark, all aids to navigation, including private aids such as pointers, poles, bush stakes, beacons, buoys, etc. Note buoys which tow under or do not watch properly. Where the distinctive characteristic of an aid is its color, state whether it is generally clearly distinguishable.

(*g*) Give points where services of pilots are necessary, where they can be obtained and rates, extent of traffic, development or settlement of region, and mention places where supplies, provisions, gasoline, oil, water, ice, and hotel accommodations can be obtained; also facilities for watering vessels and coaling, where small craft can be repaired, hulls, machinery, or both; give location of marine railways and the length, beam, draft forward and aft and tonnage they can haul.

(*h*) In remote districts telegraph, telephone, railroad, steamboat, or other lines of communication and postal facilities should be described.

(*i*) Occurrence of obstructive growths such as hyacinth, grass, kelp, etc., and season in which they are found, occurrence of ice and to what extent and for what period navigation is affected.

(*j*) Note especially localities where changes of any sort affecting navigation are likely to occur and which should receive frequent attention in order to keep publications up to date.

(*k*) *Entrances and inlets.*—Describe principal marks and aids; directions for approaching entrance with description of outlying or other dangers and how avoided; least depth and width in entrance, across bar in channel, and locate same. To what change in depth and position is entrance subject; if any, give rate and direction.

(*l*) Does bar break in ordinary or only heavy weather? Give direction and velocity of wind producing this effect. How far out do breakers extend? Can entrance be made while bar is breaking and, if so, for what draft?

TIDES.

403. Purpose.—Tide observations are made in connection with hydrographic work in order to furnish data for computing the plane of reference, for reducing the soundings to that datum, and for use in making predictions and giving tidal information for the Tide Tables, Coast Pilots, and Charts. Tide observations also furnish determinations of mean sea level for use in connection with precise leveling, and give information valuable for other engineering and scientific purposes. One or more tide gauges must be maintained in connection with all hydrographic work, and the tide observations should be made as complete as circumstances will permit.

404. Location of gauge.—The corrections necessary to refer soundings to the adopted plane of reference shall be in error not more than one-fifth of the allowable error in the determination of depth; where the allowable error in depth is one-half foot or less the correction shall not be in error more than one-tenth foot. Gauges shall be located so as to approximate the conditions on the working ground within the limits stated. Should doubt attach to any gauge in use, a temporary staff shall be established in the immediate vicinity of the work and the results at the gauge in question verified. In connection with hydrographic work, it will in general be desirable to set up an automatic tide gauge at some central point, and continue it there throughout the season; subsidiary tide staffs are also to be established in the immediate vicinity of the work, as may be necessary. In selecting a site for a tide gauge, existing facilities and the accessibility of the location to the observer must generally be taken into account. It will be convenient to place an automatic tide gauge on a wharf if a substantial one exists. It is important, however, that the location shall be such that there is free communication with the sea, shelter from storm waves, and deep water close to the position at low tides. For use in connection with the hydrography on the outer coast it is advisable to avoid a location for a gauge well inside of a river mouth or shallow estuary, or in any body of water having only a narrow connection with the sea. For surveys of offshore bars and exposed channel approaches, where especially accurate soundings will be required for which the record of an inshore tide staff will not be sufficient, a temporary tide staff should be established by pumping down a scantling, or otherwise.

405. Abnormal tides due to configuration of shore.—In straits connecting two areas having tides of different ranges and epochs of occurrence, it will usually be found that there is a portion of the strait in which the tide varies rapidly from place to place. For instance, within a single mile at Hell Gate, East River, N. Y., the time of tide changes about an hour, and the mean range varies about 1 foot. Similarly, in the channel north of Vancouver Island, British Columbia, there is a difference of about 2 hours in the time of tide, and of about 5 feet in the mean range, within a few miles. There may be an appreciable difference in both time and height of tide on the different sides of the same island in an archipelago, for it often happens that rapid changes occur in the tides and currents of such groups. Sometimes the occurrence of a shoal near one end of a rather small detached island will cause the tides to differ considerably on opposite sides of the island, depending upon the location of the shoal with reference to the approach of the tide wave.

406. Abnormal tides due to wind and shallow water.—In large shallow bays, in broad stretches of rivers or along shores where the water is shoal, the wind sometimes has considerable effect upon the level of the water surface, and two tide stations differently exposed to the wind may be affected unequally.

Failure to detect the conditions that cause abnormal tides, and to adopt measures that will permit the elimination of these abnormalities, has caused sounding lines to fail to cross by several feet, and, in some instances, has seriously vitiated the survey.

Where the conditions described prevail, an additional staff should be established in the immediate location of the work, and comparison of the tide observations made with those of the standard gauge. The observations at the auxiliary gauge should include one complete range of the tide on each day that the gauge is used, unless its bench mark is connected with the bench mark of the automatic tide gauge by a line of levels. In that case the observations at the auxiliary gauge may cover only those hours during which sounding dependent upon the gauge is being done.

407. Tide gauges.—There are four types of tide gauges, known as tide staffs, box gauges, pressure gauges, and automatic gauges. The plain tide staff is the simplest and most common form of tide gauge, and whenever possible should be used in connection with the other kinds of tide gauges in order to refer the tidal results to permanent bench marks. The box gauge is sometimes employed when the water is too rough to obtain satisfactory readings from a plain staff. The pressure gauge may be used from a vessel at anchor where the water is too deep to erect a tide staff. The automatic gauge is used when a continuous record of the tide for a long period is desired.

408. Tide staff.—The simplest form of the gauge is a plain board, about 5 inches wide, 1 inch thick, and the length should be based on the extreme fluctuation of the water surface in the locality in which it is to be used. It should be graduated to feet and tenths (not inches) with numbers increasing upward, the lowest graduation being zero (0). It must be securely fastened in a vertical position to a pile or other suitable support. The zero should be placed lower than the lowest known tide, and a temporary bench mark established as close to it as practicable, in order that the staff may be readily returned to its original position if displaced by accident. For reference to permanent bench marks see paragraphs 514–520. It is desirable that the tide staff be painted, especially if it is to be used for a considerable length of time. In the latter case the graduation should be cut into the wood on the edge of the staff.

409. Glass tube.—When the water is rough it is a great advantage to have a glass tube, partially closed at the submerged end by a notched cork or otherwise, secured to the face of the staff. Some floating object should be introduced into the tube in order to give definition to the water line within, such as a ball cut out of cork and scorched to blacken it, or a little colored oil. This ball should be somewhat smaller than the bore of the tube, as it otherwise tends to increase the capillarity in the tube and indicate heights a little above the true.

410. Portable staff.—It will sometimes be preferable to use a movable tide staff, which may be taken out and cleaned or repainted or removed for use in another locality. A guideboard is secured in a vertical position to a pile or other suitable support, and pieces nailed to it so as to form grooves in which to slide the tide staff, exposing only its graduations. This guideboard need not extend lower than mean tide level. A metal plate is screwed to the top of the guideboard, forming a stable support for a metal shoulder which is fastened upon the back of the movable staff. This metal plate serves as a temporary bench mark, whose relation to the zero of the graduation must be stated.

411. Portable staffs are recommended for use especially in connection with automatic tide gauges at stations where the observations are to be continued for several years. An ordinary fixed staff left in the water soon becomes discolored and the graduations illegible, necessitating frequent removals for painting. A portable staff that is placed in the water only when it is to be read and is kept in the tide house at other times remains in a good condition much longer. For convenience in storing in the tide house the staff may be in sections fastened together with a hinge, which should usually be placed on the face of the staff so as not to interfere when the latter is lowered in its guides. As it may sometimes be convenient to use the same portable staff at different stations a standard size is desirable. It is recommended that such staffs be made 5 inches wide and 1 inch thick or slightly less when dressed. The guides should be constructed with the sliding space about 5½ inches by 1¼ inches to provide sufficient margin for the staff to be lowered without binding.

412. Multiple staffs.—When the range of tide is too great to be measured by a single staff, a succession of staffs may sometimes be used along shores with gentle slopes. A field glass will usually enable the observer to read the outer staff. When possible, these should be arranged so that the graduations will be continuous from one staff to the other, so that the readings on all the staffs will be referred to the same zero.

413. Box gauge.—This form may sometimes be employed when more accurate readings are required or when the swell renders the use of a simple staff inconvenient. It consists essentially of a float that rises and falls in a vertical box to which the tide has access; and to the float is attached either an index that moves over a fixed scale or a graduated rod that moves over an index. The float is usually a copper cylinder about 8½ inches in diameter and 3 inches high, the bottom being weighted to give it steadiness in the water. The top may be provided with a socket for a graduated rod or with a ring for an index wire or cord. The float box is similar to that used for an automatic gauge (see pars. 441 and 442 for description), but the opening in the bottom may be somewhat larger. A hole 1½ inches in diameter in a float box that is 12 inches in diameter will permit the water to enter freely enough to give a perceptible slow motion to the float when the water outside is rough. Such a motion is desirable in order that the observer may be assured that the box is not clogged with sediment or other obstruction.

414. A convenient form of box gauge, where the range of tide is not too great, is to have a light wooden rod fixed in a socket on top of float and steadied by cross pieces at the upper end of the float box, so as to rise and fall in a vertical line. The rod should be numbered from above downward, zero being at the upper end. The top of the box, or of a board or a piece of sheet metal placed at a convenient height for the eye, is used as the reading point.

415. In another form of box gauge one end of a small flexible wire is attached to a ring in the top of the float, while the wire passes over one or more pulleys and terminates with a counterpoise. An index on the wire passes over a fixed scale, which may for convenience be either vertical or horizontal. The scale is usually that of nature, but sometimes it is desirable to either increase or diminish the scale, which can be done by passing wires over drums of different sizes or by means of movable pulleys.

416. A form of box gauge adapted especially for use in the rough waters on shoals offshore consists of a white-pine pole staff, cross section 1 by 1 inch, with rounded edges, graduated on each of the four sides in feet and two-tenths with the zero (0) at the top, and set in a hollow cylindrical white-pine float 1½ inches outside diameter and seven-eighths inch inside diameter. The float should be thoroughly covered with shellac and liquid paraffin. The length of the rod will depend upon the range of tide in the locality where it is to be used, and the length of the float should be about four-tenths that of the rod. The float well consists of a 2-inch iron pipe, the bottom of which is set in a 1000-pound concrete block to serve as an anchor. The pipe should be long enough to reach above the ordinary waves at high tide, and a one-fourth inch hole should be drilled in the side several feet above the concrete anchor. A cap with a square hole for the staff is to be screwed on top of pipe after the float staff has been placed inside. Just below the cap, a 2-inch flange for the attachment of guy wires may be screwed on the pipe, and four small sheaves, one for each guy wire, secured to this flange by wire loops. The top of the pipe is to be secured by four guy wires of No. 6 wire with leads making an angle of 60° or more with the vertical. The end of each guy wire is to be anchored with concrete blocks, giving a total weight of about 2000 pounds to each anchor. For convenience in handling, each concrete block may be cast with wire-rope loops projecting. After the anchors have been set the guy wires are led through the sheaves at the top of the float pipe and drawn taut, a fence-wire stretcher being convenient for this purpose.

417. Reference of box gauge to bench mark.—The reference of a box gauge to a bench mark should be such as to indicate clearly the elevation of the mark above the water surface when the gauge reads zero (0), the position of the water surface at this time being the true datum of the box-gauge readings. This reference can generally be most satisfactorily obtained by erecting a plain fixed staff near by, the zero of which is referred to the bench marks by spirit levels. Simultaneous readings of the water on both gauges are taken when the water is reasonably smooth. A comparison of these readings will give the difference between the datums of the two gauges, which difference applied to the elevation of the bench mark above the zero of the fixed staff will give the elevation of the bench above the datum of the box gauge. The difference between the box-gauge readings and the fixed-staff readings should be frequently checked, as a small leak in the float of the box gauge might change the line of flotation and consequently modify the datum.

418. The relation of a bench mark to the box-gauge datum may also be obtained directly as follows: (*a*) When a graduated rod, with scale inverted, is attached to the float and moves over an index known as the reading point. In this case obtain the elevation of the bench mark above the reading point and add the length of the float rod as measured from the zero (0) graduation to the water line on the float. In case the bench mark is below the reading point, this distance should of course be subtracted from the length of the float rod. (*b*) When an ungraduated rod with an index is attached to the float and moves over a fixed vertical scale, the graduations increasing upward, the elevation of the bench mark above the zero of the scale should be added to the length of the float rod as measured from the index to the water line on the float. (*c*) When a cord or wire connects the float with an index, a direct measurement is usually impracticable. In this case the elevation of the bench mark above the water surface should be obtained when the water is smooth, and to this should be added the box-gauge reading taken at the same time. In every case the separate measurements must be entered in the record in order that the results may be properly interpreted and verified.

419. Pressure gauge.—This is an instrument for determining the tide by measuring the variation in pressure at the bottom, due to the rise and fall of the water. Although the results are very rough as compared with those obtained by a plain tide staff, the gauge is serviceable in obtaining the approximate tides on shoals where the water is too deep to erect an ordinary tide gauge but is sufficiently shoal to anchor a boat. A simple form of this gauge formerly used by this Survey consisted of a strong rubber bag, holding about 6 gallons, connected with a flexible, air-tight tube, having an inside bore about one-fourth inch, and made in sections like garden hose. The upper end of the tube has a stopcock and a steam gauge. The bag is incased in an iron box, which is nearly water-tight, so as to exclude the influence of short-period waves, the same as for a box gauge. The iron box containing the inflated bag is lowered to the bottom, the gauge on board the vessel being read at intervals, the rise and fall of tide being indicated by change of pressure.

420. The aero-mercurial gauge and manometer, two other forms of pressure tide gauges, have also been used and description of them can be furnished when desired.

421. Automatic tide gauge.—This machine, which is known also as a self-registering gauge, traces a curve that graphically represents the rise and fall of the tide, the abscissæ indicating time

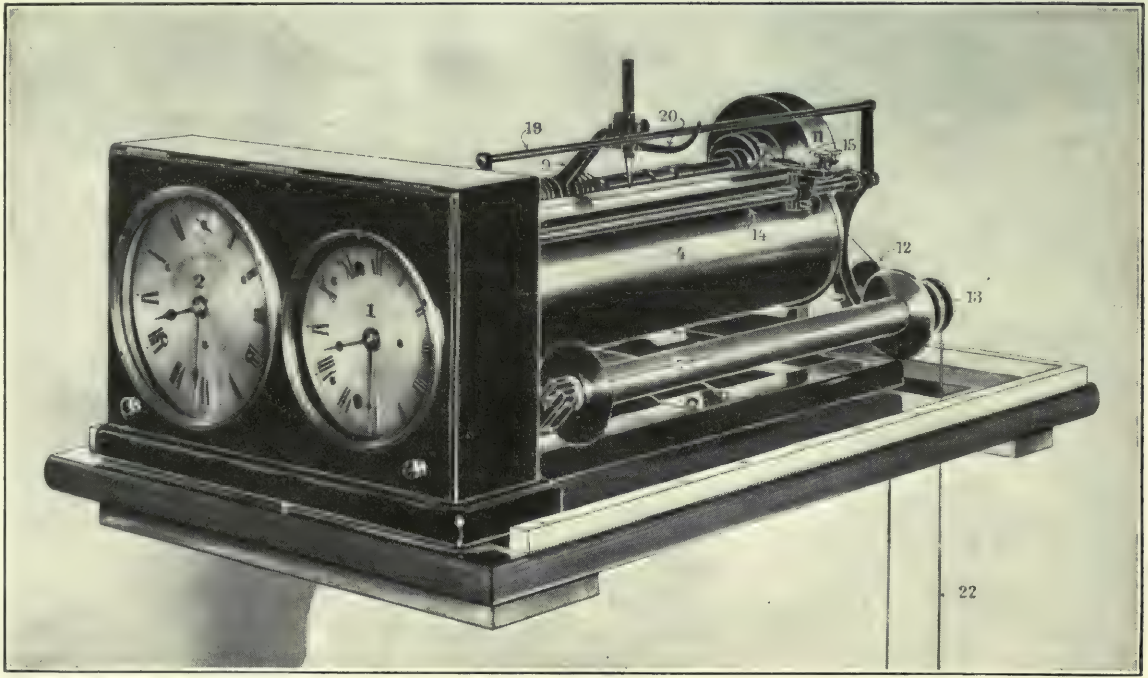

FIG. 18.

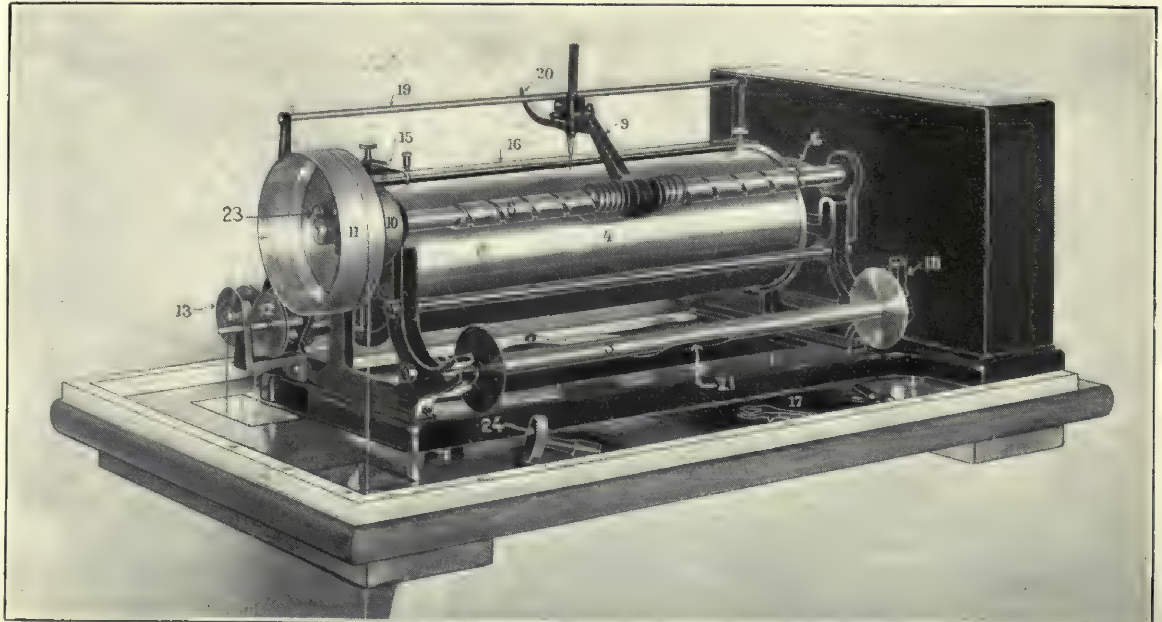

FIG. 19.

and the ordinates the height of the tide. The essential parts of the machine consist of a clock that moves paper forward at a uniform speed and a float that is free to rise and fall with the tide, and is so connected with a tracing pencil that the latter moves perpendicularly to the motion of the paper and proportional to the rise and fall of the tide. The combined motion of the paper and the pencil produces a tide curve, sometimes called a marigram, from which the height of the tide for any desired time can be read by means of a scale. The automatic tide gauge now in use by this Survey is illustrated in figures 18 and 19 and is described in the following paragraphs:

422. Clocks.—There are two clocks, as illustrated in figure 18. The one on the right-hand side, No. 1 in the figure, is the *motor clock*, and the other one, No. 2, is the *time clock*. The *motor clock* turns the main cylinder which regulates the motion of the paper. The cylinder, which is 12 inches in circumference, turns once in 12 hours, moving the paper forward at the rate of 1 inch per hour. The motor clock has two mainsprings, both being connected with the driving apparatus, and in case of one of these breaking by accident it is sometimes possible to operate the machine with the remaining one until there is an opportunity for repairs. The purpose of the *time clock* is to mark the hours on the record. It is similar to an ordinary striking clock; one spring runs the clock and the other operates a device that trips the recording pencil, making a short horizontal mark on the record each hour.

423. Each of the clocks will run eight days with one winding, but it is recommended that they be wound twice a week. The clocks may be regulated and corrected as similar clocks in ordinary use. The minute hand of the time clock must not be turned backward when it is between 10 minutes before and 5 minutes after the hour mark "XII," in order to avoid injury to the hour-marking device.

424. Rollers.—There are three rollers; the *supply roller* (fig. 19, No. 3), a round brass rod with flanges at each end, one of which is removable for putting in the paper; the *main cylinder* (figs. 18 and 19, No. 4); a hollow drum made of brass tubing about 1 foot in circumference, with 12 sharpened steel pins set at equal intervals around the cylinder near each end, designed to prevent the paper from slipping over the smooth surface of the cylinder as it is revolved by the motor clock; and the *receiving roller* (fig. 18, No. 5), a hollow tube of sheet brass, with a small slit running its entire length, and two flanges, one of which is removable, so that the completed tide roll may be removed.

425. Connection between clock and gauge.—The axle of the hour hand of the motor clock extends through the back of the case and has a toothed or carrier wheel upon it (fig. 19, No. 6). The main cylinder has a hinged carrier arm attached to its axis, which can be thrown into or out of the teeth of the carrier wheel, thus making or breaking the connection between the motor clock and the gauge.

426. Paper.—The *paper* used on the machine is about 13 inches wide and is furnished in rolls about 66 feet long, which is sufficient for one month of record. This roll is placed on the supply roller, fed over the main cylinder, where it receives the tidal record, and is then mechanically wound upon the receiving roller.

427. Tension weight.—This is the smaller of the two weights furnished with the machine. It is attached to a cord (fig. 18, No. 22), which is wound around the *tension weight pulley* (figs. 18 and 19, No. 13). This pulley is provided with a pawl and ratchet for winding up the tension weight from time to time. The action of the tension weight winds the tide roll on the receiving roller, keeps the paper on this side of the machine taut, and also assists the motor clock in turning the main cylinder.

428. Tension spring (fig. 19, No. 21).—This spring presses against the supply roll of paper and keeps the paper on that side of the machine taut. As the paper is prevented from slipping over the main cylinder by a set of sharpened pins (par. 424), an excess of tension on either side of this cylinder is likely to cause the paper to tear, especially if it is damp.

429. Float.—The float furnished with the tide gauge is a copper cylinder, 8½ inches in diameter, 3 inches high, and weighted so as to float with about one-third of its height above the water surface. It is connected with the float pulley of the machine by phosphor-bronze wire, No. 23 American wire gauge. When in use the float rises and falls with the tide in a float box to which the water has access through a small opening. (See par. 441.)

430. Float pulley (figs. 18 and 19, No. 11).—A set of four interchangeable pulleys with circumferences of 6 inches, 9 inches, 12 inches, and 16 inches is provided with each machine in order to adapt it to different ranges of tide. Special pulleys of other sizes are also sometimes used. These pulleys are about 1 inch wide and have threads cut in their faces to prevent the float wire, one end of which is attached near the edge of the pulley, from winding upon itself. There are from 18 to 24 turns of the thread on each pulley. For the removal or adjustment of the pulley there are two clamp nuts (fig. 19, No. 23), which are set by means of a special wrench (fig. 19, No. 24). This pulley together with the counterpoise pulley is clamped to the pencil screw (fig. 19, No. 8), and causes the latter to turn as the tide rises and falls.

431. Counterpoise pulley (fig. 19, No. 10).—This pulley, which is threaded like the float pulley to which it is clamped, carries a wire or cord to which is attached a counterpoise weight.

432. Counterpoise weight.—This is the larger of the two weights provided with the tide gauge. Attached by a wire or cord to the counterpoise pulley it serves to take up all slack in the float wire, and rewinds the latter as the tide rises.

433. Sliding grooved pulley (fig. 19, No. 12).—This is free to slide on a long axle near the counterpoise pulley. It is designed to carry the counterpoise cord away from the float wire, and at the same time keep the wire as it winds or unwinds always opposite its proper thread on the counterpoise pulley. When the counterpoise cord is carried directly to a fixed pulley in the ceiling of the tide house, this sliding pulley is unnecessary.

434. Pencil screw (fig. 19, No. 8).—This is made of phosphor bronze about five-eighths inch in diameter, and has a square thread with a 1-inch pitch. For stations having a large range of tide, a pencil screw with a one-half inch pitch is frequently used. The threads at each end of the pencil screw are turned down to prevent the pencil arm from jamming.

435. Pencil arm (figs. 18 and 19, No. 9).—This arm carries the recording pencil. In its bearing is a nut that fits in the thread of the pencil screw so that as the latter is turned the arm moves along the screw, toward the clocks for a rising tide and in the reverse direction for a falling tide. If a very high or a very low tide moves the arm to either end of the pencil screw, the nut becomes disengaged from the screw thread and jamming is prevented. Springs are provided on each side of the pencil arm to force the nut back into the thread of the screw when the tide begins to reverse.

436. Datum pencil holder (fig. 19, No. 15).—This holds the pencil that traces the datum line. It may be clamped in any position on the *datum pencil rod* (fig. 18, No. 14), but it is desirable to have it clamped near the middle of the rod.

437. Scale.—The height scale of the gauge depends upon the circumference of the float pulley and the pitch of the pencil screw. These should be chosen according to the probable range of tide at the station. The following table will indicate the proper pulleys and pencil screw to be used:

Extreme range.	Scale.	Float pulley circumference.	Pencil screw pitch.
		Inches.	*Inch.*
Less than 6 feet	1:6	[illegible]	1
From 6 to 9 feet	1:9	9	1
From 9 to 12 feet	1:12	12	1
From 12 to 16 feet	1:16	16	1
From 16 to 18 feet	1:18	9	½
From 18 to 24 feet	1:24	12	½
From 24 to 32 feet	1:32	16	½

438. A metal scale (fig. 19, No. 16) is attached to the gauge by a clamping screw at each end. Both sides and both edges are graduated, making four different scales of 1:6, 1:9, 1:12, and

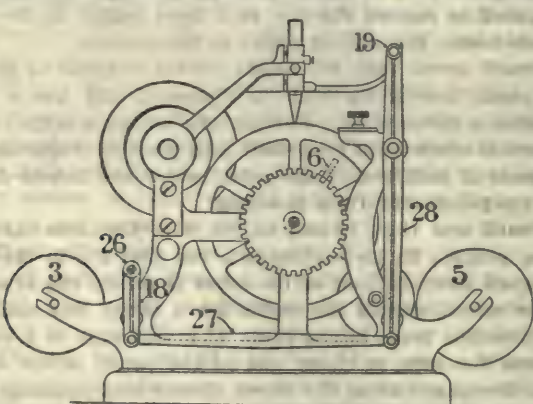

FIG. 20.

1:16. Any of these edges may be turned toward the main cylinder. To refer a point on the tide curve to the scale, there is a broad, two-pronged fork (fig. 19, No. 17), which may be slid along the scale.

439. Hour-marking device.—The time clock is like an ordinary striking clock, but instead of striking a bell it moves a lever (figs. 19 and 20, No. 18), connected with a tripping rod (figs. 18 and 20, No. 19), which is supported on rocker arms about 2 inches above the metal scale. The pencil arm is jointed and provided with a hook which passes under or over the tripping rod. On the hour the striking mechanism of the clock moves the lever outside, which in turn rocks the tripping rod. The latter engages the pencil hook and pulls the pencil arm, causing the pencil to make a short stroke parallel to the edges of the paper. The pencil, which is tracing the tide curve, is returned to position by a spring.

440. Installation of an automatic tide gauge.—When an automatic tide gauge is to be established at a station, a fixed or portable tide staff should be set up first in order that a rough estimate of the mean range of the tide and of the reading for mean sea level may be obtained from a few observations. The half sum of mean high and mean low water for any four consecutive tides may be taken as mean tide level for the purpose of setting the automatic gauge. (See also par. 408.)

441. Float box.—This should be located where the water is not less than several feet deep at the time of the lowest tides. The box should be about 1 foot square on the inside, or 1 foot in diameter if cylindrical in shape, and long enough to reach several feet below the lowest tides. It must be set and maintained in a vertical position to prevent the float from scraping against the sides as the tide rises and falls, and should be well braced. A single opening from three-fourths to 1 inch near the bottom of the box has been found to be most satisfactory. This opening should be below the lowest tides and should be so located that it can readily be cleared out if it becomes clogged. An opening in the bottom rather than in the side of the box has the advantage of being easily cleared by means of a stiff wire or slender gas pipe lowered down into the inside of the box. This enables the tide observer to do in a few minutes that which would often require the services of an extra man and a boat when the opening is in the side of the box. When necessary to remove the float attach a small clamp to the wire just beneath the table to prevent unwinding on the drum.

442. For a station that is to be occupied for only a short time a plain square wooden box made of boards or plank from 1 to 2 inches thick is sufficient. For stations that are to be occupied for several years a cylindrical cast-iron pipe, 1 foot inside diameter, is frequently used. To the bottom of such a pipe, if supported several feet above the ground, is attached an inverted conical-shaped casting with a three-fourth-inch opening in the apex. The chief disadvantage that has been experienced with this kind of pipe is the formation of rust scales, which clog the opening in the bottom and are often difficult to remove. Probably the most satisfactory form of float box that is used by the

Survey at stations where the observations are continued for many years is a copper tube, 1 foot in diameter, protected by an outer wooden casing. Such a tube should be not less than one-sixteenth inch thick, as a thinner tube is not only too frail to handle but would also require more frequent renewals. A tube one-sixteenth inch thick, if not located too near other metal in the water, causing electrolysis, might reasonably be expected to last for 15 years without renewal. For a longer series of observations a heavier tube would be more economical in the end. An inverted conical-shaped copper bottom with a three-fourth-inch hole in the apex should be soldered to the tube. If this bottom, instead of being a true cone, were made a little one-sided so that the apex came near the side of the tube, it would permit the hole to be cleaned by a slender rod lowered into the tube without removing the float.

443. To prevent freezing.—To prevent the formation of ice in the float box during cold weather and the consequent stoppage of the gauge, petroleum or kerosene has been frequently employed. A column of oil in the float tube of 2 or 3 feet in height would suffice for ordinary latitudes, and one of 4 or 5 feet in height, it is believed, would suffice for stations in Alaska. For a 12-inch tube it will require about 6 gallons of oil for every foot in height. If possible the gauge should be located where the depth at very low tides would be about 2 feet more than the length of the column of oil required. The amount of petroleum that can be used is limited by the depth of the small opening in the pipe below the lowest tides, for when a greater amount is used there will be a loss through the opening at extreme low tides. As the specific gravity of kerosene is less than that of water, the surface of the oil inside the tube will be higher than the water surface outside. This height will be equal to about one-eighth of the whole column of oil. If a gauge has been working with ordinary sea water only, the introduction of petroleum in the float tube changes the line of flotation of the float and also the relation of the curve to the datum line. But this will not cause any inaccuracy of record if the observer furnishes readings of the staff, to which the curve can be referred. In locations where there is an extensive land drainage, such as near the mouth of a large river, the difference between specific gravity of the water at the end of the flood and at the end of the ebb may be sufficient to cause a sensible periodic oscillation in the height of the surface of the petroleum with reference to that of the sea outside the tube, thus introducing a periodic variation which is not tidal and which it would be difficult to get rid of. Therefore petroleum can not be employed where there is much change in the specific gravity of the water.

444. The tide house (fig. 21).—A rough house is usually constructed to protect the gauge from the weather and from being interfered with. This structure may be about 6 by 6 feet at the base and 7 feet high at the eaves, with a door and windows. It should be well bolted down to the wharf. Sometimes it may be convenient to have the float box outside the house, especially at permanent stations, as it permits of easy renewals of the box without having to remove the roof from the house; in this case a sloping cover must be provided for the box, which may be hinged and padlocked to permit of easy access to the float, while protecting it from being interfered with. A float-tube opening inside of the tide house should also be provided with a cover to prevent anything from being dropped down the tube. Such a cover may be made of two pieces with a narrow slit in the center for the float wire. For the support of the tide gauge, a strong table or shelf about 2½ feet high should be provided. If reasonably protected from molestation, an automatic tide gauge may be operated for a limited time without a house, but protected by a box with a hinged lid with padlock and a canvas cover.

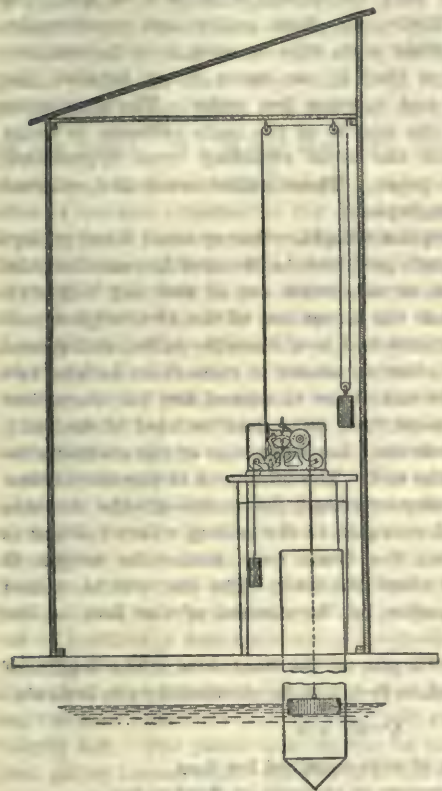
FIG. 21.

445. Setting up gauge.—When the top of the float box opens inside of the tide house, the gauge is usually set upon the table or shelf so that the float pulley is directly over the float box. Otherwise a series of pulleys must be provided to lead the float wire to the float box. The gauge is to be adjusted so that at approximately mean tide level the pencil arm will be near the middle of the main cylinder, the float pulley and counterpoise pulley each about half filled with wire or cord, and the counterpoise weight arranged so that it can move freely between the limits of extreme high and extreme low water. The datum-line pencil is to be set near the middle of the main cylinder in order to reduce to a minimum the error resulting from hygrometric changes in the tide-roll paper. These adjustments are referred to in the following paragraphs.

446. Attaching counterpoise weight.—One or more fixed pulleys are placed overhead in such positions as to carry the counterpoise to one side of the house, or otherwise out of the way (fig. 21). The counterpoise, which is the larger one of the two weights provided with the gauge, is attached to a movable pulley and placed upon a block of wood or other substance to raise it an inch or two above the floor. Pass the end of the varnished fish line, furnished for the purpose (the bronze float wire may be used if desired), through the small drill hole near the inner edge of the counterpoise pulley and tie a knot at the end. The other end of the line is then passed over the fixed pulley overhead, down through the movable pulley on the weight and up again to the ceiling where the end is fastened. After removing the block from under the weight it should hang just a little above the floor. The line will be wound upon the counterpoise pulley by the descent of the float to the water.

447. Attaching float.—To put on the float wire. The length of wire required for the float, in feet, may be obtained by the formula:

$$L=BC+D$$

where L=number of feet of wire required for float.

B=one-half the number of threads on float pulley.

C=circumference of float pulley used, expressed in feet.

D=distance from float pulley to mean sea level in feet, measured by the route the wire must take to the float.

448. Unclamp the float pulley by *turning the nuts a very little,* as too much slack will cause it to jam. Undo the end of the wire on the spool, holding a finger on the coils to prevent its springing off the spool, pass the wire through the small drill hole near the outer edge of the float pulley, twisting it a few times around itself to make it fast. Now revolve the float pulley, holding the spool of wire with the other hand and keeping sufficient tension to wind the wire smoothly in the threads cut in the pulley. The number of feet of wire which may be wound upon the float pulley is $2BC$, and if this is less than L wind the pulley entirely full, clamp it tightly to the counterpoise pulley, and measuring off $L-2BC$ feet of additional wire, cut it off and fasten the end to the float. Some one must keep tension on the wire or hold a finger on the float pulley while this is being done, or the wire will spring off the pulley. If L is less than $2BC$, find $\frac{2BC-L}{C}$, which is the number of threads of the float pulley to be left unwound when the wire is cut and attached to the float. Place the float in the float box, letting it down gently until all the slack wire is used, and then hold the float pulley with friction enough to prevent any hasty descent of the float to the water. At the beginning of unwinding the wire from the float pulley by the descent of the float, take care that the counterpoise line enters the thread of its pulley, after which it will take care of itself. After the float is attached the position of the gauge should be adjusted so that the float hangs in the center of the float tube, and this position made secure by fastening the gauge to the table and the latter to the floor.

449. Adjustment of pencil arm.—The pencil arm should now be adjusted so as to bring the pencil about the middle of the paper at mean tide level. It is not necessary to wait until the tide is actually at its mean level, for knowing the difference between that level and the actual stage of tide the pencil may be set accordingly by the metal scale provided with the gauge. If the arm is very far out of position, a first approximate adjustment should be made by running the arm to the end of the pencil screw nearest the clocks, thus disengaging it from the screw thread. This is done by turning the float pulley, so that the float will rise and the counterpoise weight fall. The pencil arm should be held at this end and the float pulley turned either backward or forward until it lacks three turns of being filled with the float wire. The pencil arm should be then released and the float permitted to descend until it rests upon the water. This should bring the pencil arm within 1 inch of its proper position. To bring it closer to the position desired, press on the counterpoise pulley with one finger, to prevent the weight from turning it, a finger of the same hand resting upon the last coil of wire on the float pulley to prevent the wire from springing out of the grooves; then with the other hand slightly unclamp the two set screws within the float pulley. Next revolve the counterpoise pulley until the pencil is in the desired place, when the float pulley is firmly reclamped.

450. Attaching tension weight.—This weight is attached by a cord to the pulley at one end of the receiving roller. This pulley has a small hole in one flange, through which the end of the cord may be passed and knotted. As with the counterpoise cord, it is desirable that this cord also be led over a pulley in the ceiling of the tide house in order to provide as much space as possible for the falling of the weight. By suspending the weight by means of a movable pulley its motion is diminished one-half.

451. Starting the gauge.—The roll of paper provided for the record should be placed on the gauge, as described in paragraph 454, the tension weight wound up, and both clocks wound and set to the correct time. The datum-line pencil should be placed in the holder and the latter clamped near the middle of the main cylinder. The recording pencil should be adjusted in its holder. The tide observer who is to have charge of the station should be given the necessary instructions for the care and operation of the gauge.

452. Report on establishment of tide station.—When an automatic tide-gauge station is established, a separate report describing the same should be sent to the office. Such a report should include the following information:

(*a*) Name of town or place, with latitude and longitude.

(*b*) Name and location of wharf. A sketch showing location is desirable.

(*c*) Name of owner of wharf and a statement of arrangements made with him.

(*d*) Give position of tide staff and automatic gauge on wharf.

(*e*) Describe tide staff, giving dimensions, limits of graduations, and a statement whether it is portable or fixed.

(*f*) If a portable tide staff is used, state how it is supported and give the reading of the tide staff that corresponds to the fixed point of support.

(*g*) Give number and scale of the automatic gauge.

(*h*) Describe the float box, giving dimensions, method of securing it in position, exact position and size of opening in the bottom and the depth of the water below this opening. Give also the depth of this opening below the zero of the tide staff. A knowledge of the exact position of this opening is especially important when the float box becomes clogged and it is necessary to clear it.

(*i*) State what precaution was taken to prevent freezing in the float box. If kerosene is used, give the quantity.

(*j*) Give a brief statement relative to the recovery of old bench marks and the establishment of new ones. Complete descriptions of the bench marks are to be given separately in connection with the leveling record.

(*k*) Give the date when the installation of the gauge was complated and the record started.

(*l*) Give the name and occupation of the tide observer left in charge of the station.

(*m*) Give any other information about the tide station that may be important.

453. Operation of automatic tide gauge.—The observer in charge of a station shall visit the gauge at least once each day for inspection and comparison. Every effort must be made to secure a continuous record by keeping the gauge in running order. When out of order and necessary repairs at permanent stations are possible, they must be made at once and the bill sent to the office for payment or paid for by the observer and an account rendered. Details in such cases must be reported to the office without delay. When a self-registering gauge is maintained in connection with hydrographic operations in the field, a continuous record shall be secured by making staff readings every hour whenever the gauge is out of commission, and the conditions must be reported immediately to the chief of party.

Each day the gauge is visited the tide staff should be read and an entry made on the tide roll. A statement concerning the correctness of the time clock should also be entered, and if this clock is in error it should be set correct. (See par. 461.) The condition of the wind and any other matter that may affect the record should be noted also. All notes should be initialed by the observer. The tension weight should be wound up each day the gauge is visited. The clocks are to be wound twice a week. The tide roll should be changed once a month. If the observations are to be continued for a year or more, the change in rolls should take place on the first or second day of each calendar month, excepting the February roll for common years, which should be removed on March 2 or 3. These duties are described in detail in the following paragraphs.

454. Placing paper on gauge.—The supply roller, which is the one with the solid rod, is removed from the gauge and the roll of paper placed on it, which may be readily done by removing one of the flanges and replacing it again after the rod has been passed through the central hole in the roll of paper. The roller is then placed in the gauge, turning it in such a way that the loose end of the paper may pass from below inward toward the main cylinder. It makes no difference which end of the roller has the movable flange. The main cylinder is then disconnected from the motor clock by throwing out the carrier lever from the toothed carrier wheel, using a slender stick or lead pencil to reach it, if necessary. Pass the paper over the main cylinder and insert the end about three-fourths inch into the slit in the receiving roller. Several turns of the paper should then be wound around this roller, the paper passing from the main cylinder over the top of the receiving roller. The main cylinder must be again connected with the motor clock, the tension weight wound up, and the pencils adjusted. Before placing paper on the gauge, it should have written on the inside, at the beginning of the record, the name of station, date, scale of gauge, kind of time used, name of observer, and, in hydrographic work, the chief of party.

455. Removing paper from gauge.—Place the tension weight on the gauge table or some other support, unwrapping by hand from the pulley as much cord as may be necessary. Disconnect the main cylinder from the motor clock. Wind up the remaining paper on the receiving roller, and take it from the gauge. Remove one of the flanges, revolve the other flange so as to force a little more paper into the central groove, when the paper can be removed from the roller. One roll of paper is sufficient for a month of record.

456. After the roll has been removed it should be rewound on a wooden core to bring the record on the inside and to prevent injury in transit to the office.

457. Label.—The label, Form 489, should then be pasted on the outside of the roll. First, fold a few inches of the beginning of the paper down on the side containing the record, thus making a square, smooth edge of double thickness. Then, on the side of the paper which has no record, paste the label parallel to this edge and about 2 inches from it, the bottom of the label being toward the edge. Never paste the label as a seal to keep the roll from unwinding, as it must not be broken to open the record. The label should be filled out as completely as possible. The first marigram or tide roll of the series should be numbered 1 and the others numbered consecutively throughout the series. The gauge number will generally be found on the face of the clock upon the tide gauge. On this label the beginning and ending of the record refers to the particular tide roll and not to the entire series of observations at the station, as on Form 138.

458. Reading tide staff.—Every time the gauge is visited the tide staff should be read to the nearest 0.05 foot, and recorded on the marigram. If the water is too rough to obtain directly a reliable mean reading, record both the highest and lowest oscilla-

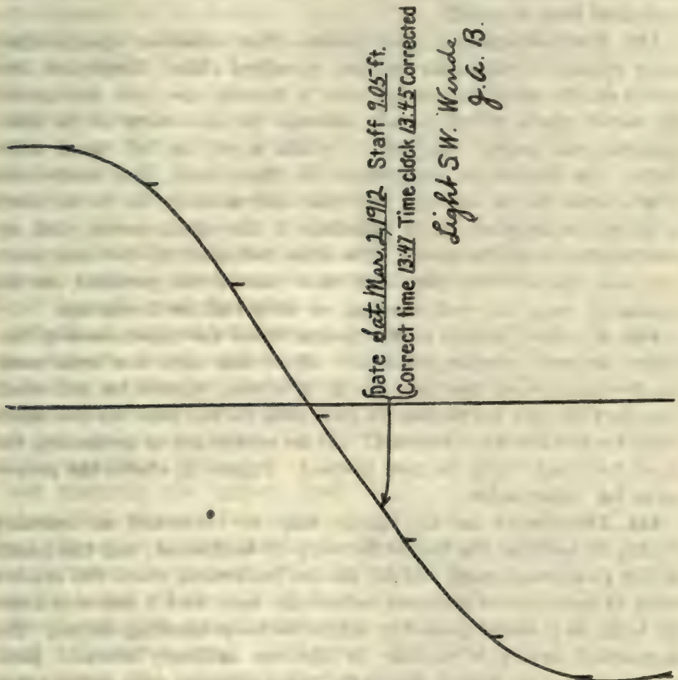

Fig. 22.

tions of the waves. The tabulator will take the mean of these two readings for comparison of staff and scale on Form 455. The exact position of the recording pencil of the gauge at the time each staff reading is made must be indicated by an arrowhead with a line connecting it with the note of the staff reading. The manner of connecting the note and tide curve is shown in figure 22.

The note may be placed either above or below the curve, but it must be connected by a line with the exact position of the recording pencil at the time the comparisons are made.

At the time the above note was made the recording pencil was at the point in the curve indicated by the arrowhead, and only that part of the curve to the left of this point was completed. The portion of the curve to the right of the arrowhead was made after the note had been entered.

459. Time comparison and clocks.—The observer should have some means of obtaining correct standard time. There are two clocks on the automatic gauge now in general use; one, designated the motor clock, which merely controls the movement of the main cylinder and paper; the other, which is on the left hand when facing the clocks, is designated the time clock, and makes the hour marks on the curve. The time indicated by the motor clock is of no consequence; it is sufficient if this clock moves with approximately uniform speed. The time indicated by the time clock and also the correct time and date should be recorded on the marigram near the staff reading, on each visit to the gauge.

460. A rubber stamp of the proper form for these notes is furnished to each regular observer. *After* this note has been made on the marigram, the time clock, if wrong, should be corrected. The fact of this correction is indicated in the note on the marigram by the word "corrected." If no correction is necessary, the word "correct" may be used instead. Figure 22 shows the proper form for these notes.

461. The clocks on the gauge may be corrected as ordinary clocks, by turning the hands forward or backward; but the hands of the time clock must not be turned backward when the minute hand is between 10 minutes before the hour and 5 minutes after the hour, as it would probably injure the hour-marking device. The regulating device is similar to that on ordinary clocks. Both clocks should be wound regularly twice a week, care being taken not to wind them too tightly.

462. Tension weight.—This weight, which winds the paper on the receiving roll, should be wound up every day that the gauge is visited. It is connected with the receiving roll by pawl and ratchet, and while winding it up with one hand the receiving roll must be held steady with the other hand.

463. Pencils.—These should be examined frequently. The datum pencil points furnished for the gauge are usually too long and should be broken to the proper length. The point should be carefully adjusted so as to make a distinct line and still not tear the paper under unfavorable conditions. It should project about one-sixth inch from the holder, and this adjustment can be kept by screwing down the cap a little from time to time as may be necessary. When the holder is lifted to remove or put in paper, care must be taken not to lose the lead from the brass holder. For the recording pencil that makes the tide curve, a good quality of No. 2 pencil is best. This should be kept carefully sharpened and adjusted in its holder. Upon this adjustment depends the efficiency of the hour-making device. It should be such that the hook attached to the pencil holder will just clear the tripping rod.

464. Lost record.—If any portion of the record is lost from any cause, move the paper forward a few inches before starting the gauge again. To do this the main cylinder must be disconnected from the motor clock in the manner described in paragraph 454, but the cylinder must be held steady with one hand when disconnected, as otherwise the paper would be jerked forward by the tension weight. This may be done by placing the hand on the paper over the main cylinder.

465. Changes in adjustment.—After an automatic tide gauge has been properly set up, changes in the adjustment of the float pulley or in the position of the datum line should be avoided unless actually necessary; and when any change is made, a note of the fact and the reason for the change should be immediately entered on the marigram.

466. Cleaning the pencil screw.—The pencil screw must be cleaned from time to time, otherwise the pencil arm may be raised from the paper on a falling tide, or pressed so firmly against the main cylinder on a rising tide as to tear the paper, either accident causing a loss of record. A small rag moistened with gasoline passed around the pencil screw and drawn back and forth several times will keep it clean. Never put oil on the pencil screw, as it soon catches dirt and makes it worse than it was before.

467. Operating troubles.—Some of the difficulties likely to be met in the operation of an automatic gauge are:

Failure to keep the float box in a vertical position, causing the float to scrape on side of pipe.

Breaking the float wire, which is nearly always due to sharp bends or kinks in the wire when it is slack; a new wire should be put in, rather than to splice the old one.

Vibration of pencil on record; this is due to too large openings in the tide box and if serious may require repair of box.

Failure of gauge to record full range of tide, as shown by comparison with staff readings; this is due to clogging of openings in float box, and is likely to render the record worthless, and calls for immediate examination of box and clearing of openings.

Jamming of paper rolls, due to paper not running true; rolls should be examined to see that they are in their right position, and paper rewound if necessary. Often the paper can be slipped away from the flange by hand.

Failure of hour-marking device. This is usually due to lack of proper adjustment of the recording pencil, causing too much space between the tripping rod and the hook attached to the pencil holder, or causing the hook to be jammed too tight against the rod. The adjustment should be such that the hook just clears the rod. If the trouble is due to the time clock itself it may be necessary to remove the clock and have it repaired by a clock maker.

468. Tabulation of tide records.—In order to establish uniformity in the records to be filed in the office, the tabulations should be neatly made in black ink and in accordance with the forms as outlined in the following paragraphs. For interpolated values to fill in gaps caused by lost record, red ink is generally used. In all forms in which both sides are to be used and in which there is a difference in the width of the left-hand margin on the two sides, the side having the wider left-hand margin should be taken as the front or first page of the sheet and be used in beginning the tabulations on that sheet. In all the forms the heading on the front side of each sheet should be filled out as completely as possible. On the back of the sheet the name of the station and the year and month of the observation should be repeated. The words "Party of" or "Chief of party" may be taken as equivalent to "Observer" when the latter has charge of the tide station. On the label of a tide roll, the dates of the beginning and end of observations refer to the particular tide roll only, but in the headings of the forms for the tabulation of these rolls these dates refer to the entire series of the observations at the station. If the observations are still being continued at the time the tabulations are made, the space after "Observations end" should be left blank. In the tabulations, the hours of the day are to be designated consecutively from 0^h (midnight) to 23^h (11:00 p. m.), thus avoiding the terms a. m. and p. m. Before tabulating a marigram or tide roll the following preliminary work is usually necessary:

469. Marking the hours.—The time notes should be examined and if it is found that the time clock never varies more than three minutes from the correct time, the small horizontal hour marks automatically made by this clock may be accepted as correct and marked accordingly. The hour itself begins at the instant the mark leaves the curve, and no account need be taken of the length of the stroke. These marks should be numbered consecutively from 0 (midnight) to 23 (11:00 p. m.), and the numbering should be checked at each time note on the marigram.

470. In cases where the hour-marking device has failed to work, or when the hour marks are unreliable on account of the time clock being more than three minutes in error, the following method may be used: First: From the time notes ascertain the position on the curve of the nearest exact hour. This may usually be best accomplished by laying off 1 inch on a piece of paper and subdividing it in 12 equal parts. The inch, measured parallel to the datum line, will represent one hour on the tide curve, and each of the subdivisions will represent five minutes. This is known as a *time scale.* The correct time of the point on the curve indicated by the time note being known, the nearest exact hour may be readily laid off by this little scale. Second: Draw lines through the points indicating the exact hours perpendicular to the datum line and extending across the paper. Third: Prepare a strip of paper somewhat longer than the greatest distance between the time notes on the marigram, pasting successive pieces together if one is not long enough. On one edge lay off equal divisions a little greater than 1 inch long, and if made about $1\frac{1}{32}$ inches long they will generally be about right. These divisions should be numbered consecutively from 6^h to 23^h, and then from 0^h to 23^h, repeated as often as may be necessary, the last division ending with any hour. In general it will be convenient to start the numbering with 6^h at the left-hand end of the scale, as the time notes will seldom be made at an earlier hour in the morning. This strip is known as a *dividing scale.* This scale is then adjusted obliquely between two consecutive cross lines passing through the correct hour points, so that the numbers on the scale will agree with the hours represented by the cross lines. With the scale in this position, held fast from slipping by paper weights, each division may be marked on the marigram or tide roll by a dot. Fourth: By means of a square and a straightedge placed near the bottom of the paper and parallel to the datum line, these hour dots may be readily referred to the tide curve and indicated by vertical lines crossing the curve. These hour lines should be numbered in the same manner as the hour marks that are made automatically by the machine.

471. Comparative readings (Form 455, fig. 23).—This form is used to obtain the relation between the scale of an automatic tide-gauge record and the fixed tide staff. It is fundamental and of the greatest importance, for upon it chiefly depends the accuracy of the reference of all tide planes to fixed bench marks, so that they may be recovered at any future time. The work must be thoroughly checked by the observer so as to remove all accidental errors, for any mistake made here will affect all tabulations for the month.

472. The scale reading of the datum line for the comparison may be taken at any arbitrary number, but for convenience and to avoid negative differences it is desirable to have it such that the scale readings of the curve will be from ½ to 1½ feet less than the corresponding staff readings. The reading scales are usually made of glass or celluloid and are graduated to represent feet and tenths. The foot divisions may be numbered with ink as desired. To choose an original scale setting for the datum line, place the scale with one of the foot divisions on the datum line at a point where a staff comparison is noted, and then number the foot divisions of the scale so that the point on the curve will read by the scale about a foot less than the staff reading. It would be well to test this same setting with several notes. The number of the foot division on the datum line will be adopted as the original scale setting and entered in the heading of the form. In using a glass or celluloid scale the side on which the division lines are cut should be kept down next to the paper. The numbering of the divisions should be written with india ink on the upper surface. On the underside of scale draw an india-ink line across the scale through the foot division that is to be used as the datum line.

473. Prepare table of comparative staff and scale readings on Form 455 as in the accompanying sample. Staff and scale readings should both be given to two decimals of a foot, but it will be sufficient to give merely the nearest 0.05 foot. The scale reading is subtracted from the staff reading for the difference. If the scale reading is larger than the staff reading, the difference will be negative.

474. If the gauge has run without any accident, the differences "A–B" for the marigram ought to be approximately equal; but if there has been any change in the machine, such as moving the datum pencil, breakage of float wire, or increase of kerosene in float tube, etc., the differences will form distinct groups, one set of differences for each adjustment of the gauge.

Form 455
DEPARTMENT OF COMMERCE
COAST AND GEODETIC SURVEY

Specimen of form 455

TIDES: COMPARATIVE READINGS.

Station San Diego (La Playa), California ... Lat. 32°43' N.
Party of ... John A. Watkins ... Time meridian 120°W. Long. 117 14 W.
Obs begin Jan.20, 1906 Obs end ... Tabulated by Jno. Smith Date Aug. 5, 1912
Tide Gauge No. 76 ... Scale 1:12 ... The scale reading of Datum Line for this comparison is 6.0 feet.

DATE Year 1912 (mo.)	(d)	TIME OF STAFF READING (h)	(m)	STAFF A (feet)	SCALE B (feet)	DIFFERENCE A − B (feet)	PHASE OF TIDE *	REMARKS
July	1	7	32	4.90	3.90	1.00	R	
	2	7	39	4.55	3.60	0.95	R	
	3	7	32	4.10	3.20	0.90	R	
	4	7	50	4.25	3.30	0.95	R	
	5	8	11	4.50	3.50	1.00	R	
	6	8	16	4.70	3.80	0.90	L	
	7	9	54	5.25	4.30	0.95	R	
	8	7	32	5.65	4.70	0.95	F	
	9	7	49	6.10	5.20	0.90	F	
	10	6	27	6.90	5.80	1.10	H	
	11	8	05	7.05	6.10	0.95	H	
	12	7	40	7.20	6.20	1.00	R	
	13	9	00	7.50	6.50	1.00	R	
	14	8	45	7.00	6.00	1.00	R	
	15	6	37	3.95	3.00	0.95	R	
	16	7	20	4.05	3.10	0.95	R	
	17	8	25	4.90	4.00	0.90	H	
	18	8	27	4.60	3.60	1.00	R	
	19	8	05	4.30	3.40	0.90	R	
	20	7	14	4.90	3.90	1.00	L	
	21	6	46	5.70	4.80	0.90	F	
	22	7	25	6.20	5.30	0.90	F	
	23	7	05	6.95	6.00	0.95	H	
	24	6	45	7.20	6.20	1.00	F	
	25	7	32	7.25	6.30	0.95	F	29.70/31 = Sum
	26	7	50	7.15	6.20	0.95	R	0.96 = Mean
	27	7	22	6.55	5.60	0.95	R	6.00 = Original Setting
	28	7	40	6.45	5.50	0.95	R	6.96 = Corrected "
	29	7	13	5.55	4.60	0.95	R	
	30	7	32	5.50	4.50	1.00	R	
	31	7	23	5.05	4.10	0.95	R	
						31 / 29.70		

* In the column headed "Phase of Tide" write the appropriate one of the four following symbols: H. for high water, L. for low water, R. for rising tide; and F. for falling tide. Use Form 138 for tabulating high and low water.

FIG. 23.

475. In case there has been no change of adjustment during the month, examine the differences carefully to see that they agree fairly well with one another. Small variations in the differences are to be expected, but if any one of them varies by half a foot (0.50) or more from the apparent average, revise the difference and also the scale reading. If both are found to be correct, an error must have been made in the staff reading, and as this can not then be corrected, the difference must be rejected, which is done by making a pencil line around it, and that difference is then omitted from the computation of the mean difference.

476. In case there has been one or more changes in the adjustment of the gauge during the month, consider each set of differences by itself, and proceed as in the preceding paragraph, omitting accidental discrepancies.

477. Sum all those differences which are approximately similar and obtain their mean by dividing the sum by the number of differences used, carrying the quotient to two decimal places. In case a change was made in the adjustment of the gauge there may be two or more separate means required for the month. In either case, the mean difference plus the scale reading of the datum line for this comparison is the true setting of the scale on the datum line for tabulating high and low waters and hourly readings for the period covered by the uniform differences. Erase the temporary mark on the scale which was used for Form 455, and mark the true scale setting with India ink on the lower side of the scale, if transparent; or on its upper side, if opaque. Before using this mark it should be tested by seeing that when this mark is set on the datum line the scale reading of the curve will be nearly the same as any staff reading.

478. Tabulation of high and low waters (Form 138, figs. 24 and 25).—This form is used for the tabulation of high and low waters, which may be either read from the tide curve made by an automatic gauge or taken from plain staff readings as recorded in a tide book. The times are to be expressed in hours and tenths instead of hours and minutes. This is the general practice in the office work, and has been found to save considerable time in the computation of the lunitidal intervals. One-tenth of an hour is equivalent to six minutes, which is as close as an observed high or low water can usually be determined. The fol-

Specimen of front of Form 138.

Form 138
DEPARTMENT OF COMMERCE
COAST AND GEODETIC SURVEY

TIDES. HIGH AND LOW WATERS

Station: San Diego (La Playa), California — Lat. 32°42' N.
Acc. No. .... Party of John A. Watkins — Long. 117 14 W.
Observations begin Jan. 20, 1906 — Observations end .... — Time meridian 120° W.

DATE Year 1912	MOON'S TRANSITS (Greenwich mean civil)	TIME OF— High Water	TIME OF— Low Water	LUNITIDAL INTERVAL High Water	LUNITIDAL INTERVAL Low Water	HEIGHT OF— High Water	HEIGHT OF— Low Water	REMARKS
mo. d.	hr. dec.	hr. dec.	hr. dec.	hr. dec.	hr. dec.	feet.	feet	
July 1	1.3	11.5	4.8	10.2	3.5	7.3	3.2	
	(13.7)	22.0	15.5	(8.3)	(1.8)	[illegible]	6.1	
2	2.1	12.0	5.2	9.9	3.1	7.3	3.4	
	(14.5)	[illegible]	16.5	(8.0)	(2.0)	9.0	6.1	
3	[illegible]	12.5	6.0	[illegible]	3.2	7.3	3.6	
	(15.2)	23.0	17.0	(7.8)	(1.8)	8.7	6.1	
4	[illegible]	13.5	6.5	[illegible]	2.9	7.4	3.7	
	(15.9)	23.5	[illegible]	(7.6)	(2.1)	8.2	6.3	
5	4.2	-- -	7.0	- -	2.8	- -	4.2	
	(16.5)	14.0	19.4	9.8	(2.8)	7.6	6.3	
6	4.9	[illegible]	7.5	(7.9)	2.6	7.5	4.6	
	(17.3)	14.5	21.0	9.6	(3.7)	7.9	6.0	
7	5.6	1.5	8.2	(8.3)	3.6	7.0	4.9	
	(18.0)	15.5	22.0	9.9	(4.0)	8.2	5.0	
8	6.3	3.0	9.0	(9.0)	2.7	6.7	[illegible]	
	(18.7)	16.0	[illegible]	9.7	(4.9)	8.7	5.0	
9	7.1	6.0	10.0	(10.3)	2.9	6.8	5.7	
	(19.5)	16.5	-- -	9.4	- -	9.2	- -	
10	7.9	6.5	0.5	(11.0)	(5.0)	6.8	4.1	
	(20.4)	17.5	10.8	9.6	2.9	9.6	5.8	
11	8.8	7.8	1.0	(11.4)	(4.6)	7.1	3.2	
	(21.4)	18.5	11.5	9.7	2.7	10.2	6.0	
12	9.9	8.5	2.0	(11.1)	(4.6)	7.5	2.8	
	(22.4)	19.2	13.0	[illegible]	3.1	10.7	6.1	
13	11.0	[illegible]	[illegible]	(10.8)	(4.6)	7.6	2.2	
	(23.6)	20.0	13.5	9.0	2.5	10.8	6.0	
14	----	10.0	3.5	(10.4)	(3.9)	7.7	2.0	
	12.1	21.0	14.5	8.9	2.4	11.0	5.7	
15	(0.6)	10.8	4.2	(10.2)	(3.6)	8.0	2.0	
	13.2	21.8	15.5	8.6	2.3	11.0	5.7	
16	(1.7)	11.5	6.0	(9.8)	(3.3)	8.1	2.2	
	14.2	22.2	16.2	8.0	3.0	10.4	5.5	
17	(2.6)	12.0	6.5	(9.4)	(2.9)	8.4	2.7	
	15.1	23.4	17.4	[illegible]	2.3	9.5	5.5	
Sums; carried forward				33 310.7	33 103.0	33 278.9	33 153.1	

FIG. 24.

Form 138
DEPARTMENT OF COMMERCE
COAST AND GEODETIC SURVEY

Specimen of back of Form 138.

TIDES: HIGH AND LOW WATERS

Station: San Diego (La Playa), California *Lat.*
Highest tide Date July 14.15 *Height* 11.0 *ft* *Lowest tide Date* July 14.15 *Height* 2.0 *ft* *Long*
I = ... $(K_1+O_1)\div M_2$ *or* $2(DHQ+DLQ)\div Mn$ = 1.2 $F(Mn)$ = 1.02 $F_1\times 1.02$ = 0.80 *Time meridian* 120° W.

DATE Year 1912	MOON'S TRANSITS (Greenwich mean civil)	TIME OF— High Water	TIME OF— Low Water	LUNITIDAL INTERVAL High Water	LUNITIDAL INTERVAL Low Water	HEIGHT OF— High Water	HEIGHT OF— Low Water	REMARKS
mo d	hr dec	hr dec	hr dec	hr dec.	hr dec	feet	feet	
Brought forward				33 310.7	33 102.0	33 278.9	33 153.1	*27 days:* July 2 - 28 (Give first and last date)
July 18	(3.5)	13.0	6.4	(9.5)	(2.9)	8.7	3.2	*HHW* *LLW*
	15.9	-- -	18.5	- -	2.6	- -	5.5	*Sums* 35 236.2 25 88.3
19	(4.3)	0.5	7.0	8.6	(2.7)	8.7	4.0	*Means* 9.45 3.53
	16.7	13.8	20.0	(9.5)	3.3	8.8	5.6	
20	(5.1)	1.5	7.5	8.8	(2.4)	7.9	4.5	*DHQ* = 1.01 *DLQ* = 1.19
	17.4	14.5	21.2	(9.4)	3.8	8.9	5.3	
21	(5.8)	2.5	8.2	9.1	(2.4)	7.2	5.4	*Corrected Mn* = 3.72 ×1.02 = 3.79 *feet*
	18.2	15.5	23.0	(9.7)	4.8	9.1	4.8	*Corrected DHQ* = 1.01 ×0.80 = 0.81
22	(6.6)	5.0	9.5	10.8	(2.9)	6.8	6.0	*Corrected DLQ* = 1.19 ×0.80 = 0.95
	19.0	16.0	-- -	(9.4)	- -	9.1	- -	
23	(7.4)	5.5	0.2	11.5	5.2	7.1	4.3	
	19.8	17.5	10.5	(10.1)	(3.1)	9.3	5.3	
24	(8.2)	7.5	1.0	12.0	5.2	7.4	3.9	
	20.6	18.2	12.2	(10.0)	(4.0)	9.5	6.5	
25	(9.1)	8.5	1.5	11.9	4.9	7.5	3.5	
	21.5	19.0	12.5	(9.9)	(3.4)	9.6	6.3	
26	(10.0)	8.5	2.2	11.0	4.7	7.4	3.2	
	22.4	19.5	13.0	(9.5)	(3.0)	9.7	6.1	
27	(10.8)	9.2	3.0	10.8	4.6	7.5	3.0	
	23.2	20.0	13.5	(9.2)	(2.7)	9.8	6.0	
28	(11.6)	10.0	3.5	10.8	4.3	7.6	3.0	
	-- -	20.5	14.5	(8.9)	(2.9)	9.2	5.9	
29	0.0	10.2	4.0	10.2	4.0	7.5	3.0	
	(12.4)	21.0	15.0	(8.6)	(2.5)	9.2	5.7	
Sums, 29 days: July 1-29 (Give first and last date)				56 539.9	56 184.4	56 472.4	56 264.4	
Means				9.64	3.29	8.44	4.72	
Correction to intervals				-0.09	-0.09	4.72		
				9.55	3.20	3.72	*Mn*	
Duration of rise				6.35		6.58	*MTL*	
Mean rise interval				6.38				
July 30	0.8	10.5	4.2	10.0	3.4	7.5	3.1	
	(13.2)	21.5	15.5	(8.3)	(2.3)	9.4	5.6	*Tabulated by* Jno. Smith
31	1.6	11.2	4.3	9.6	2.9	7.7	3.3	*Date* Aug. 6, 1912
	(13.9)	23.0	16.0	(8.1)	(2.1)	9.0	5.8	*Reduced by* Jno. Smith
								Date Aug. 6, 1912

FIG. 25.

lowing tables give the equivalents of the minutes in tenths of an hour:

Minutes.	Tenths of hour.	Minutes.	Tenths of hour.	Minutes.	Tenths of hour.	Examples.
						h. m. hrs.
0 to 3	0.0	21 to 27	0.4	45 to 51	0.8	4 02=4.0
4 to 8	.1	28 to 32	.5	52 to 56	.9	4 31=4.5
9 to 15	.2	33 to 39	.6	57 to 59	1.0	4 50=4.8
16 to 20	.3	40 to 44	.7			4 58=5.0

479. The heights should usually be referred to the zero of the tide staff, and should be given in feet and tenths of a foot. If the position of the tide staff has been changed during the observations, the heights should all be referred to the zero of one of the staffs, and a full explanation given in the column of "Remarks." Any point of an automatic tide-gauge curve is readily referred to the zero of staff by using the true or corrected scale setting, as calculated from the comparative readings (par. 477) on the datum line.

480. When the series of observations is less than 6 months the high and low waters should be tabulated in groups of 29 days each, beginning each group on the first line of the front side of a sheet. Allow two lines for each day, which will enable 17 days of record to be tabulated on the front page, and the remaining 12 days of the group will be tabulated on the back of the form. If any part of the record is lost, leave vacant lines for missing tides. If the series is longer than 6 months, the high and low waters should be tabulated by calendar months. Begin each sheet with the first of the month, and after 29 days have been tabulated, place the remaining days of the month below the long black horizontal line near the bottom of the back of the form. For February of common years, insert March 1 after February 28 in order to complete the 29-day group. The high and low waters for March 1 should be repeated at the beginning of the sheet for March.

481. The method of representing the year, month, and days is shown in the specimen forms that follow. The repetition of the name of the month in the date column on the same side of the sheet is not desired; and although two lines are allowed for each day, the day of the month is written only on the first of these lines. Generallly, the morning tides are entered on the first line and the afternoon tides on the second line for each day. A tide occurring at midnight (0^h) is taken as belonging to the morning of the day just beginning. While tabulating the times and heights of the high and low waters, the columns of "Moon's transits" and "Lunitidal intervals" are left blank. These are to be filled in afterwards in case the reductions described in paragraph 493 are made.

482. After the times and heights have been tabulated, the highest and lowest tide occurring during the entire month, or during the period represented by the sheet if the tabulations are not made by calendar months, should be selected and entered in the heading on the back of the sheet. If during this time the observer was unable to obtain a complete record because of some abnormal weather conditions, an estimation of the height of an extreme high water or extreme low water referred to the tide staff may be made from the evidence at hand and an explanation entered in the column of "Remarks."

483. Tabulation of hourly readings (Form 362, fig. 26).—The heights in this form should generally be referred to the zero of the tide staff, and should be expressed in feet and tenths of a foot. When heights are taken from a tide roll they are readily referred to staff by using the corrected scale setting on datum line (par. 477). The month and day of month are to be indicated in the spaces provided. The name or abbreviation for the month should be written only once on a page, except that the month should always be given for its first day. The series may begin at any time and the days are to be entered consecutively without regard to calendar months or to time of changing tide rolls, seven days to the page, and using both sides of the form. After a year of observations has been completed a new series should be started. If any part of the record is lost, unless it is great enough to break the series into separate parts, blank spaces should be left for the missing tides. In the space after the "Day of series," the days are to be numbered consecutively, 1, 2, 3, etc., throughout the series, without regard to the month or day of month.

484. As stencils are to be used in connection with this form, it is important that the heights be written in their proper spaces in the columns headed "Feet" and in the lines opposite the number of the hour. In the form, these columns have the decimal points already printed. The columns without the decimal points are to be left vacant.

Form 362
DEPARTMENT OF COMMERCE
U. S. COAST AND GEODETIC SURVEY

Specimen of Form 362

TIDES: HOURLY HEIGHTS

Station. San Diego (La Playa), California — Year: 1912
Chief of Party. John A. Watkins — Lat. 32°42' N. — Long. 117°14' W
Time Meridian: 120th W — Tide Gauge No. 76 — Scale 1: 12 — Reduced to Staff. —
11—760.

Month and Day	July 1	2	3	4	5	6	7	Horizontal Sum.
Day of Series	183	184	185	186	187	188	189	
Hour	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet
0	7.6	8.2	8.5	8.4	8.1	7.6	6.8	55.2
1	6.3	7.1	7.6	7.8	7.9	7.6	7.0	51.3
2	5.1	5.9	6.5	6.9	7.3	7.3	7.0	46.0
3	4.0	4.8	5.4	5.9	6.5	6.8	6.9	40.3
4	3.2	3.9	4.5	5.0	5.7	6.1	6.5	34.9
5	3.2	3.4	3.8	4.3	4.9	5.5	6.0	31.1
6	3.6	3.5	3.6	3.9	4.4	5.0	5.5	29.5
7	4.4	4.1	3.9	3.9	4.2	4.7	5.1	30.3
8	5.3	4.9	4.5	4.3	4.3	4.7	5.0	33.0
9	6.2	5.2	5.4	5.0	4.9	5.0	5.0	36.7
10	7.0	6.5	6.1	5.9	5.7	5.5	5.4	42.1
11	7.3	7.1	6.8	6.6	6.4	6.2	6.0	46.4
Noon	7.3	7.3	7.2	7.1	7.1	6.9	6.7	49.6
13	6.8	7.1	7.2	7.5	7.5	7.4	7.3	50.8
14	6.5	6.7	7.0	7.4	7.6	7.8	7.9	50.9
15	6.2	6.3	6.6	7.1	7.5	7.8	8.2	49.7
16	6.2	6.1	6.3	6.6	7.1	7.5	8.2	48.0
17	6.6	6.2	6.2	6.4	6.7	7.1	7.8	47.0
18	7.2	6.7	6.3	6.3	6.4	6.8	7.2	46.9
19	8.0	7.3	6.7	6.5	6.3	6.2	6.6	47.6
20	8.8	8.1	7.3	7.0	6.3	6.1	6.0	49.6
21	9.3	8.7	7.9	7.4	6.7	6.1	5.7	51.8
22	9.4	9.0	8.4	7.9	7.0	6.2	5.5	53.4
23	9.0	9.0	8.7	8.2	7.4	6.4	5.7	54.4
Sum.	154.5	153.1	152.4	153.3	153.9	154.3	155.0	1076.5

Sum for 29 days, 1 to 29 of — = — Divisor=696; mean for 29 days=

Tabulated by John Smith Date Aug. 6, 1912 Summed by John Smith Date Aug. 6, 1912

FIG. 26.

485. When the record is to be continued for many years it is generally divided into series of 369 days each, commencing on the 1st day of January of each year, the last three or four days of one series being repeated as the first days of the following series. As a check on the arrangement of the days in the form, the following table gives the page, column of page, and day of series, for the first of each calendar month, when the series commences with January 1. This table is not applicable to a series beginning on any other date than the 1st of January.

Common year.				Leap year.			
Month.	Page.	Column.	Day of series.	Month.	Page.	Column.	Day of series.
Jan. 1	1	1	1	Jan. 1	1	1	1
Feb. 1	5	4	32	Feb. 1	5	4	32
Mar. 1	9	4	60	Mar. 1	9	5	61
Apr. 1	13	7	91	Apr. 1	14	1	92
May 1	18	2	121	May 1	18	3	122
June 1	22	5	152	June 1	22	6	153
July 1	26	7	182	July 1	27	1	183
Aug. 1	31	3	213	Aug. 1	31	4	214
Sept. 1	35	6	244	Sept. 1	35	7	245
Oct. 1	40	1	274	Oct. 1	40	2	275
Nov. 1	44	4	305	Nov. 1	44	5	306
Dec. 1	48	6	335	Dec. 1	48	7	336
Dec. 31	53	1	365	Dec. 31	53	2	366
Jan. 4	53	5	369	Jan. 3	53	5	369

486. If the series of observations is to be less than four years long it is usually best to begin on the first complete day of record as the first day of series. After 369 days have been tabulated, a new series should be commenced on the same month and day of month as the first series, the last three or four days of one series being repeated as the first day of the following series.

487. At permanent tidal stations the tabulated hourly readings when complete are to be summed both vertically and horizontally and the results written in the spaces provided on the form. The total of the horizontal sums on any page must equal the total of the vertical sums, and this total page sum should be written in the proper space near the lower right-hand corner of the form. If any of the columns are incomplete because of lost record, the missing readings may be estimated by interpolation, and entered in the form with red ink to distinguish them from the actual observed readings. Generally if the tide observer does not understand the method of interpolation, he may leave this part of the work to be done in the office. In this case he should enter the sums of all incomplete lines, columns, or pages, with lead pencil, in order that they may be modified after the interpolations have been made. The final sums are to include both observed and interpolated readings. A tide observer who tabulates his own records should send to the office only those pages of Form 362 which have been entirely completed so far as his gauge record will permit, retaining any partially filled form to complete when the record for the following month is removed from the gauge.

488. Interpolations.—Before beginning the reductions, if any portion of the record is lost, it is desirable that the missing tides be supplied by interpolation. Interpolated tides should be written in red ink or else inclosed in parenthesis to distinguish them from observations. If only a few tides are lost, plot time and height upon profile paper for a number of days before and after the break, leaving space for the missing tides; connect the alternate tides with curved line, which must be extended across the gap on the plotting as nearly as may be in accordance with the apparent law of change in time and height. There will usually be eight distinct curves—four for height and four for time, including both high and low waters. In order to prevent the curves from becoming confused by intersecting too much, they may be plotted upon scales which are dropped one below the other.

489. If there is a simultaneous series in the vicinity the missing tides may be supplied by comparison with it.

490. If the series is long enough take the means of the times and heights occurring 29 days before and 29 days after each missing tide, smoothing out the results by plotting.

491. In some cases a direct linear interpolation will suffice, especially when only a few tides are missing. In this mode of interpolation divide the difference between the times of alternate tides and also that of the corresponding heights by one more than the number of missing tides and add the quotient to the preceding time and heights. If it happens that one of the tides occurs near noon or midnight, it may chance that only one tide of that phase occurs in the civil day, and care must be taken to allow for this in counting up the number of missing tides.

492. Reduction of tide records.—To obtain tidal constants and tidal datums for any station, the tabulated tides, together with intervals and ranges depending upon them, must be reduced to their mean values. The mean of a series of items is obtained by dividing the sum by the number of items included in that sum. In order to secure uniformity, the spaces for the sums are generally indicated in the forms, and the number of items included in each sum should usually be written in small figures just above the sum, as indicated in the specimens of Form 138 (pp. 163–164). In the tabulations, the individual times and heights are given to one decimal place, but in obtaining the means the results should be carried to two decimal places. The last decimal figure should be taken to the nearest hundredth, but if the remainder should be exactly one-half of the divisor, the second decimal should be made even, if not already even, by adding one. The means directly obtained require certain corrections, which are explained in the following paragraphs.

493. Lunitidal intervals (Form 138).—This computation is made directly on the form on which the high and low waters have been tabulated.

First: The moon's transits for the meridian of Greenwich are copied in the column provided for the purpose. If the transits are obtained from an almanac, care must be taken to refer them to civil time and to convert the minutes into tenths of an hour. Photostat copies of a table of transits expressed in hours and tenths, Greenwich mean civil time, may be obtained from the office. The times inclosed by parentheses are for the lower transits of the moon, the unmarked ones being for the upper transits. They should be similarly indicated in the copy.

Second: Subtract from the time of each high and low water the time of the first preceding moon's transit, and write the difference in the appropriate column on the same line as the tide from which it was obtained. In case the time of high or low water is nearly the same as that of the moon's transit, take the transit which precedes the tide by about 12 hours, but in no case must the same transit be used for two consecutive high waters or for two consecutive low waters. The lower transit of the moon applies to both high and low waters, just the same as the upper transit does. When the time of the moon's transit is on one day and the following high or low water is on the next day, the time of this tide must be increased by adding 24 hours before attempting to subtract the time of the transit. The high-water intervals will usually be approximately six hours greater or less than the low-water intervals, but the intervals for each phase of tide will rarely vary among themselves more than several hours. Intervals from the lower transits of the moon are to be indicated by parentheses.

Third: Sum both columns of the intervals for 29 days, placing the results in the spaces provided on the back of the form.

Fourth: Obtain the means by dividing each sum by the number of intervals combined to obtain it, carrying the results to two decimal places, and enter the results just below the sum.

Fifth: Apply the correction to intervals, as obtained from the table on pages 173 to 175, and enter the results in the spaces provided below the second horizontal black line near the bottom of the form. The corrected high-water interval thus obtained is known also as the corrected establishment of the port.

494. Corrections for lunitidal intervals.—The true lunitidal interval is the difference between the mean local time of the tide and the mean local time of the moon's transit over the local meridian. But on account of the use of standard time instead of local time and the inconvenience of changing the moon's transits to the local meridian, it is customary to compute fictitious lunitidal intervals, which are the difference between the standard time of the tide and the Greenwich time of the moon's transit over the meridian of Greenwich, and then correct the mean once for all, thus saving considerable work.

Let L =west longitude of station in degrees and decimals.

S =west longitude of time meridian used for tides.

S'=west longitude of time meridian used for transits.

X =correction to lunitidal intervals in hours and decimals.

Then the correction for lag of the moon is—

(1) $X_1=\frac{24.8412-24.0000}{360}(S'-L)=0.00233667\ (S'-L)$

The correction for reduction of standard time to local time is—

(2) $X_2=\frac{24}{360}(S-L)=0.06666667\ (S-L)$

Combining (1) and (2) gives—

(3) $X=0.06666667\ (S-L)+0.00233667\ (S'-L)$

When Greenwich transits are used $S'=0°$, and—

(4) $X=0.06666667\ S-0.06900334\ L$

When Greenwich transits and mean local time are used

$L=S$, and (4) becomes—

(5) $X=-0.00233667\ L.$

495. The following table has been computed from formula (4) for west longitude. For east longitude reverse the signs in this table.

496. It is directly applicable when standard time has been used for the tides. Take the correction for the degrees of local longitude from the column headed by the time meridian used and add to this the correction for the minutes of local longitude. The latter part of the correction is independent of the time meridian.

497. For any other time meridian S_1 the table may be adapted by using the nearest standard time meridian (S) of the table, proceeding as before, and then apply the following correction to the result from the table:

$X = \pm 0.06667\ (S_1 - S)$, + for west longitude, − for east longitude.

498. When transits for the meridian of L' are used, the table may be adapted by proceeding as before and applying the following correction to the result:

$X = \pm 0.00234\ L'$, + for west longitude, − for east longitude.

499. When mean local civil time and Greenwich transits are used, it is probably more convenient to use formula (5) independently of the table.

Correction for lunitidal intervals (in hours and decimals).

[For west longitude use sign given; for east longitude reverse sign.]

Time meridian, 0°.		Time meridian, 15°.		Time meridian, 30°.		Time meridian, 45°.	
Longitude.	Correction.	Longitude.	Correction.	Longitude	Correction.	Longitude.	Correction.
°	*Hour.*	°	*Hour.*	°	*Hour.*	°	*Hour.*
		5	+0.655	20	+0.620	35	+0.585
		6	+ .586	21	+ .551	36	+ .516
		7	+ .517	22	+ .482	37	+ .447
		8	+ .448	23	+ .413	38	+ .378
		9	+ .379	24	+ .344	39	+ .309
		10	+ .310	25	+ .275	40	+ .240
		11	+ .241	26	+ .206	41	+ .171
		12	+ .172	27	+ .137	42	+ .102
		13	+ .103	28	+ .068	43	+ .033
		14	+ .034	29	− .001	44	− .036
0	0.000	15	− .035	30	− .070	45	− .105
1	− .069	16	− .104	31	− .139	46	− .174
2	− .138	17	− .173	32	− .208	47	− .243
3	− .207	18	− .242	33	− .277	48	− .312
4	− .276	19	− .311	34	− .346	49	− .381
5	− .345	20	− .380	35	− .415	50	− .450
6	− .414	21	− .449	36	− .484	51	− .519
7	− .483	22	− .518	37	− .553	52	− .588
8	− .552	23	− .587	38	− .622	53	− .657
9	− .621	24	− .656	39	− .691	54	− .726
10	− .690	25	− .725	40	− .760	55	− .795

Time meridian, 60°.		Time meridian, 75°.		Time meridian, 90°.		Time meridian, 105°.	
Longitude.	Correction.	Longitude.	Correction.	Longitude.	Correction.	Longitude.	Correction.
°	*Hour.*	°	*Hour.*	°	*Hour.*	°	*Hour.*
50	+0.550	65	+0.515	80	+0.480	95	+0.445
51	+ .481	66	+ .446	81	+ .411	96	+ .376
52	+ .412	67	+ .377	82	+ .342	97	+ .307
53	+ .343	68	+ .308	83	+ .273	98	+ .238
54	+ .274	69	+ .239	84	+ .204	99	+ .169
55	+ .205	70	+ .170	85	+ .135	100	+ .100
56	+ .136	71	+ .101	86	+ .066	101	+ .031
57	+ .067	72	+ .032	87	− .003	102	− .038
58	− .002	73	− .037	88	− .072	103	− .107
59	− .071	74	− .106	89	− .141	104	− .176
60	− .140	75	− .175	90	− .210	105	− .245
61	− .209	76	− .244	91	− .279	106	− .314
62	− .278	77	− .313	92	− .348	107	− .383
63	− .347	78	− .382	93	− .417	108	− .452
64	− .416	79	− .451	94	− .486	109	− .521
65	− .485	80	− .520	95	− .555	110	− .590
66	− .554	81	− .589	96	− .624	111	− .659
67	− .623	82	− .658	97	− .693	112	− .728
68	− .692	83	− .727	98	− .762	113	− .797
69	− .761	84	− .796	99	− .831	114	− .866
70	− .830	85	− .865	100	− .900	115	− .935

Correction for lunitidal intervals—Continued.

Time meridian, 120°.		Time meridian, 135°.		Time meridian, 150°.	
Longitude.	Correction.	Longitude.	Correction.	Longitude.	Correction.
°	*Hour.*	°	*Hour.*	°	*Hour.*
110	+0.410	125	+0.375	140	+0.340
111	+ .341	126	+ .306	141	+ .271
112	+ .272	127	+ .237	142	+ .202
113	+ .203	128	+ .168	143	+ .133
114	+ .134	129	+ .099	144	+ .064
115	+ .065	130	+ .030	145	− .005
116	− .004	131	− .039	146	− .074
117	− .073	132	− .108	147	− .143
118	− .142	133	− .177	148	− .212
119	− .211	134	− .246	149	− .281
120	− .280	135	− .315	150	− .351
121	− .349	136	− .384	151	− .420
122	− .418	137	− .453	152	− .489
123	− .487	138	− .522	153	− .558
124	− .556	139	− .591	154	− .627
125	− .625	140	− .660	155	− .696
126	− .694	141	− .729	156	− .765
127	− .763	142	− .798	157	− .834
128	− .832	143	− .867	158	− .903
129	− .901	144	− .936	159	− .972
130	− .970	145	−1.005	160	−1.041

Time meridian, 157° 30′.		Time meridian, 165°.		Time meridian, 180°.	
Longitude.	Correction.	Longitude.	Correction.	Longitude.	Correction.
°	*Hour.*	°	*Hour.*	°	*Hour.*
148	+0.288	155	+0.304	170	+0.269
149	+ .219	156	+ .235	171	+ .200
150	+ .149	157	+ .166	172	+ .131
151	+ .080	158	+ .097	173	+ .062
152	+ .011	159	+ .028	174	− .007
153	− .058	160	− .041	175	− .076
154	− .127	161	− .110	176	− .145
155	− .196	162	− .179	177	− .214
156	− .265	163	− .248	178	− .283
157	− .334	164	− .317	179	− .352
158	− .403	165	− .386	180	− .421
159	− .472	166	− .455	181	− .490
160	− .541	167	− .524	182	− .559
161	− .610	168	− .593	183	− .628
162	− .679	169	− .662	184	− .697
163	− .748	170	− .731	185	− .766
164	− .817	171	− .800	186	− .835
165	− .886	172	− .869	187	− .904
166	− .955	173	− .938	188	− .973
167	−1.024	174	−1.007	189	−1.042
168	−1.093	175	−1.076	190	−1.111

Correction for minutes of longitude.

Longitude.	Correction.	Longitude.	Correction.	Longitude.	Correction.
′	*Hour.*	′	*Hour.*	′	*Hour.*
1	−0.001	21	−0.024	41	−0.047
2	−.002	22	−.025	42	−.048
3	−.003	23	−.026	43	−.049
4	−.005	24	−.028	44	−.051
5	−.006	25	−.029	45	−.052
6	−.007	26	−.030	46	−.053
7	−.008	27	−.031	47	−.054
8	−.009	28	−.032	48	−.055
9	−.010	29	−.033	49	−.056
10	−.012	30	−.034	50	−.058
11	−.013	31	−.036	51	−.059
12	−.014	32	−.037	52	−.060
13	−.015	33	−.038	53	−.061
14	−.016	34	−.039	54	−.062
15	−.017	35	−.040	55	−.063
16	−.018	36	−.041	56	−.064
17	−.020	37	−.043	57	−.066
18	−.021	38	−.044	58	−.067
19	−.022	39	−.045	59	−.068
20	−.023	40	−.046	60	−.069

500. Mean high water (HW), mean low water (LW), mean range (Mn), and mean tide level (MTL), (Form 138).—First: Add the high and low water heights for 29 days. Second: Obtain the means by dividing each sum by the number of high or low waters included. Third: Obtain the mean range (Mn) by subtracting the mean of the low waters from the mean of the high waters, and enter the result in the space before the symbol "Mn." Fourth: Obtain the mean tide level (MTL) by taking one half of the sum of the mean high water and the mean low water, and enter in the space before the symbol "MTL." Fifth: The mean range should be corrected for longitude of moon's node in accordance with paragraph 503.

501. Mean higher high water (HHW), mean lower low water (LLW), and diurnal inequalities (DHQ and DLQ) (Form 138).—First: Check off the higher of the two high waters and the lower of the two low waters of each day for 27 days, omitting the first and last days of the 29-day group. When only one high or one low water occurs on a calendar day, by reason of one of the tides having occurred after midnight and therefore on the next calendar day, the single tide should be checked if the tide just above it is unchecked, otherwise it should not be checked. If, however, the tide has become diurnal and only one high and one low water occur during the tidal day, these should both be checked. Second:

The higher high waters and lower low waters thus checked should be summed and the results entered in the spaces provided in the column of "Remarks" on the back of the form. Third: Obtain the means and enter the results in the line below the sums. Fourth: Subtract the mean of all the high waters from the mean of the higher high waters and enter the difference after the symbol DHQ on the back of the form. Fifth: Subtract the mean of the lower low waters from the mean of the low waters and enter the difference after the symbol DLQ. Sixth: Correct the DHQ and DLQ in accordance with paragraph 506.

502. Correction for the longitude of the moon's node.—The moon's node is the place where the lunar orbit intersects the ecliptic or earth's orbit, and the position of the node is continually changing. The effect of this change in the longitude of the node is to vary the maximum declination of the moon by more than 10 degrees, there being periods of years during which this maximum is less than that of the ecliptic, and other periods of years when the maximum declination of the moon is greater than that of the ecliptic. A change in the moon's declination affects both the mean range and the diurnal inequalities of the tide, so that these quantities as found from observations for any year must be corrected to obtain a true mean value.

503. To correct the mean range for the longitude of the moon's node, apply the factor "F(Mn)," or "Factor for mean range," which may be obtained from the following table for the years 1915 to 1934. The factors have been computed for the middle of each year, but as they change very slowly, the same value may be taken for any month of the year. The line in the table from which the value is to be taken is determined by the argument $\frac{2\,(DHQ+DLQ)}{Mn}$, which may be computed to one decimal place from the uncorrected values of *DHQ*, *DLQ*, and *Mn* as obtained from Form 138.

504. Factor $F(Mn)$.—*For reducing the observed range of tide to its mean value.*

$\frac{2(DHQ+DLQ)}{Mn}$	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924
0.0 to 0.2	1.02	1.02	1.01	1.00	0.99	0.98	0.97	0.97	0.97	0.98
0.3 to 0.4	1.02	1.02	1.01	1.00	.99	.98	.97	.97	.97	.98
0.5 to 0.6	1.02	1.02	1.01	1.00	.99	.98	.98	.97	.97	.98
0.7 to 0.8	1.02	1.01	1.00	1.00	.99	.98	.98	.98	.98	.98
0.9 to 1.0	1.02	1.01	1.00	1.00	.99	.99	.98	.98	.98	.98
1.1 to 1.2	1.01	1.01	1.00	1.00	.99	.99	.99	.98	.98	.99
1.3 to 1.4	1.01	1.01	1.00	1.00	1.00	.99	.99	.99	.99	.99
1.5 to 1.6	1.01	1.00	1.00	1.00	1.00	.99	.99	.99	.99	.99
1.7 to 1.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

$\frac{2(DHQ+DLQ)}{Mn}$	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
0.0 to 0.2	0.98	0.99	1.00	1.01	1.02	1.03	1.03	1.03	1.03	1.02
0.3 to 0.4	.98	.99	1.00	1.01	1.02	1.03	1.03	1.03	1.03	1.02
0.5 to 0.6	.98	.99	1.00	1.01	1.02	1.02	1.03	1.03	1.02	1.02
0.7 to 0.8	.98	.99	1.00	1.01	1.02	1.02	1.02	1.02	1.02	1.02
0.9 to 1.0	.99	.99	1.00	1.01	1.01	1.02	1.02	1.02	1.02	1.01
1.1 to 1.2	.99	1.00	1.00	1.01	1.01	1.02	1.02	1.02	1.02	1.01
1.3 to 1.4	.99	1.00	1.00	1.01	1.01	1.01	1.01	1.01	1.01	1.01
1.5 to 1.6	1.00	1.00	1.00	1.00	1.00	1.01	1.01	1.01	1.01	1.00
1.7 to 1.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

505. For stations on the Atlantic coast of the United States from Maine to Florida, $\frac{2(DHQ+DLQ)}{Mn}$ is usually small, and if the values of *DHQ* and *DLQ* have not been obtained, the top line of the table may generally be taken without material error. For stations on the coast of the Gulf of Mexico from Key West to the Rio Grande, the mean range of the tide is very small and the factor $F(Mn)$ need not be applied. For other localities, where *DHQ* and *DLQ* are usually computed, as on our Pacific coast, Alaska, etc., the value of $\frac{2(DHQ+DLQ)}{Mn}$ should be obtained and entered in the space provided in the heading on the back of Form 138. If it is larger than 1.8, no correction need be applied to the mean range.

506. The diurnal inequalities *DHQ*, *DLQ*, should be corrected by the factor 1.02 F_1, which may be obtained from the following table for the years 1915 to 1934. These factors have been computed for calendar months and may be used without modification for series of 29 days beginning on the 1st day of the month. If a 29-day series begins on any other day of the month, the factor may be obtained from the table by interpolation.

507. Factor 1.02 F_1.—*For correcting DHQ and DLQ.*

Month.	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924
Jan.	0.81	0.83	0.86	0.89	0.92	0.97	1.01	1.03	1.03	1.02
Feb.	.94	.97	1.01	1.05	1.11	1.16	1.22	1.26	1.26	1.23
Mar.	1.08	1.11	1.16	1.21	1.29	1.37	1.45	1.49	1.49	1.46
Apr.	1.01	1.03	1.08	1.13	1.21	1.27	1.33	1.37	1.36	1.33
May	.86	.88	.91	.96	.99	1.04	1.08	1.10	1.10	1.07
June	.78	.81	.83	.86	.91	.94	.97	.98	.98	.96
July	.82	.84	.86	.90	.95	.98	1.01	1.03	1.02	1.00
Aug.	.95	.98	1.01	1.06	1.13	1.18	1.22	1.24	1.23	1.19
Sept.	1.10	1.13	1.19	1.26	1.34	1.42	1.48	1.51	1.48	1.43
Oct.	1.02	1.05	1.11	1.17	1.23	1.31	1.35	1.37	1.35	1.30
Nov.	.86	.88	.92	.96	1.01	1.06	1.09	1.09	1.08	1.04
Dec.	.81	.82	.85	.89	.92	.96	.98	.98	.97	.94

Month.	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
Jan.	0.98	0.94	0.90	0.86	0.83	0.82	0.80	0.80	0.80	0.82
Feb.	1.17	1.12	1.06	1.01	.98	.95	.93	.93	.93	.96
Mar.	1.37	1.29	1.22	1.15	1.11	1.08	1.06	1.05	1.06	1.08
Apr.	1.26	1.19	1.12	1.07	1.03	1.00	.99	.99	1.00	1.02
May	1.02	.98	.93	.90	.87	.85	.84	.84	.85	.86
June	.92	.88	.85	.81	.79	.78	.77	.77	.78	.79
July	.96	.91	.86	.84	.82	.81	.80	.80	.81	.82
Aug.	1.13	1.07	1.02	.98	.95	.93	.92	.92	.93	.95
Sept.	1.43	1.26	1.19	1.13	1.09	1.07	1.06	1.06	1.07	1.10
Oct.	1.22	1.15	1.10	1.04	1.01	1.00	.99	.99	1.00	1.03
Nov.	1.00	.95	.91	.88	.85	.84	.83	.83	.84	.87
Dec.	.90	.86	.83	.80	.79	.78	.77	.77	.78	.80

508. Annual inequality in mean sea level.—At most stations there is a variation in the reading of mean sea level upon the staff at different times of the year, depending in general upon the seasonal changes in the direction and strength of the wind, and in river stations also upon the rainfall or melting snow. There is a rough periodicity in these variations of mean sea level, but they can not accurately be foretold. The inequality may to some extent be eliminated from a short series of observations by a comparison with simultaneous observation at a near-by station where the tidal planes have already been determined from a long series of observations.

509. Comparison of simultaneous observations (Form 248, fig. 27).—If tidal data have been well determined for one station, satisfactory data for another station near by may generally be obtained by observing the tides simultaneously for several days

DEPARTMENT OF COMMERCE
U. S. COAST AND GEODETIC SURVEY
FORM 248

Specimen of Form 248

TIDES: Comparison of Simultaneous Observations

(A) Subordinate station Arcata Whf., Humboldt B., Calif. Lat. 40° 51' N. Long. 124° 07' W.
(B) Standard station N. Jetty Landing, " " Lat. 40° 46' N. Long. 124° 13' W.
Chief of party R. B. Lukens Time Meridian. (A) 120° W. (B) 120° W.

DATE.	(A) STATION.		(B) STATION.		(A)—(B)		(A) STATION.		(B) STATION.		(A)—(B)	
Year.	Time of—		Time of—		Time difference.		Height of—		Height of—		Height difference.	
1919	HW.	LW.	HW.	LW.	HW.	LW.	HW.	LW.	HW.	LW.	HW.	LW.
Mo. D.	Hours.	Hours.	Hours.	Hours.	Hours.	Hours.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.
Oct. 14		9.8		9.0		0.8		6.0		4.5		1.5
	15.9	22.7	15.0	22.2	0.9	0.5	10.8	2.5	8.7	1.5	2.1	1.0
15	6.0	10.6	5.1	10.0	0.9	0.6	9.0	6.0	7.1	4.6	1.9	1.4
	16.9	23.6	16.2	23.3	0.7	0.3	10.0	2.8	8.1	1.7	1.9	1.1
16	7.2		6.3		0.9		9.0		7.2		1.8	
Sums							HHW 20.8	HLW 12.0	HHW 16.8	HLW 9.1	HHW 4.0	HLW 2.9
Means							10.40	6.00	8.40	4.55	2.00	1.45
Sums					3.4	2.2	LHW 18.0	LLW 5.3	LHW 14.3	LLW 3.2	LHW 3.7	LLW 2.1
Means					0.85	0.55	9.00	2.65	7.15	1.60	1.85	1.05

	HW.	LW.	
(1)=	+0.85	+0.55	=Mean difference in time of high and low water respectively
(2)=	+0.01	+0.01	=Correction for difference in longitude. (Table on back of form.)
(3)=	+0.86	+0.56	=(1)+(2)=Mean difference in high and low water intervals, respectively

Feet. / Feet.

(4)=10.40 =Mean HHW height at (A).
(5)=6.00 =Mean HLW height at (A).
(6)=9.00 =Mean LHW height at (A).
(7)=2.65 =Mean LLW height at (A).
(8)=1.40 =(4)−(6)=2DHQ at (A).
(9)=3.35 =(5)−(7)=2DLQ at (A).
(10)=9.70 =½[(4)+(6)]=Mean HW height at (A).
(11)=4.32 =½[(5)+(7)]=Mean LW height at (A).
(12)=5.38 =(10)−(11)=Mn at (A).
(13)=7.01 =½[(10)+(11)]=MTL at (A).

(14)=2.00 =Mean HHW difference.
(15)=1.45 =Mean HLW difference.
(16)=1.85 =Mean LHW difference.
(17)=1.05 =Mean LLW difference.
(18)=0.15 =(14)−(16)=2DHQ difference.
(19)=0.40 =(15)−(17)=2DLQ difference.
(20)=1.92 =½[(14)+(16)]=Mean HW difference.
(21)=1.25 =½[(15)+(17)]=Mean LW difference.
(22)=0.67 =(20)−(21)=Mn difference.
(23)=1.58 =½[(20)+(21)]=MTL difference.

(24)=1.14 =(12)÷[(12)−(22)]=Mn ratio.
(25)=1.12 =(8)÷[(8)−(18)]=DHQ ratio.
(26)=1.14 =(9)÷[(9)−(19)]=DLQ ratio.

Results from comparison of Stations A and B.	HWI.	LWI.	MTL.	Mn.	DHQ.	DLQ.
Length of Series.	Hours.	Hours.	Feet.	Feet.	Feet.	Feet.
Accepted values for standard station, from 4 mos. of observations	11.80	5.48	5.46	4.50	0.70	1.20
Differences and ratios. (3), (23), (24), (25), (26)	+0.86	+0.56	+1.58	X1.14	X1.12	X1.14
Corrected values for subordinate station	12.66	6.04	7.04	5.13	0.78	1.37

Mean LW on staff at subordinate station=MTL−½Mn = ... feet.
Mean LLW on staff at subordinate station=MTL−½Mn−DLQ= 3.11 feet.

Computed by S. H. Reed, May 11, 1920. (Date.) Verified by L. A. Cole May 12, 1920. (Date.)

FIG. 27.

at the two stations and comparing the results. For this purpose there should be at least two days of both day and night tides observed, and if the stations are very far apart a longer series should be observed. It is generally most satisfactory, especially when there is a large diurnal inequality, to have the tides compared consist of a whole number of tidal days so that the number of higher high waters, lower high waters, higher low waters, and lower low waters will be the same.

510. Explanation of Form 248. (See page 179).—This form is designed for the comparison of tides at a subordinate station for which tidal results are sought, with the tides observed simultaneously at a standard station for which tidal constants are known. For short series of observations the high and low waters observed at the subordinate station may be tabulated immediately in this form, in which case it will be unnecessary to tabulate them also in Form 138. The time and height differences are to be obtained by subtracting the values at the standard station from the values at the subordinate station and the results entered with proper signs in the columns indicated.

Find the sums and means of columns of time difference, height of tide at both stations, and height difference. For stations on the Pacific coast, where the plane of reference is mean lower low water, the heights of the higher high, lower high, higher low, and lower low waters are to be summed separately, the higher highs and lower lows being indicated by pencil check marks. For stations on the Atlantic coast, where the plane of reference is mean low water, the heights of the high waters may be all combined into a single sum, and similarly the low water heights; the headings of their sums being made to read HW and LW, respectively, by striking out the extra letters. All mean results should be given to two decimals of its unit, whether hour or foot. If any individual difference varies greatly from the apparent average, and an examination of the original record fails to show an error, that difference should not be included in the sum; and such a value should be encircled to show that it has been rejected.

For stations on the Atlantic coast omit (4) to (9), (14) to (19), (25), (26), and the computation of DHQ and DLQ at the bottom of the form. Take (10) = mean high water height at the subordinate station, (11) = mean low water height at subordinate station, (20) = mean high water difference, and (21) = mean low water difference. For stations on the Pacific coast the lower part of the form should be filled out completely as indicated.

The correction for difference in longitude (2) may be obtained from the following table. Find the difference in longitude by subtracting the longitude of the subordinate station from the longitude of the standard station, considering west as positive and east as negative. The correction has the same sign as the resulting difference of longitudes. If the kind of time used at the two stations is different, apply this difference, expressed in hours, to the difference in the time of tide as directly obtained, adding if the time meridian of the subordinate station is west of the time meridian of the standard station, and subtracting if the time meridian of the subordinate station is east of that of the standard station.

511. Correction for difference in longitude.—

Difference.	Correction.	Difference.	Correction.	Difference.	Correction.	Difference.	Correction.	Difference.	Correction.	Dif-difence.	Correction.
°	*Hour.*	°	*Hour.*	°	*Hour.*	°	*Hour.*	°	*Hour.*	°	*Hour.*
1	0.069	31	2.139	61	4.209	91	6.279	121	8.349	151	10.420
2	0.138	32	2.208	62	4.278	92	6.348	122	8.418	152	10.489
3	0.207	33	2.277	63	4.347	93	6.417	123	8.487	153	10.558
4	0 276	34	2,346	64	4.416	94	6.486	124	8.556	154	10.627
5	0.345	35	2.415	65	4.485	95	6.555	125	8.625	155	10.696
6	0.414	36	2.484	66	4.554	96	6.624	126	8.694	156	10.765
7	0.483	37	2.553	67	4.623	97	6.693	127	8.763	157	10.834
8	0.552	38	2.622	68	4.692	98	6.762	128	8.832	158	10.903
9	0.621	39	2.691	69	4.761	99	6.831	129	8.901	159	10.972
10	0.690	40	2.760	70	4.830	100	6.900	130	8.970	160	11.041
11	0.759	41	2.829	71	4.899	101	6.969	131	9.039	161	11.110
12	0.828	42	2.898	72	4.968	102	7.038	132	9.108	162	11.179
13	0.897	43	2.967	73	5.037	103	7.107	133	9.177	163	11.248
14	0.966	44	3.036	74	5.106	104	7.176	134	9.246	164	11.317
15	1.035	45	3.105	75	5.175	105	7.245	135	9.315	165	11.386
16	1.104	46	3.174	76	5.244	106	7.314	136	9.384	166	11.455
17	1.173	47	3.243	77	5.313	107	7.383	137	9.453	167	11.524
18	1.242	48	3.312	78	5.382	108	7.452	138	9.522	168	11.593
19	1.311	49	3.381	79	5.451	109	7.521	139	9.591	169	11.662
20	1.380	50	3.450	80	5.520	110	7.590	140	9.660	170	11.731
21	1.449	51	3.519	81	5.589	111	7.659	141	9.729	171	11,800
22	1.518	52	3.588	82	5.658	112	7.728	142	9.798	172	11.869
23	1.587	53	3.657	83	5.727	113	7.797	143	9.867	173	11.938
24	1.656	54	3.726	84	5.796	114	7.866	144	9.936	174	12.007
25	1.725	55	3.795	85	5.865	115	7.935	145	10.005	175	12.076
26	1.794	56	3.864	86	5.934	116	8.004	146	10.074	176	12.145
27	1.863	57	3.933	87	6.003	117	8.073	147	10.143	177	12.214
28	1.932	58	4.002	88	6.072	118	8.142	148	10.212	178	12.283
29	2.001	59	4.071	89	6.141	119	8.211	149	10.281	179	12.352
30	2.070	60	4.140	90	6.210	120	8.280	150	10.351	180	12.421

Difference.	Correction.	Difference.	Correction.	Difference.	Correction.	Difference.	Correction.	Difference.	Correction.	Difference.	Correction.
′	*Hour.*	′	*Hour.*	′	*Hour.*	′	*Hour.*	′	*Hour.*	′	*Hour.*
1	0.001	11	0.013	21	0.024	31	0.036	41	0.047	51	0.059
2	0.002	12	0.014	22	0.025	32	0.037	42	0.048	52	0.060
3	0.003	13	0.015	23	0.026	33	0.038	43	0.049	53	0.061
4	0.005	14	0.016	24	0.028	34	0.039	44	0.051	54	0.062
5	0.006	15	0.017	25	0.029	35	0.040	45	0.052	55	0.063
6	0.007	16	0.018	26	0.030	36	0.041	46	0.053	56	0.064
7	0.008	17	0.020	27	0.031	37	0.043	47	0.054	57	0.066
8	0.009	18	0.021	28	0.032	38	0.044	48	0.055	58	0.067
9	0.010	19	0.022	29	0.033	39	0.045	49	0.056	59	0.068
10	0.012	20	0.023	30	0.035	40	0.046	50	0.058	60	0.069

512. Planes of reference.—Upon the Atlantic and Gulf coasts of the United States, including Porto Rico and the Atlantic coast of the Panama Canal Zone, all soundings are reduced to mean low water. Corrected mean low water is obtained by subtracting one-half of the corrected mean range from the corrected mean tide level. In localities where the mean rise and fall of the tide is less than 1 foot, as in the greater part of Albemarle and Pamlico Sounds, a plane one-half foot below the mean water level should be taken as the equivalent of the datum of mean low water.

Upon the Pacific coast of the United States, Alaska, Hawaii, and the Philippines, all soundings are reduced to the plane of mean lower low water, except that for Wrangell Strait the datum is 3 feet below mean lower low water. Corrected mean lower low water is obtained by subtracting the corrected diurnal low-water inequality (DLQ) from the corrected mean low water.

Upon the Pacific coast of the Panama Canal Zone the soundings are reduced to the plane of mean low water springs. For this datum the spring range of tide is first obtained from the high and low waters observed at the time of new and full moon. One-half of the spring range is then subtracted from the mean tide level to obtain mean low water springs.

513. Difference in time of tide.—When there is much difference in the time or height of the tide at the place of sounding and at the tide gauge, allowance should be made in the reduction of the soundings. The difference may generally be estimated from observations made at several stations in the vicinity of the work, but when it has been impossible to establish more than one tide station in the locality, the following formula may be useful in estimating the velocity of a progressive tidal wave, and enable one to obtain the approximate difference in the time of the tide:

$$v=\sqrt{gd}=5.67\sqrt{d}\text{ feet per second,}$$

when $g=32.17$ feet per second and $d=$depth of water for the average cross section between stations, in feet.

In order to convert feet per second into nautical miles per hour, multiply by $\frac{3600}{6080}=0.592$, and we have

$$v=3.36\sqrt{d}\text{ nautical miles per hour.}$$

The time required for the tide wave is

$$t=\frac{6080}{60\times5.672\sqrt{d}}=\frac{17.87}{\sqrt{d}}\text{ minutes per nautical mile.}$$

$$t=\frac{5280}{60\times5.672\sqrt{d}}=\frac{15.51}{\sqrt{d}}\text{ minutes per statute mile.}$$

For convenience the following brief table is given:

Time required for the tide wave to travel.

Depths.	1 nautical mile.	1 statute mile.	Depths.	1 nautical mile.	1 statute mile.
Fathoms.	*Minutes.*	*Minutes.*	*Fathoms.*	*Minutes.*	*Minutes.*
1	7.3	6.3	9	2.4	2.1
2	5.2	4.5	10	2.3	2.0
3	4.2	3.7	15	1.9	1.6
4	3.6	3.2	20	1.6	1.4
5	3.3	2.8	30	1.3	1.2
6	3.0	2.6	40	1.2	1.0
7	2.8	2.4	50	1.0	0.9
8	2.6	2.2	60	0.9	0.8

514. Bench marks.—A bench mark is a definite point on a permanent object used as a reference for elevations. No matter how temporary the occupation of a tide station is, if any plane of reference is computed or assumed, the tide staff should be referred to at least *three* permanent bench marks. This is of great importance to make the results of the tidal observations available for future use. These marks should be sufficiently scattered so that they are not likely to be all destroyed by a common cause.

515. Qualities of a good bench mark.—The principal qualities of a good bench mark are that it is not likely to be destroyed or its elevation changed, and that it may be easily found and identified.

It should be so placed that a leveling rod can be held vertically over it. A mark set horizontally is generally more convenient to use than one set in a vertical wall. In a settled community permanent and substantial buildings afford the best location. In a rocky country, a ledge of rocks will serve. If the ground is sandy, a mass of concrete containing not less than a cubic yard of material and buried so that its top projects a few inches above the surface of the ground, will generally constitute a suitable foundation for the bench. For a concrete bench mark, great care should be taken to obtain a proper mixture; one part sand, two parts cement, and three parts broken stone constitute the usual proportions. Bench marks should not be placed on buildings which are known to rest upon filled-in ground, as such structures are liable to settle. Water hydrants, curbstones, and growing trees are very unsatisfactory as bench marks except for temporary use.

516. An identification mark is required, for no matter how well the bench mark may be described there is nearly always danger of mistaking the point used, unless it is clearly marked. The best identification mark, which should be used when it is practicable to do so, is the standard disk or cap bench mark of this Survey. These are made of brass about 3½ inches in diameter and have the following inscription "U. S. COAST & GEODETIC SURVEY B. M. $250 FINE OR IMPRISONMENT FOR DISTURBING THIS MARK." The disk bench mark has a shank about 3 inches long for insertion in a building or other substantial support. It should usually be set with its face flush with the wall and secured with cement. On the face is a short line, which should be placed horizontal and which serves as the reference point. The disk bench mark may with advantage be set with its stem vertical in rock or cement, in which position it is more convenient to place a rod on than when set in a wall. The cap bench mark is threaded inside and is designed to screw on top of an iron pipe which is sunk in the ground and secured to a mass of concrete, the top of the pipe projecting a few inches above the ground. This cap bench mark may be set directly in the top of a concrete base, when no suitable pipe is available. In the center of the top of cap is a space inclosed by a circle which is the point of reference. When a standard disk or cap bench mark is used, the year of establishment and the number of the mark should be stamped into the metal. Duplication of numbers should be avoided, and a number that has previously been assigned to another bench mark in the same locality, whether destroyed or extant, should not be used again for a new bench mark. Sets of dies for stamping letters and figures may be secured from the office.

517. If the standard bench marks are not available, a small cross + cut on a rock, building, or other structure, or in some cases a drill hole, will serve to indicate the point on which the leveling rod was held. The addition of lettering, especially in rock, will make the identification more certain. In a rocky ledge subject to weathering, a copper bolt is desirable, as a cross or inscription may become too indistinct to identify with certainty.

518. Permission from the Treasury Department to place standard disk bench marks on any Federal building has been obtained, as indicated by the following letter:

TREASURY DEPARTMENT,
Washington, November 11, 1914.

The honorable the SECRETARY OF COMMERCE,
Washington, D. C.

SIR: By direction of the Secretary I have the honor to acknowledge the receipt of your communication of the 7th instant, requesting that permission be granted to the officers of the Coast and Geodetic Survey to place on the Federal buildings under the control of this department small inscribed metal tablets, which are to be used as bench marks in connection with the system of leveling, the custodians of the buildings to designate where the tablets are to be placed.

In reply, you are advised that no objection will be interposed by this department to the placing of the tablets on the various public buildings, as desired, and this letter, or a copy thereof, upon its presentation to the custodian of a Federal building, is to be considered by him as his authority for permitting the placing of one of the tablets on the building in his custody.

Respectfully,

B. R. NEWTON,
Assistant Secretary.

519. Leveling.—The bench marks and tide staff should be carefully connected with each other by forward and backward lines of spirit levels. Great care should be taken to keep the instrument in proper adjustment. When the forward and backward measures between two bench marks differ in feet by more than 0.05 K (in which K is the distance leveled between the two bench marks in statute miles), or for distances under 500 feet by more than 0.015 foot, both the forward and backward measures are to be repeated until the difference between two such measures falls within the limit. No one of the questioned measures is to be used with a new measure to get this agreement. If work has been previously done in the vicinity, all the old bench marks that can be recovered should be connected with the tide staff by spirit levels. It is desirable that bench marks established by other organizations, and also city and railroad datums, should be connected with the Survey bench marks.

520. Record of bench marks and leveling.—Before leaving the general locality where bench marks have been established, a description of each one must be written and sent to the office, together with the leveling record, and must also be written in the Tide Book, Form 277, when this is used for recording staff readings at the station, or in the Leveling Record, Form 258. Care should be taken to make the descriptions of the bench marks as clear and distinct as possible, and sufficiently complete to enable another person to readily find and identify the marks. When a bench mark is made on a building in a city or town, the street and number should be given when possible. When not on a prominent structure, the distance and direction to several landmarks that are more or less permanent in the neighborhood should be given. Sketches or photographs which would aid in locating or identifying the bench marks are desirable.

521. Inspection of tide stations.—The tide observer should be interviewed to ascertain whether he thoroughly understands his work. The care taken to keep the gauge clocks correct, and the manner of making the staff comparison should be noted, special attention being given to the observer's habit in regard to the scale on the gauge to see whether he is inclined to enter the scale reading rather than the actual staff reading on the marigram. The value of many of our tidal records has been impaired because of the uncertainties arising from the habit of some of our tide observers of entering modified scale readings instead of the actual staff readings on the tide roll. In general, the metal scales serve no useful purpose in securing the tidal records and have been already removed from some of our gauges. Unless there is some special reason for leaving the scale on the gauge, it may be removed and returned to the office.

522. The gauge should be adjusted so that, at approximately mean tide level, the recording pencil will be near the center of the paper, and the float pulley and the counterpoise pulley about half filled with wire or cord. The datum-line pencil should be set near the center of the paper. The counterpoise weight should be so arranged that it may move freely between the limits of extreme high and extreme low water. In order to secure a sufficient range of motion for the counterpoise weight and also for the tension weight, it is generally desirable to carry each supporting cord over a pulley in the ceiling of the tide house. After these adjustments have been made, there will be no occasion for the tide observer to change them unless the float wire breaks or other accidents occur. When this happens the observer should enter a clear explanation of the fact on the tide roll. Such changes are very undesirable except when actually necessary, and the observer should be so informed.

523. The position of the float in the well should be examined to ascertain if it is free to move within the limits of the tide without scraping on the sides of the float box and, if necessary, the gauge should be moved to bring the float into a more nearly central position. If there is any evidence of the float box being clogged with mud, barnacles, or other matter, the opening should be cleared.

524. The tide staff should be examined to see if it is in good condition. If there is more than one staff at the station, make a note of which one the tide observer is accustomed to using. If the staff is a portable one, it should be placed in position for use and a note made of the reading on the staff that is level with the support on the fixed guide. It is important that the staff be actually placed in position, as it may happen that some obstruction in the guide will prevent the staff from being lowered to the position indicated by the shoulder or angles attached to the staff. If there appears to have been a change in the position of the staff, ascertain, if possible, from the tide observer or other source, the time when such change took place, as this information is very important in the interpretation of our records. The fixed guide for the portable tide staff should be examined to see that it is in good condition.

525. As many bench marks as practicable should be connected with the tide staff by spirit levels. If there is more than one staff at the station, all should be connected with the bench marks by levels. If a portable staff is used, it should be placed in position to determine its true relation to its support. At permanent tide stations not less than five permanent bench marks should be maintained. One of these should be as near the tide staff as practicable to afford a ready means of checking the elevation of the staff. It is also desirable that a temporary mark be placed directly alongside of the staff, which would enable the staff to be replaced without the use of a level should it be removed from any cause. The present condition of the bench marks should be noted, deficiencies in the descriptions supplied, and new marks established when necessary.

526. A separate report should be made for each tide station inspected. This report should include recommendations concerning repairs to the station, with an estimate of the cost whenever it is possible to do so.

527. Estimates for the inspection of tide stations should be submitted as soon as possible after the receipt of instructions. A small amount should be included to cover small incidental repairs which may be required, and these repairs should be made if possible while the inspecting officer is at the station. At remote stations, when repairs are urgently required which exceed in amount the sum allotted for repairs, and when it is desirable that these repairs be made while the inspecting officer is at the station, to avoid the expense incidental to sending some one else to superintend the work, telegraphic approval of the estimates for this work should be requested from this office in case circumstances will not permit the delay of obtaining authority by mail.

CURRENTS.

528. General remarks.—Currents are of two types, tidal and nontidal. Tidal currents are due to the tides and nontidal currents are due to winds, land-water discharge, differences of density, and other such causes. What chiefly distinguishes these two kinds of currents from each other is the fact that tidal currents are periodic while nontidal currents are not periodic.

In passages from one body of water to another, in narrow entrances to bays and in constricted parts of rivers, currents frequently attain considerable velocity. In such places, as well as off capes and wherever strong currents or countercurrents are believed to exist, current observations are desired.

529. Location of stations.—The location of each current station should be determined by angles between three or more objects plotted on charts or hydrographic sheets, and angles should be taken during both flood and ebb. When observing currents offshore out of sight of land the position of the station should be given by latitude and longitude with as much precision as the means at hand will permit. In all cases soundings should be frequently made, as these aid in identifying the station.

530. Length of observations.—Continuous observations covering a period of at least 2 tidal days or 50 hours are desirable. In every case the aim should be to secure at least 25 hours of continuous observations. In places where daylight observations only are feasible two sets of observations should be made, each covering a period of 2 days and separated by an interval of 1 or 2 weeks.

531. Frequency of observations.—Observations should be made as frequently as practicable and preferably at definite intervals of time, as quarter-hourly, half-hourly, or hourly. Near the time of strength of current it is of advantage to make observations every 10 minutes or even oftener.

532. Measuring current velocity.—For measuring the velocity of the current either a log line and current pole or a current meter is generally used. Where dangerously swift currents prevent the anchoring of a boat the velocity of the current may be determined by noting the time taken by a free float to pass a measured distance between two ranges. Observations made by following up a free float with a boat are, as a rule, of little use, since the station is continually changing.

533. Log line.—The log line should have a sufficient length of stray line to permit the current pole to attain a position beyond the effect of the disturbed waters in the wake of the vessel. One hundred feet of stray line is generally satisfactory. Part of this stray line should be much heavier and stronger than the log line, because it is used to lift the heavy-current pole out of water; A one-half inch rope is often used for the first 25 feet of stray line, to which is attached a log line three-sixteenths of an inch in diameter.

When the log line has been thoroughly wet, it is marked by tags or otherwise into principal divisions representing knots, or nautical miles per hour, and secondary divisions for the tenths of a knot. The length of these divisions will vary according to the period of time that the float is allowed to run, and may be conveniently found from the following equation:

$$K = T \times \frac{6080}{3600} = 1.6889 \times T.$$

Where K=the length in feet of the graduation representing one knot,

T=number of seconds during which the pole runs out.

The log line should preferably be marked for an observation interval of 60 seconds for use with a stop watch into principal divisions representing knots, each 100 feet 4 inches in length. Tenths of knots will then be shown by lengths of 10.13 feet, which should be marked in a suitable manner.

Occasionally, as with very strong or very weak currents, it is more convenient to use a shorter or a longer time interval. In that case the following formula will give the velocity. If $L=$ length of line in feet run out during an interval of T seconds, the velocity in knots is

$$V=\frac{L}{T}\times\frac{3600}{6080}=0.592\frac{L}{T}.$$

The log line should be measured occasionally, when wet, and any error in length noted in the record book. If the line breaks it should be carefully repaired and a note to that effect entered into the record book.

Velocities expressed in feet per second may be converted into knots, or nautical miles per hour, by the following equation:

$$V=F\times\frac{3600}{6080}=0.5921\times F.$$

Where $F=$the velocity in feet per second.

534. Current pole.—This is generally a pole or other cylindrical body 2 or more inches in diameter and from 6 to 20 or more feet in length, according to the depth of current to be measured. The pole may be made of wood or of sheet metal, and in either case is to be weighted at one end so as to float vertically with about 1 foot out of water. The weight of lead or other material required may be estimated from the following equation:

$$W=64\,r^2\pi\,(L-1)-w, \text{ in pounds.}$$

Where 64=pounds in 1 cu. ft. of sea water.

r=radius of pole, in feet.

π=3.1416.

L=length of pole, in feet, which is diminished by 1 because 1 foot is out of water.

w=weight of pole, in pounds.

When a wooden pole is used, while most of the lead may be a solid casting, some of it should be in the form of sheet lead wrapped around the lower part of the pole and secured by a nail; for the pole will absorb water after it has been in use some time, as will be indicated by a gradual decrease in the length of pole above water, and then by unwrapping a portion of the sheet lead, and cutting it off, the former line of flotation may be restored.

535. Observing with log line and pole.—The reel carrying the log line should be mounted upon a stand or other support. About five minutes before the time for observations lower the pole into the water and allow it to run out the length of the stray line. On the exact time for observing, release the line and press the stem of the stop watch. If necessary assist the line by hand, but do not pay out faster than the pole can take it away. When the stop watch has completed one minute, stop the reel and at the same instant press down the stem of the stop watch. Then count the number of knots and tenths that have run off the log line.

536. Direction of current.—For determining the direction of the current one of the two following methods may be used, either alone or preferably together: (*a*) Measuring with a sextant the angles between the pole and fixed objects on the shore; (*b*) noting the angle the current line makes with a graduated circle called a pelorus.

537. Use of the sextant.—When measuring the angle between the float and some fixed object on shore, the angle should be marked "R" if the float is to the right of the object of reference and "L" if it is to the left. This rule should be invariably followed. In using fixed objects on shore for azimuth, it is of advantage to choose objects rather remote and few in number.

538. Use of the pelorus.—A simple form of the pelorus consists of a circular brass disk about 8 inches in diameter graduated every 10 degrees, from 0° to 360°, clockwise. It is fastened to the boat so that the 0° and 180° marks fix a fore-and-after line parallel to the keel of the ship with the 0° forward.

After the current pole has run out the observation interval for determining the velocity of the current, the log line is stretched across the center of the pelorus and the angle made by the line to the nearest 5 degrees is recorded. The heading of the ship by the ship's compass at the same time is noted, which, with the pelorus reading, gives the direction of the current.

When the log line is stretched across the pelorus, two angles, differing from each other by 180°, are determined. In order that no confusion may arise, that arc is read which is farthest away from the pole. This will be the forward semicircle of the pelorus, unless the pole happens to be drifting forward of the beam, when the after semicircle is read.

539. Current meters.—All meters whose measurements depend upon the impact of water against a rotating wheel or propeller should be rated at frequent intervals. This may be done at the Bureau of Standards or may be accomplished by attaching the meter, well submerged, to the bow of the boat and drawing it at uniform rates through still water. The boat is driven at various speeds over a measured course and the number of revolutions of the meter per second is noted. A rating curve may then be drawn by plotting on cross-section paper the speed in feet per second as abscissas and the revolutions per second as ordinates. With all meters sent out from the office rating tables will be furnished.

540. Use of current meters.—In smooth water measurements with a meter may be successfully made within a foot of the surface. If waves exist, the measurements should be taken at such a depth that the flow appears to be practically steady.

If the velocity is to be determined at a depth of only a few feet below the surface, the meter may be attached to a pole; if at a considerable depth, it must be suspended by a strong slender cord or cable, and to the lower extremity of the meter sufficient weight should be attached to keep the meter in a nearly horizontal position.

When using a meter which measures velocity only, a current pole should be used for determining the direction of the current. Care should be taken to make the average depth of the resisting surface of the pole about equal to the depth at which the meter is suspended. Another method for ascertaining the direction of the current at the depth of the meter is to suspend a heavy body of suitable specific gravity to that depth, the position taken by the suspending wire indicating the direction of the stream.

Photostat copies of instructions covering the care of current meters may be secured from the office.

541. Kind of time used.—Since it is desired to determine not only the velocity and direction of the current, but also the time of maximum and minimum velocities, correct time is essential. The record should clearly state the kind of time used, whether standard time, mean local time, or apparent local time. If standard time is used, as is generally the case in coastal waters, the standard meridian should be specified.

542. Checking the time used.—The time used should be checked frequently; of the observer can readily consult a reliable clock, a time comparison can be made each day. A note in the column of remarks of the record book should state the observer's time when the comparison was made, the correct time, and whether or not the observer's time was corrected.

If the time is obtained from a noon mark or from sextant observations upon the sun it can be reduced to local mean time by applying the equation of time. Local mean time is reduced to standard time by adding a number of minutes equal to four times the number of degrees which the standard meridian is to the eastward of the local meridian.

In localities having a water horizon, the time of sunrise or sunset (using the upper limb of the sun) should occasionally be noted in the column of remarks.

543. Record of observations.—The form of record book now available for current observations is numbered 270, and all items called for should be filled in as completely as possible. Particular attention is directed to the items at the beginning of the record calling for the deviation table and information regarding the kind of time used, location of stations, and description of current apparatus used.

544. Reduction of observations.—The method used in reducing any given series of current observation, other than by the harmonic analysis, depends on the type of current under discussion. In the inland waters and close inshore along the coast, both on the Atlantic and the Pacific, the currents are of the rectilinear or reversing type. Offshore, on both coasts, the currents are of the rotary type. But whereas on the Atlantic coast the currents show practically no diurnal inequality, the Pacific coast currents, both of the rectilinear and rotary types, show considerable diurnal inequality. The method of reduction of each of these types of currents is outlined below.

545. Atlantic coast rectilinear currents.—Where the current has a distinct period of flood followed by a slack and then by a period of ebb current, the observations should be plotted on cross-section paper, taking the hours of the day as abscissas. Two curves will then result for each day, one the curve of velocities and the other the curve of directions (azimuths). From the smoothed curves there is then entered on Form 451 the times of slack and strength of flood and ebb, together with the velocities and directions pertaining to them. On the same form, under the heading "Moon's Transit or H. W., L. W.," there is entered the times of tide, predicted or observed, at some near-by station. If no satisfactory tides be available, the times of the moon's upper and lower transit may be used. The tidal-current or luni-current interval for each element of the current is then entered in the proper column, and a mean value from the whole series of observations derived.

546. Atlantic coast rotary currents.—Offshore the currents do not flow in one general direction during the flood and in an opposite direction during the ebb. Instead, the direction of the current changes continually at an average rate of about 30° per hour. In reducing a series of observations of this type of current, the observations are plotted on cross-section paper, as indicated for the rectilinear currents. In addition, the times of high and low water, predicted or observed, at some near-by place, are indicated on the cross-section paper. The hourly velocities and directions of the current from three hours before to three hours after high and low water, are then entered into Form 507, and the mean for all the hourly values found. Where no suitable tide is available, the hourly values of the velocity and direction of the current with reference to the moon's upper and lower transit from six hours before transit to six hours after transit should be used.

547. Pacific coast rectilinear currents.—Because of the considerable diurnal inequality found in the Pacific coast currents, some modification of the procedure outlined for the reduction of the corresponding current on the Atlantic coast is necessary. The observations are plotted on cross-section paper and the times of slack and ebb referred to some suitable tide. But it will be necessary to distinguish the two high waters and the two low waters. One set of the current elements will be referred to higher high water another to lower low water, the third to lower high water, and the fourth to higher low water. The tidal-current intervals and the velocities of the various currents with reference to the various tides must be kept distinct, and the means of each group found separately.

548. Pacific coast rotary currents.—Offshore the currents on the Pacific coast become rotary. In the reduction of this type of current the method followed is that outlined for the corresponding current on the Atlantic coast, except that the hourly values of the velocity and direction of the current are referred to both higher high and lower high waters and to lower low and higher low waters from three hours before time of tide to three hours after.

549. Weak rotary currents.—Where the velocities of rotary currents do not exceed half a knot, the effect of wind or river discharge will frequently completely mask the tidal currents. In such cases, the tabulated hourly values of the current, with reference to the time of tide, must be resolved into north-and-south and east-and-west directions, before summing for the mean. This may easily be done by means of a traverse table, but is best left for computation at the office.

550. Winds.—In the open sea the effect of a continued wind is to cause a nontidal current, setting somewhat to the right of the wind in the Northern Hemisphere and to the left in the Southern Hemisphere. Near the coast, local conditions modify the above rule. It is therefore essential that the direction and velocity of the wind be recorded every hour in the record of current observations, so that the local effect of the wind on the curent may be ascertained.

MAGNETIC OBSERVATIONS.

551. General remarks.—For detailed information in regard to instruments and methods of observing reference should be made to "Directions for Magnetic Measurements" published in 1911. New edition in preparation (1920).

To secure the best results, particular attention should be paid to the following points:

Be sure that all articles of iron and steel are removed to a safe distance before beginning magnetic observations. This applies particularly to articles about the person of the observer, such as knives, keys, belt and suspender buckles, eyeglasses, watch, steel in brim of stiff hat, etc.

Be sure that the instrument is level and the levels in adjustment before beginning observations, especially in latitude and azimuth observations.

Be careful to keep the magnets and dip needles dry and clean, especially the pivots of the dip needles.

Handle the chronometer with care at all times.

552. Equipment.—Observers engaged exclusively in magnetic work are supplied with a complete magnetic outfit, consisting of theodolite-magnetometer, dip circle, half-second pocket chronometer, and nonmagnetic observing tent. When magnetic observations are to be made only as opportunity offers in connection with other branches of the field work of the Survey, the equipment is often less complete, either a dip circle with special needles for total intensity observations and a compass attachment for determination of the magnetic declination, or simply a compass declinometer for declination alone. In such cases the true meridian is usually known from triangulation, or else the instrumental equipment includes a theodolite and timepiece with which the necessary astronomic observations can be made.

553. General survey parties working in remote regions, such as Alaska or the Philippines, will in general be furnished with a compass declinometer for measuring the magnetic declination. In connection with triangulation where the true azimuths are known, the magnetic declination can readily be obtained, and this should be done at intervals of about 20 miles along the progress of the triangulation, or at shorter intervals where there is indication of local disturbance. In the regions mentioned this should be considered a regular part of the work of general survey parties. The making of complete magnetic observations, including dip and intensity, will be required only when there are special instructions. The declinometer may be set up directly at the triangulation station; or if this is impracticable because of the presence of iron, height of tripod, or other cause, a magnetic station may be established by alignment between the triangulation station and the mark.

554. Selection of stations.—The conditions to be satisfied in choosing a magnetic station are freedom from present and probable future local disturbance, combined with convenience of access. A station on suitably situated public property, or property belonging to an educational institution, is to be preferred, as it is less likely to be disturbed. Proximity of electric railways, masses of iron or steel, gas or water pipes, buildings of stone or brick, should be avoided. A quarter of a mile from the first, 500 feet from the second, 200 feet from the third and fourth may be considered safe distances. The station should be at least 50 feet from any kind of building. If any doubt arises in the selection of a station on account of the possible existence of local disturbances, two intervisible points a hundred yards or more apart should be selected and the magnetic bearing of the line joining them observed at both. A lack of agreement between the two results is evidence of local disturbance.

555. Description of station.—Each point occupied should be described with sufficient detail to render possible its recovery. The description should begin with the general location—enough to indicate the park or field in which the station is situated—this to be followed by measured distances to fences or other near-by fixed objects, and the manner in which the station is marked. It should include the approximate distance and direction from the center of town or from some point which can be definitely located on a map, so that a rough check on the latitude and longitude may be made. In case a new station is established in a locality where observations have been made before, the distance and direction from the old station should be given if possible. It is desirable to give a rough sketch showing the relation of the station to surrounding objects, indicating on it the direction of north (which should always be toward the top of the sketch) and the direction of the marks of which the true bearings are determined.

556. Azimuth marks.—These marks should be well-defined objects as nearly in the horizon as practicable and likely to be available for future use. Where an observing tent is used, it is preferable to have the mark to be used in azimuth and declination observations in a southerly direction, so that it may be sighted upon through the opening in the south side of the observing tent. It should be one-quarter of a mile or more from the station if possible, so that a small error in recovering the station or a small change in the position of the marking stone would not materially affect the azimuth of the mark. As an angle of 1′ subtends an arc of approximately 1 inch at a distance of 300 feet, the effect at any given distance may be readily computed.

557. Marking of stations.—Every station intended for future use should be marked in as permanent a manner as conditions will warrant, to assist in its subsequent recovery, using the bronze magnetic station marking disk whenever possible. To avoid being disturbed the station mark should project little, if any, above the surface of the ground and should extend 2 feet or more into the ground.

558. Meridian lines.—When a meridian line is to be established the magnetic station should be selected so as to form one end of the line and the distance to and location of the other end should be given in the description. The line should be not less than 300 feet long, and extra precaution should be taken to secure the marking stones against future disturbance. The azimuth observations must be made with special care and the computations revised before the second stone is set.

559. Repeat stations.—Where observations are to be made at an old station for the purpose of determining the secular change, especial effort should be made to occupy the precise point at which the earlier observations were made. Any change in the immediate surroundings should be noted in the description of station. If local conditions have changed to such an extent that a reoccupation of the old station is clearly undesirable, then a new station must be established. There may be cases, however, in which it will be best to reoccupy the old station and also establish a new one, as for example when the old station, while not satisfying the requirements of future availability, may still suffice to determine the secular change since the former observations. When, owing to change in the immediate surroundings or defect of the original description, it is impossible to locate the exact spot from the measured distances, the desired result may sometimes be accomplished with the aid of the bearings of prominent objects. Having three well-defined objects which were connected by angular measures at the time of the former occupation, successive trials with the theodolite will serve to locate the spot at which those angular measures are reproduced.

560. Care of instruments.—Care should be taken to keep the instrument in good adjustment and free from dust. The magnets should be touched with the hands as little as possible and should always be wiped with clean chamois or soft tissue paper at the close of observations. They should not be allowed to touch each other nor come in contact with iron or steel objects and should in the Northern Hemisphere be kept in the box with north end down. The dipping needles should be wiped with tissue paper both before and after observations and the pivots and agate edges cleaned with pith. In reversing polarity the bar magnets should be drawn smoothly from center to ends of needle, as nearly parallel to the axis of the needle as possible. The bar magnets should be wiped after using to prevent rusting and should not be allowed to touch except at ends of opposite polarity.

561. Order of observations.—When a complete instrumental outfit is supplied the observations at a station comprise morning and afternoon azimuth, latitude at noon, one set of dip with each of two needles, two sets of declination, deflections, and oscillations, and angles between prominent objects. It is desirable that the azimuth observations should be made at nearly equal times not less than two hours before and after apparent noon. Latitude observations should begin about 10 minutes before maximum altitude of the sun (apparent noon) and continue until about 10 minutes after. They need not be made when a reliable latitude is available. As the declination and horizontal intensity are usually changing more rapidly in the morning than in the afternoon, it is preferable to make the magnetometer observations in the afternoon. They should be made in the following order: Declination, oscillations, deflections, deflections, oscillations, declination. At stations far removed from a magnetic observatory, particularly where the diurnal variation is large, as in western Alaska, it is desirable to make additional declination observations at other times of the day, preferably at about the times of maximum and minimum, as a control on the correction of the results for diurnal variation. The mean of the maximum and minimum values of declination is usually a close approximation of the mean value for the day.

562. Thermometer.—The same thermometer must be used throughout a set of intensity observations and placed as near the *long* magnet as possible. Before beginning observations the thermometer should be examined to see that the mercury column is not broken and that none of the mercury is in the upper recess. A broken column can usually be joined by holding the thermometer in the hand and striking the wrist sharply against the knee or by attaching it securely to a string and swinging it rapidly in a circle.

563. **Discrepancy limits.**—Before leaving the station the computation should be carried far enough to show that there is nothing radically wrong with the observations. Thus, in good work, the two consecutive sets of azimuth should agree within one minute, and the morning and afternoon sets within two minutes. A greater difference is usually due to lack of adjustment or level of the theodolite or to a mistake in pointing on a wrong limb of the sun. The effect of changes in level of theodolite should be eliminated by the method of observing described under "Elevations by vertical angles" (p. 60). In case the difference between morning and afternoon azimuth amounts to more than five minutes, the observations should be repeated. The two sets of declination should not differ more than two or three minutes when allowance is made for diurnal variation. The average time of 70 oscillations, or whatever number is used, should not differ more than a half second in the two sets, and in the deflections the two values of log sin u should not differ more than 0.00100 for either distance. when allowance is made for the difference of temperature of the two sets. When the dip results for the two needles differ by more than five minutes *in excess of the normal difference*, the observations should be repeated. Thus, if previous observations show that needle No. 1 gives on the average a dip three minutes greater than needle No. 2, the observations should be repeated when No. 1 gives a result more than eight minutes greater or two minutes less than No. 2.

564. **The record** should be kept with a hard pencil (or fountain pen) and entered at once on the proper form (not recorded on blank paper and afterwards copied on the form). All computations should be made in ink. The different sheets should be punched and fastened together in the covers provided (Form 367), arranged in the following order: (1) Description of station, (2) angles connecting the azimuth mark with other prominent objects and chronometer correction on standard time (Form 441), (3) latitude (Form 267), (4) azimuth observations (Form 266), (5) azimuth computations (Form 269), (6) declination (Form 37), (7) dip (Form 42), (8) oscillations (Form 41), (9) deflections (Form 39).

565. Abstract.—Before the record is sent to the office the computations should be completed and a copy made (on Form 442) of the results and also such quantities as would be needed to replace the computations in case the record is lost. No duplicate of the records is to be made. All records must be turned in promptly, especially at the end of the *calendar* year, in order that the results may be included in the annual publication of results, which covers the calendar year.

566. Observations with compass declinometer or with the compass attachment of a dip circle are recorded on Form 38a. Standardization observations should be made at the beginning and end of the season at some place where the declination is known from magnetometer observations.

567. Total intensity.—The total intensity may be determined with a dip circle by Lloyd's method (Form 389) when suitable standardization observations have been made at a station where the dip and intensity are known. As the determination of total intensity by this method is relative, it is necessary to guard, as far as possible, against any change in the magnetism of the two needles and to use the same weight in the field as during the standardization observations. Their polarities *must never be reversed*, therefore, and they must not be allowed in close proximity to the bar magnets when these are being used to reverse the polarity of the regular dip needles. Standardization observations should be made at the beginning and end of the season's work to determine the intensity constant.

568. Observations on board ship.—On shipboard declination is determined with the standard compass, dip and intensity with a Lloyd-Creak dip circle mounted on a suitable gimbal stand. The successful determination of declination, dip, and intensity at sea requires, first, that observations should be made with the Lloyd-Creak dip circle at a base station on shore at the beginning and end of the cruise to determine the intensity constant for the particular weight used at sea and the correction to the dip as derived from the deflection observations; and, second, that the ship be swung at the beginning and end of the cruise (and if possible in the highest and lowest latitude reached) at a place near shore where the declination, dip, and intensity are known from shore observations, in order to determine the deviations of the standard compass and the deviations of dip and intensity at the dip-circle position.

569. The accuracy of the results depends principally upon the successful determination and elimination of the effect of the ship's magnetism. For this reason observations are usually made on 8 or 24 (preferably 24) equidistant headings, steaming in a circle forward and back (with port and starboard helms), holding the ship long enough on each heading to secure good results, and taking usually not over two hours for both swings. Since a complete determination of dip and total intensity on each of 24 headings of the forward and back swings would consume too much time, the practice has been adopted of observing deflections alone while swinging ship in one direction and loaded dip alone while swinging in the opposite direction. Besides the total intensity derived from the combination of these observations, a value of dip on each heading results from the deflection observations, since the suspended needle is deflected by approximately equal amounts in opposite directions from its normal position. On each heading, observations with dip circle are made in only one position of circle and needle, as follows:

0° to 75°, Circle East, Needle Face East; 90° to 165°, Circle West, Needle Face West; 180° to 255°, Circle West, Needle Face East; 270° to 345°, Circle East, Needle Face West. In this way the observations with the dip circle can be made in about the same time as required for the compass observations, which are being carried on at the same time.

570. When instructed to make magnetic observations at sea the ship should be swung at least once a day if possible. When circumstances would not permit a complete swing, results have sometimes been obtained from observations on and near the course; e. g., on course one or two points to starboard, one or two points to port, and back on course. This requires a knowledge of the deviations on those particular headings, which may be derived from the complete swings preceding and following. (See Appendix 3, Report for 1904, pp. 192 to 197, and Forms 354, 355, 356, compass, and 390, 391, 392, dip circle.)

DESCRIPTIVE REPORTS.

571. Descriptive reports must be submitted to cover all hydrographic and topographic surveys. It is preferable to have a separate report for each sheet, but in some cases it may be more convenient to have a single report cover the consecutive sheets of a season's work in one locality where much of the information is common to the different sheets.

(*a*) The descriptive report should not be in the form of a letter, it should not be a journal of the work, and it need not contain anything about the movements of the party; it should be entirely distinct from the season's report and should give the date of the instructions under which the work was done.

(*b*) It should be headed "Descriptive report to accompany sheet (insert number and title of sheet or sheets)." Writing must not be nearer than 1 inch to left edge of paper.

(*c*) The descriptive report is for the purpose of supplementing original sheets, either hydrographic or topographic, by information not readily shown thereon, and which will be useful in the interpretation of the sheets, in the compilation of sailing directions, and in chart construction. Preference should, however, be given to showing information on original sheets themselves when practicable to do so.

(*d*) The descriptive report should be written concisely, omitting all unimportant detail, and should be arranged in a systematic manner with each class of information in separate paragraphs under suitable underscored headings.

(*e*) *Bearings* given in connection with sailing directions and hydrographic information should in general be expressed as from seaward and in degrees, and it must be clearly stated whether the bearings are true or magnetic.

572. Subject heads.—No general rules can be laid down, but the following points will be suggestive in preparing descriptive reports so far as applicable to any particular region and according to the character of the survey made. The amount of detail to be given requires much judgment; overminute details tend to obscure the most useful facts. Obviously certain classes of informaton may be useful as to a new country previously unsurveyed which may not be necessary to give in connection with the resurvey of a well-known coast.

(*a*) *General description* of the coast, following the geographic sequence of the published Coast Pilots or Sailing Directions, and including the aspect or appearance of the coast on making the land; describing prominent objects, as, on a bold coast, the headlands, peaks, etc., with their form, color, and height; or, on a flat coast, the spires, beacons, etc. Especially describe the first landfall and objects useful as guides to navigation. (See pars. 194 to 196.)

(*b*) *Outlying dangers and islands*, the limits of tide rips and breakers, and their relation to wind and tide.

(*c*) *Currents, tidal or not tidal.*—General conclusions from observation or other information. How long does flood run after high water and ebb after low water? Does current set fair with channel?

(*d*) *Landmarks.*—Description of all prominent landmarks likely to be useful to navigation or to future surveying operations should be submitted as directed in paragraphs 194 and 212. If mountains, state whether summits are often clouded. Give measured or estimated heights of mountains, hills, cliffs, islets, or rocks referred to. Describe ranges in use by pilots and means of identifying them.

(*e*) *Inshore dangers.*—Extent and nature, least depth over them; whether visible; if breaking, at what stage of tide; how much, if any, is bare at low water; marks or ranges for clearing them by day or night.

(*f*) *Bars and channels.*—Least depth, best time or place for crossing or entering, permanency of bars and of channels; breakers on bars and their extent and with what winds or tides they occur.

(*g*) *Anchorages*, with descriptions relative to their capacity, holding ground, amount of protection, and circumstances of weather under which tested.

(*h*) *Change of coast line or depths.*—Mention any reliable evidence as to recession or growth of shore line or change of depths. If a resurvey, note any important facts regarding changes observed. Give evidence, if any, of subsidence or emergence of shores.

(*i*) *Dangers reported* or shown on previous charts or surveys; if not found, or if more water found, give in each case detailed statement of effort made to find former shoal water, and any important evidence as to the reliability of the previous report.

(*j*) *Survey methods.*—Explain any unusual features of survey methods used; mention if any part of the work is incomplete or requires further examination, and the reason; also if any portion is less reliable; state the system of control of the work; mention any discrepancies and adjustments made.

(*k*) *New place names.*—When an original sheet contains new place names, i. e., place names which have not hitherto appeared on the charts, chiefs of parties will list them in the descriptive reports of the sheets affected under two heads: (1) Well-established local names; (2) names assigned by field officers. In other respects the instructions under the heading "Geographic names" will be followed. Reports should be supplemented with photographs which will illustrate the apparatus used or add to the knowledge of the locality. (See par. 592.)

PROGRESS SKETCHES.

573. A progress sketch faithfully representing the extent of the entire season's work should be prepared and forwarded at the end of each season. Each progress sketch must have a projection.

In order that the office progress charts may be kept closely corrected, a progress sketch on tracing vellum showing the hydrography and topography accomplished, shall be forwarded to the office at the end of each month. The information thereon will be transferred to the progress chart and the sketch returned to the chief of party for each succeeding month's work. If not otherwise designated, the scale of the progress sketch will correspond to that of the published chart showing the entire area outlined for the season's work.

(*a*) Progress sketches should be made on tracing vellum, using black ink only. They must not be of excessive dimensions, usually not over 18 by 24 inches. Scales of $\frac{1}{100000}$, $\frac{1}{200000}$, or $\frac{1}{400000}$ are recommended according to the extent and detail. The scale of the sketch must be stated in the title. They should be drawn sufficiently strong to be suitable for blue printing.

(*b*) In the Philippines progress sketches of general coast work should, if practicable, be on a scale of $\frac{1}{100000}$ (the scale of the Philippine coast charts); for harbor surveys a larger scale may be used if necessary to show the triangulation clearly. The stamped title form is to be used on such sketches, giving the following information: Class of work, island, locality, scale, dates, chief of party, vessel.

(*c*) The progress sketch should give the approximate limits of the topography by parallel ruled lines, not closely spaced, the approximate limits of the hydrography by widely spaced dots, and the triangulation as indicated below, including the various operations of a single party for one season on one sketch.

(*d*) Principal triangulation schemes should be in heavy lines, and base lines should be of double width. A line observed at both ends should be full throughout. A line observed at one end should be full at the observed end and broken at the other. Reconnoissance lines should be dotted if shown on the sketch with triangulation. When the sketch contains reconnoissance only, the lines should be full if they are to be observed at both ends. A line should be broken at the end from which it is not to be observed. Old stations recovered, including spires, stacks, etc., should appear thus: ⟁ New stations should appear thus: △

(e) All important points determined, including mountain peaks, should be shown as far as practicable. Lines to intersection stations should be drawn lighter than those of the main scheme. A confusion of lines may often be avoided by indicating with short lines radiating from intersection points, the stations from which they were observed. All lines, letters, figures, etc., shown on the sketch should be sufficiently bold to make a good blue print.

GEOGRAPHIC NAMES.

574. Distinct names of points, islands, shoals, rocks, towns, mountains, etc., are necessary to the intelligent use of charts and sailing directions, and the surveyor should ascertain the accepted or native names, and use such names in all possible cases. Attention should be called to all new names of geographic features; that is, names not previously used in the publications of the Survey, with a statement whether the name is in local use, and if not, what name is in use, with the reasons which prevented its adoption.

(a) The *origin* of each new name should be stated. Geographic features must not be given the names of living persons as the rules of the United States Geographic Board only permit the retention of such names in rare cases.

(b) All *new names* are submitted to the Geographic Board by the office before publication and the decisions and rules of the board in regard to names are to be followed in all cases. In the Philippines the decisions of the Philippines Committee on Geographic Names govern in the same manner.

(c) *Names already in use* on charts and maps and in the Coast Pilots should be verified; if well established and appropriate they should be adhered to, even though found to differ from the native or original name, especially if the feature is of more importance to navigation than it is to the inhabitants, and if the native name is an awkward or difficult one.

(d) *Dual names* for the same object lead to confusion and inconvenience, and special care should be taken to avoid giving a new name to an object already named, or changing a name already established. Where two names are in use it should be ascertained which is the more appropriate and the more acceptable to the people of the locality, and report should be made giving the authorities.

(e) For such objects as require them, and for which acknowledged names can not be found, names should be recommended, selecting as far as practicable designations that convey some idea of the form, character, productions, or traditions of the place, or some characteristic of its inhabitants; convenience of length of word and pronounciation should also be considered. Report should be made of names so recommended.

(*f*) In new applications of the terms "shoal," "bank," and "reef" to forms of secondary size and limited extent, but clearly separated from the surrounding bottom by a steeper slope, the following distinctions should be made, but these terms already in use should not be changed:

Shoal should be applied only to areas on which there is a depth of 6 fathoms or less.

Bank should be employed for areas of greater depth.

A *reef* is always rocky, and the term should not be used where there is more than 6 fathoms at low water.

(*g*) Where the native names ascertained have not an established written form, they should be spelled according to the system of the Geographic Board, as follows:

(*h*) The *true sound* of the word as locally pronounced is taken as the basis of the spelling.

(*i*) An approximation only to the sound is aimed at. An attempt to represent delicate inflections of sound and accent would often result in forms of words too complicated for use.

(*j*) The vowels are to be pronounced as in Italian and on the continent of Europe generally, and the consonants as in English.

a has the sound of *a* in father. Examples: Java, Banana, Somali, Bari.

e has the sound of *e* in men. Examples: Tel el Kebir, Medina, Peru.

i has the sound of *i* in ravine, or the sound of *ee* in beet. Examples: Fiji, Hindi.

o has the sound of *o* in mote.

u has the sound of *oo* in boot. Examples:: Umnak, Ung.

ai has the sound of *i* in ice. Example: Shanghai.

au has the sound of *ow* in how. Example: Fuchau.

ao is slightly different from above. Example: Nanao.

ei has the sound of the two Italian vowels, but is frequently slurred over, when it is scarcely distinguishable from from *ey* in the English they. Examples: Beirut, Beilul.

c is always soft and has nearly the sound of *s;* hard *c* is given by *k*. Example: Celebes.

ch is always soft, as in church. Example: Chingchin.

f as in English; *ph* should not be used for this sound. Thus, not Haiphong, but Haifong.

g is always hard (soft *g* is given by *j*). Example: Galápagos.

h is always pronounced when inserted.

j as in English; *dj* should never be used for this sound. Examples: Japan, Jinchuen.

k as in English. It should always be used for the hard *c*. Thus, not Corea, but Korea.

kh has the sound of the oriental guttural. Example: Khan.

gh is another guttural, as in the Turkish: Dagh, Ghazi.

ng has two slightly different sounds, as in finger, singer.

q should never be employed; *qu* is given by *kw*. Example: Kwangtung.

b, d, l, m, n, p, r, s, t, v, w, x, and *z* as in English.

y is always a consonant, as in yard and should not be used for the vowel *i*. Thus, not Mikindany, but Mikindani.

All vowels are shortened in sound by doubling the following consonant. Examples: Yarra, Tanna, Jidda, Bonni.

Doubling a vowel is only necessary where there is a distinct repetition of the single sound. Example: Nuulua.

Accents should not, generally, be used; but where there is a very decided emphatic syllable or stress which affects the sound of the word it should be marked by an acute accent. Examples: Tongatábu, Galápagos, Paláwan, Saráwak.

(*k*) In the Philippine Islands, in translating from Spanish into English nouns which are combined with geographic names, the following system should be followed, except in specific instances where a different usage has already been established:

River, *island*, *bay*, *point*, and *gulf* are to follow the proper name.

Mount, *port*, and *cape* are to precede the proper name.

Rio Grande is to be translated simply *river*, unless these words form the specific name of a stream.

ADDITIONAL INSTRUCTIONS.

575. Completion of field results.—It should be the aim of a chief of party to turn in field records, computations, and sheets in a completed condition, as far as circumstances may permit. All records and results must be transmitted as early as practicable, and in any event before the commencement of another season's work.

576. Records in general.—All records should be kept in a systematic manner on the standard forms as far as provided. They must be sufficiently distinct and clear to avoid all chance of misunderstanding, particularly numbers must be written plainly. Explanation must be given wherever necessary so that the record may be intelligible to one not familiar with the field work.

577. Original records should not be made on loose sheets of paper to be copied afterwards into the regular form of record book, but should in all cases be made at once in the book which is to be transmitted to the office, and must be consecutive and continuous in the order of time in which the observations are made.

578. Erasures should not be made in original records. Where an error is discovered, draw a line through it and write the corrected figures above or to one side.

579. Original records in pencil must not be inked. Pencils softer than No. 3 should not be used in making records. It is preferable, but not essential, to make original records in ink.

580. The duplication of records is usually to be avoided, except in cases where called for in the general or specific instructions. The requirements are specified under each head. The function of duplication is the insurance against loss in transmission, and this should be kept in view in deciding special cases.

581. Records or computations sent by mail are to be well wrapped and registered. When there is duplicate information (in whatever form) it should not be forwarded by the same mail as the original, and in general should not be kept in the possession of the observer any longer than necessary after the completion of the work.

582. **Computations in general.**—Computations should be kept up during the field work as far as practicable, and at least far enough to show that the observations are sufficient and the record complete.

583. Computations should be transmitted to the office promptly, as soon as reasonably complete. In no case should computations be held with the idea of making them perfect in the field, as the final revision of the computations is the function of the office.

584. All computations must be in a neat and orderly form, and complete, so as to be readily intelligible to others. Every important operation must be shown.

585. Standard forms for computations should be followed wherever practicable.

586. Every computation must show by whom made and by whom checked.

587. Proper titles should be written or pasted on each cahier of computations, giving all essential information, as kind of work, locality, date, observer's name, computer's name, etc. Printed labels are available to cover ordinary requirements.

588. No writing should be placed within 1 inch of the binding margin of the sheets.

589. Information affecting navigation, reports of dangers, and changes in aids to navigation.—(See pars. 374–402.)

590. Suggestions and recommendations of a definite character are invited as to survey methods or instruments, need of surveys or charts in any particular locality, economies in work, improvement or correction of charts or other publications, and concerning aids to navigation.

591. Maps, charts, and sketches (or copies of them) containing information as to geography, topography, or hydrography likely to be of value to the Survey should be obtained when practicable and forwarded to the office.

592. Photographs.—Photographs illustrative of the geographic features of new regions visited are desirable—more especially views from seaward of important features of the coast, harbor entrances, and prominent landmarks. Views illustrative of surveying operations, or of the people of the region, may also be of value when unusual. The following information should accompany every photograph: Subject, locality, position from which taken (an exact location for views of important coast features is desirable), date, and by whom taken.

593. All negatives worth preservation taken with supplies and outfits furnished by the Survey are to be transmitted to the office.

594. In the Tropics, owing to climatic conditions, plates and films should be especially cared for, used as fresh as practicable, and developed soon after exposure. If necessary, they should be forwarded for development.

595. Special effort should be made to protect plates and films from being fogged or light struck. Orthochromatic plates are recommended.

596. Care of instruments.—Proper care of instruments is important in all classes of surveying work. The officer using the instrument should personally see that it is kept in good order and not leave this to anyone else. Instruments in good condition and adjustment are essential to good work.

597. The arc of a sextant may be cleaned by wiping lightly with chamois skin or a soft rag dipped in weak ammonia. Never polish the arc with paper or cloth, as this is liable to deface the graduation.

598. Sounding wire, even when galvanized, is subject to rust if not well cared for. The reel should be wrapped around with oiled cloths and well covered from rain. When the sounding machine is idle for a short period the wire should be dried by running through cloths, and oiled, and this should be repeated once a month when the machine is not in use.

599. All surveying instruments should be cleaned from time to time. Surfaces that are liable to stick together when left in place for a long time should be moistened slightly with oil or tallow after cleansing and before assembling; this applies to the cells holding object glasses.

600. Particular care should be taken of invar and steel tapes, steel parts of drawing instruments, etc., as all steel instruments are subject to rapid deterioration, particularly on board ship or in a tropical climate. Invar and steel tapes should be cleaned and oiled after use, and the chief of party should make sure that they are carefully handled at all times; special care is required in reeling tapes.

601. A lens may be dusted with a camel's-hair brush, and when necessary may be cleaned by rubbing gently with soft tissue paper, first moistening the glass slightly by breathing on it. A lens should be examined occasionally to see that it is tight in its cell.

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