U. S. DEPARTMENT OF COMMERCE
CHARLES SAWYER, Secretary

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LEO OTIS COLBERT, Director

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MANUAL OF CURRENT OBSERVATIONS

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Foreword

This manual is issued for the purpose of presenting the general requirements of the United States Coast and Geodetic Survey in the observation and reduction of currents. It is one of a series of manuals covering the various operations of the Bureau. The subjects of currents and tides are closely related and the present volume is designed to serve as a companion to the *Manual of Tide Observations* which was issued as Special Publication No. 196.

Other publications pertaining to currents issued by this Bureau are the annual current tables containing predicted currents along the coasts of the United States, tidal current charts for certain localities and special publications containing observational data for various waterways.

The first (1938) edition of this manual was prepared by Paul Schureman, then Chief, Research Section, Division of Tides and Currents. This edition which consists largely of the original material revised to conform with the latest accepted procedures of the Coast and Geodetic Survey, was prepared by F. J. Haight, Chief, Section of Currents, under the direction of Capt. C. D. Meaney, Chief, Division of Tides and Currents.

Contents

Tables

Illustrations

Manual of Current Observations

General Explanation

1. For the purposes of this publication current may be considered as the horizontal movement of the water as distinguished from the vertical rise and fall of the tide. Current is measured by its velocity while the tide is measured by its height. Currents may be classified as *tidal* and *nontidal* but the actual current found in any locality is usually a resultant of both tidal and nontidal movements. Tidal currents are periodic and usually arise from astronomical causes. Nontidal currents are not periodic and are largely the results of meteorological conditions. Some currents may have their origin in meteorological conditions which have a rough periodicity, and so far as these currents are periodic they will be classified as tidal currents for the purpose of reduction.

2. Tidal currents are a part of the same general movement of the sea that is manifested in the tides by a vertical rise and fall. This movement may be partly of a *progressive-wave* type and partly of a *stationary-wave* type. A progressive wave is one whose crest advances along a waterway, the times of high and low waters becoming progressively later and later as the wave moves forward. A stationary wave is one that oscillates about an axis, the high water occurring simultaneously over the entire area on one side of the axis while it is low water on the other side.

3. The tidal currents have the same periods as the tides and are subject to similar variations arising from changes in astronomical conditions. Thus the tidal currents may be semidiurnal, diurnal, or mixed, according to the type of tide in the same general area. They tend to increase in velocity at the times of spring and perigean tides and to decrease at the times of neap and apogean tides and they show an increased diurnal inequality in velocity at the times of the tropic tides.

4. Tidal currents may be classified as *reversing* and *rotary*. Reversing currents are those which flow alternately in approximately opposite directions with a period of slack water at each reversal of direction. Currents of this type usually occur in rivers and straits where the direction of flow is more or less restricted to certain channels. Rotary currents are those which flow continually with the direction of flow changing through all points of the compass during the tidal period. Rotary currents are usually found offshore where the direction of flow is not restricted by any barriers.

5. Nontidal currents may be considered under two classes, *permanent* and *temporary*. Permanent currents are those which flow more or less continuously in one direction and include such well-known features of the oceanic circulation as Equatorial Current, Gulf Stream, Japan Current, etc., and also the current in a river due to the fresh water discharge. Temporary currents are those of a temporary character which are caused principally by changes in meteorological conditions. Currents created by the action of the wind form the most common example.

Reversing Tidal Currents

6. Reversing tidal currents alternate in direction of flow. When the movement is towards the shore or up a stream, the current is said to be *flooding* and when in the opposite direction, it is said to be *ebbing*. In a strait connecting two tidal bodies of water the application of the terms must be somewhat arbitrary and a special definition may be necessary to avoid ambiguity.

7. In the normal semidiurnal type of reversing current, the flow is approximately 6 hours in each direction with slack water occurring as the current changes direction. Beginning with slack water, the velocity of the current increases for about 3 hours to a maximum known as *strength of current*, then decreases for about 3 hours to the following slack. The current then reverses and begins running in the opposite direction with the velocity increasing to another maximum and then decreasing to zero, thus completing the semidiurnal tidal cycle in an average time of 12.42 hours. In the diurnal type of current a cycle covering 24.84 hours will include one complete flood period and one complete ebb period.

8. A reversing current may be graphically represented by a curve in which velocities are plotted as ordinates with times as the abscissas. By considering flood velocities as positive and ebb velocities as negative, the resulting graph will roughly approximate a cosine curve. The maximum and minimum points of the curve will usually represent the strengths of flood and ebb respectively, and the points where the curve crosses the line of zero velocity will indicate the times of slack water. Figures 1–8 are graphic representations of some different types of reversing currents.

9. In a true cosine curve referred to its own axis, it may be shown that the mean value of all positive ordinates within any cycle is equal to $2/\pi$ (or 0.637) times the maximum ordinate or amplitude of the curve. Numerically the mean of all negative ordinates within the cycle will be the same. Insofar as the current velocity curve

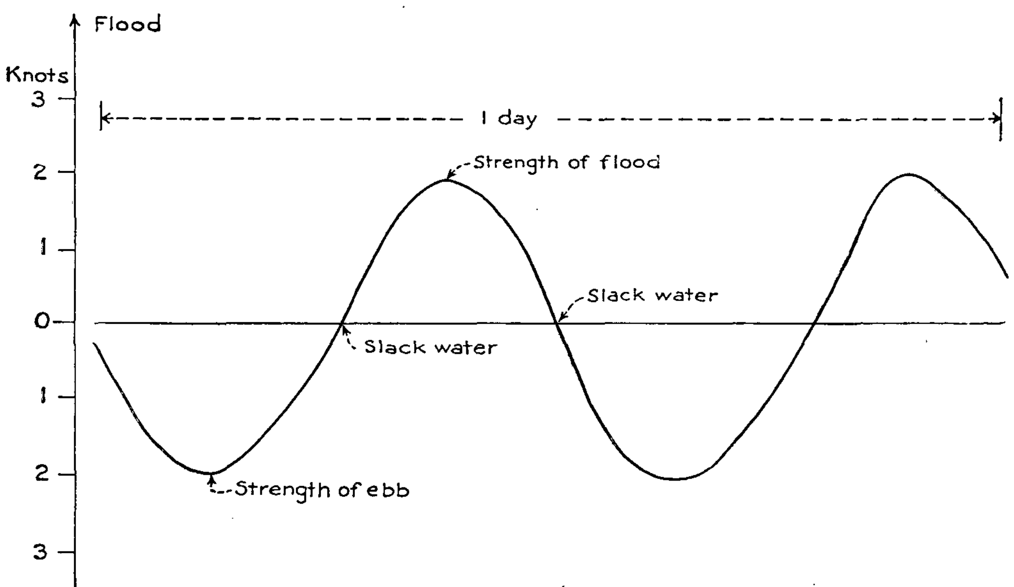

FIGURE 1.—Current in New York Harbor Entrance at time of equatorial tides. (A normal semidiurnal reversing current.)

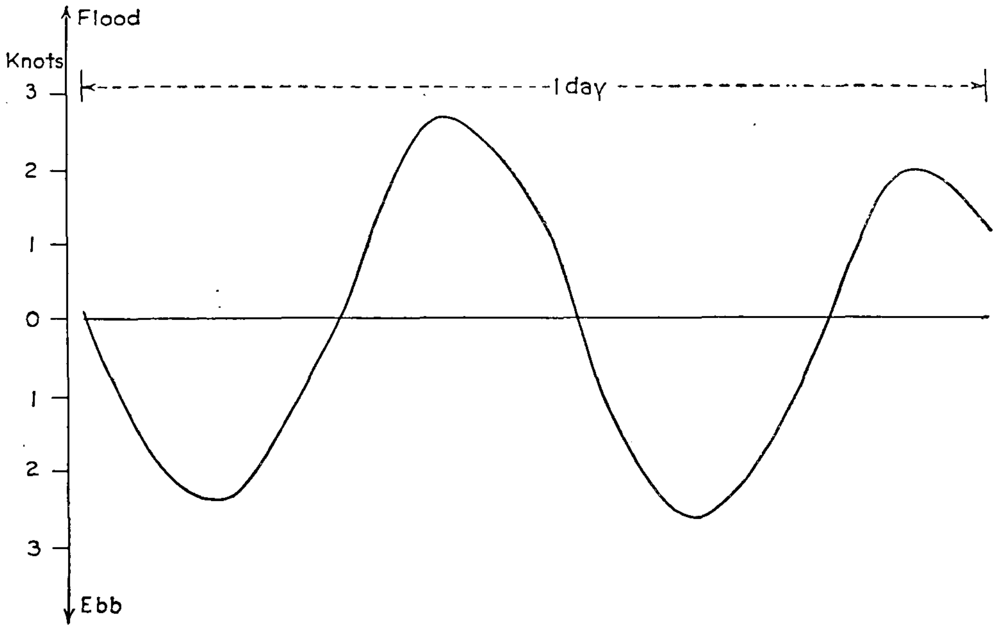

FIGURE 2.—Current in New York Harbor Entrance at time of tropic tides.

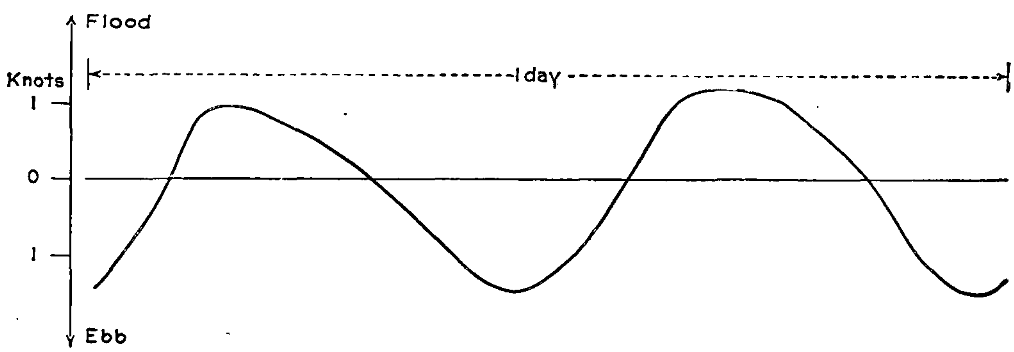

FIGURE 3.—Current in Portsmouth Harbor Entrance, N. H., showing effect of short-period constituents.

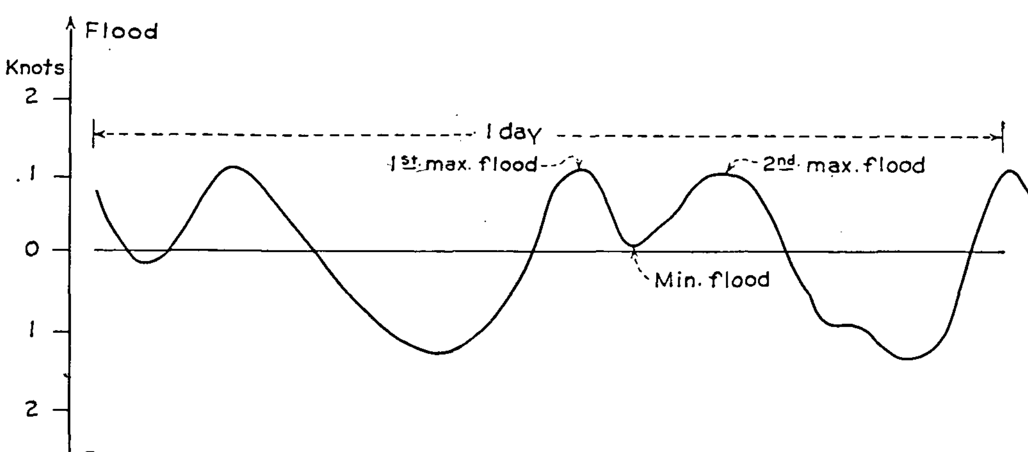

FIGURE 4.—Current in Seekonk River, R. I., showing effect of short-period constituents.

approximates a true cosine curve, the mean velocity of the current throughout a flood or ebb period may be taken as 0.637 times the velocity at the strength of current.

10. A reversing tidal current may be greatly modified when in combination with a nontidal current. The velocity of the current will be increased in the direction in which the nontidal current is moving by an amount equal to the magnitude of the latter, and will be decreased by an equal amount in the opposite direction. The duration of flow in the direction of the nontidal current will be increased and the duration

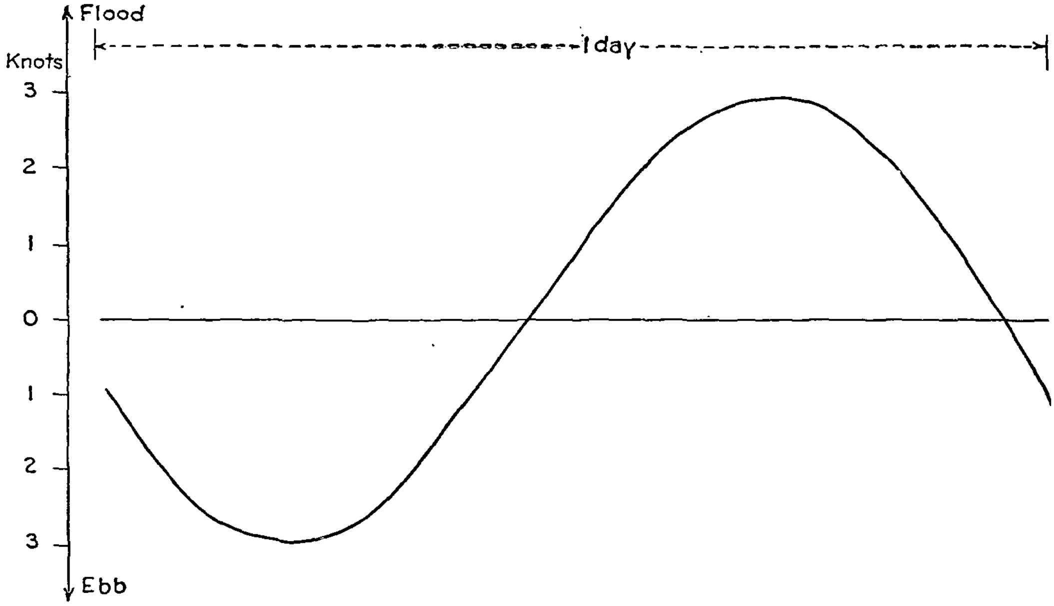

FIGURE 5.—*Diurnal current in Mobile Bay Entrance at time of tropic tides. (At time of equatorial tides tidal current is very weak and irregular.)*

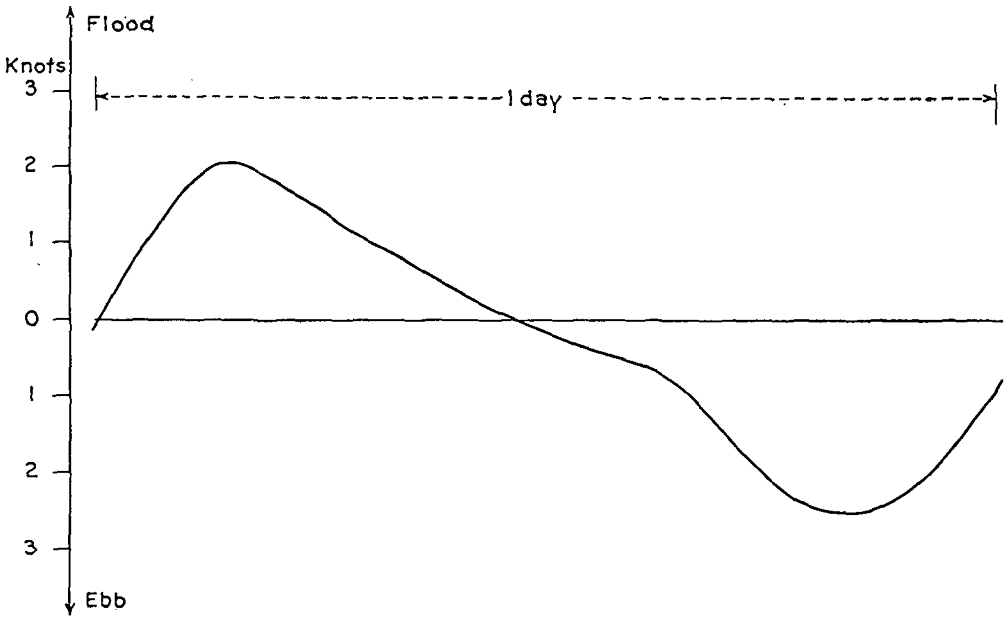

FIGURE 6.—Diurnal current in Galveston Bay Entrance at time of tropic tides. (At time of equatorial tides a normal semidiurnal current prevails.)

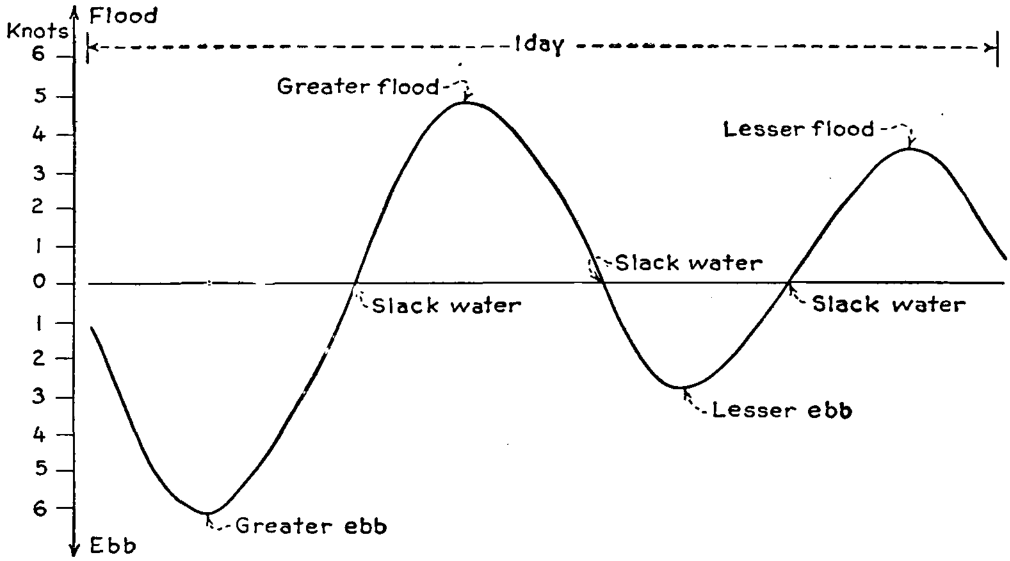

FIGURE 7.—Current in San Francisco Bay Entrance at time of tropic tides. (At time of equatorial tides a normal semidiurnal current prevails.)

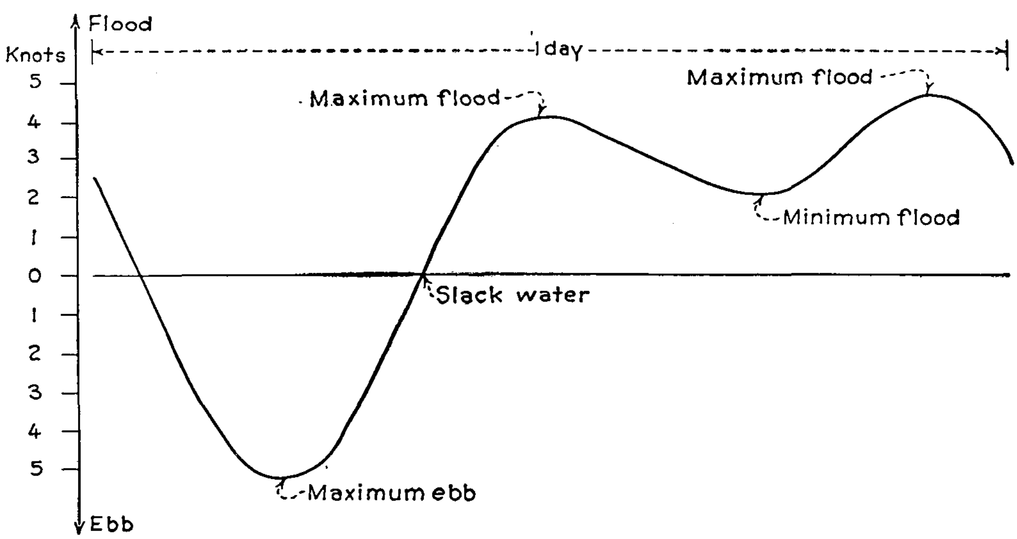

FIGURE 8.—Current in San Bernardino Strait, P. I., at time of tropic tides.

of flow in the opposite direction will be decreased by a corresponding amount. This will tend to advance the time of one slack and retard the time of the following slack. If the velocity of the nontidal current exceeds that of the tidal current, the resultant current will flow continuously in one direction without coming to a stop. In this case the velocity will vary from a maximum to a minimum and back to a maximum in each tidal cycle.

11. In a graphical representation of a combined tidal and nontidal current, the shape of the plotted curve is not affected but its position relative to the line of zero velocity is changed by an amount represented by the velocity of the nontidal current. In Figure 9 the curve represents a reversing tidal current when referred to *AB*

as the line of zero velocity. If we now assume a nontidal current of velocity n in an ebb or negative direction, its effect will be to diminish all the ordinates of the curve by the constant n. In the figure this will be equivalent to raising the line of zero velocity to a new position $A'B'$ at a distance n above the original datum. With the new datum it is evident that all ebb velocities have been increased and flood velocities have been diminished or changed into ebb velocities. The times of the strength of flood and strength of ebb have not been affected, but the slack before flood has been retarded and the slack before ebb advanced, thus diminishing the duration of the flood period and increasing the duration of the ebb period. If the assumed nontidal current has a velocity in the ebb direction that exceeds the velocity of the tidal current, the result will be represented in the graph by raising the line of zero velocity to a position $A''B''$, and the curve then shows a continuous flow in the ebb direction with minimum velocity occurring at the time of the strength of the tidal flood current and maximum velocity at time of strength of tidal ebb current.

12. **Relation of time of current to time of tide.**—The relation of current to tide depends upon whether the tidal movement is primarily of progressive or stationary wave type. In a progressive wave the times of flood strength and ebb strength occur

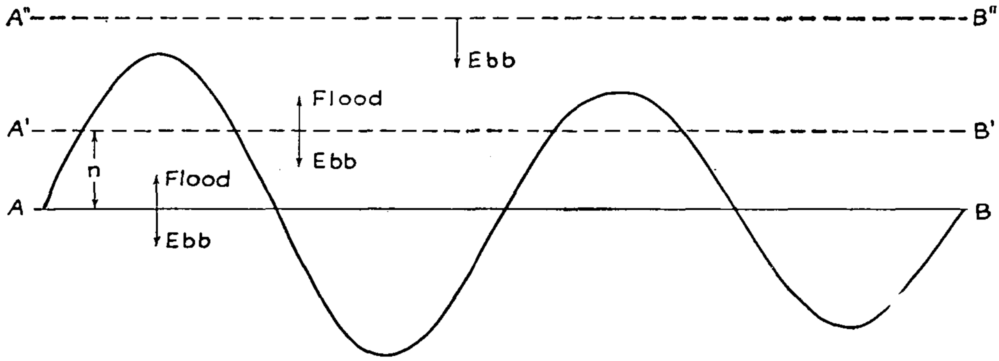

FIGURE 9.—Effect of nontidal current on reversing tidal current.

theoretically at the times of high and low water, respectively, with slack water midway between high and low water. In a stationary wave slacks come at the times of high and low water and the strength of current midway between high and low water. Tidal movements are, however, somewhat complicated and usually include both progressive and stationary waves, and the actual relation between the current phases and the tidal phases will vary in different localities. For any one locality, the relation usually approximates to a constant which may be determined from a comparison of observational data.

13. **Relation of velocity of current to range of tide.**—In the progressive type of tide wave the velocity of the current is expected to be the strongest where the range of tide is greatest, but in an area where the stationary wave predominates the strongest currents usually occur in the vicinity of the axis of oscillation where the range of tide is the least while the weakest currents are found in the vicinity of the loops of the wave where the rise and fall of the tide is greatest. In a combination of progressive and stationary wave movement the relation between current and tide becomes somewhat complicated.

14. For any one place, if it is assumed that the velocity of the tidal current is proportional to the speed at which the tide rises and falls, it may be shown that the

amplitudes of the constituents in an harmonic expression of the current velocity will be proportional to the corresponding amplitudes of the tidal constituents multiplied by their respective speeds. This becomes evident when the speed of the rise of tide is expressed by the first derivative of the formula for the height. Although our assumption may be only approximately correct, the result suggests that the relative importance of the diurnal constituents as compared with the semidiurnal constituents is only about one-half as great in the currents as in the tides. For the same reason the relative importance of the quarter-diurnal and sixth-diurnal constituents may be expected to be greater in the currents than in the tides.

15. **Hydraulic current.**—This name is applied to a reversing current in a strait when it results from a difference in the tidal head of water at the two ends of the passage. The hydraulic current may be considered the indirect result of tidal action rather than a direct part of the tide wave. A difference in head may result either from a difference in the range of tide at the two entrances to a passage or from a difference in phase of the tide, or most generally it results from a combination of range and phase differences. Excepting for a lag due to friction and inertia, the hydraulic current would attain its maximum velocity at the time of maximum difference in head, and come to a slack when the difference in head is zero. The velocity of the hydraulic current should vary as the square root of the difference in head.

16. **Current variations in cross section of a stream.**—Currents may be expected to vary in respect both to time and to velocity at different points in the cross section of a stream. In general, the current near the sides and bottom of a stream turns earlier and reaches its maximum strength sooner than it does on the surface in the center of the stream. This is due primarily to the friction of the moving water against the sides and bottom of the waterway. This friction tends to overcome the inertia of the moving water thus advancing the times of occurrence of the different current phases. For the same reason the velocity of the current is less near the shores and bottom of a stream than it is on the surface in the center. The actual maximum velocity of the current is usually found a short distance below the surface because of the friction between the water surface and the overlying atmosphere.

17. The differences in the times and velocities of the current at different points in the cross section of a stream will depend largely upon local conditions. The depth of water and uniformity of shoreline and bed of stream are important factors and eddies may be created by the presence of some nearby obstruction. Differences of a half hour or more in the time of the turning of the current near the shore and in midstream are quite common. Velocities may vary greatly, but for the purpose of computing stream flow through a waterway, it has been roughly estimated that the mean velocity through a cross section of a regular channel is approximately three-fourths as great as the central surface velocity, this estimate being consistent with observational data obtained in some localities. Since the mean velocity for an entire flood or ebb period may be taken as approximately 0.637 times the velocity at strength of current (par. 9), it follows that the approximate average velocity in the cross section for the tidal period may be obtained by multiplying the central surface velocity at time of strength by the product (0.75×0.637), or roughly one-half.

18. A very important factor in the flow of current through a cross section of a river is the fresh water drainage into the stream. This fresh water because of its lesser density tends to override the heavier salt water brought in by the tides, especially in the lower reaches of the river. Thus, near the surface of the stream there is a more or less permanent nontidal flow which increases the velocity of the ebb and diminishes

the velocity of the flood current, while near the bottom of the stream the tidal current may be little affected by this fresh water discharge. This tends to increase the difference between the surface velocity and that at the bottom when the current is ebbing, but during the flood period the surface velocity may become less than that at the bottom of the stream. The fresh water discharge also affects the surface currents by advancing the time of slack before ebb and retarding the time of slack before flood.

Rotary Tidal Currents

19. Rotary currents are those that flow continuously with the direction of flow changing through all points of the compass during the tidal cycle. Rotary currents are usually found offshore where the direction of flow is not restricted by any barriers. The tendency for the rotation in direction has its origin in the deflecting force of the earth's rotation, and unless modified by local conditions the change of direction is clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere. The velocity of the current usually varies throughout the tidal cycle, passing through two maxima in approximately opposite directions and two minima with the direction of the current at approximately 90° from the direction of maximum velocity. The maximum velocity attained on a rising tide or near high water corresponds to the flood of the reversing current, and the maximum velocity attained on a falling tide or near the time of low water corresponds to the ebb of the reversing current.

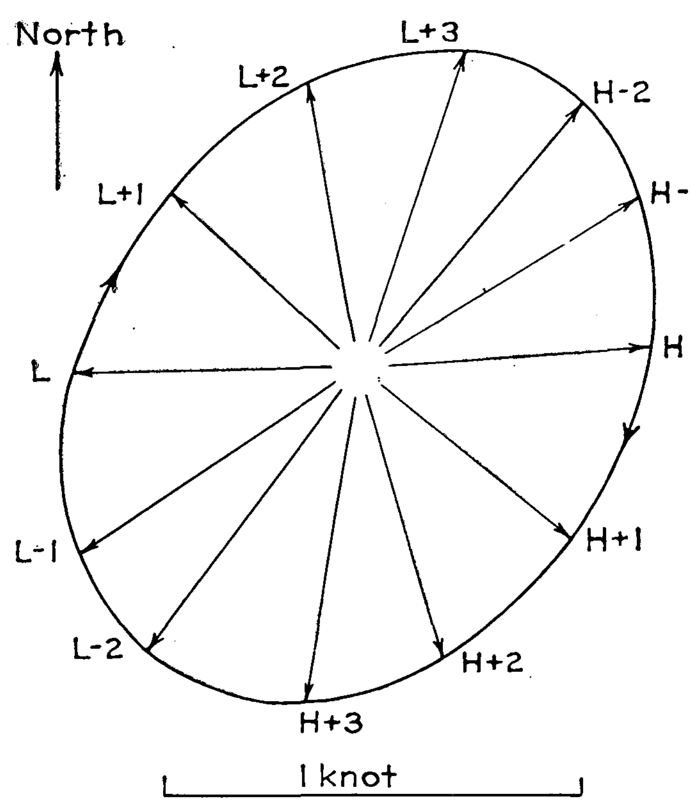

FIGURE 10.—Mean current curve for Nantucket Shoals Lightship, referred to tides at Boston.

20. In the semidiurnal tidal movement, the direction of the rotary current makes two complete cycles each lunar day, the velocity variations being approximately the same for each cycle. In the diurnal movement there is only one cycle during the day. In the mixed type of tide there is a tendency for two cycles each day with marked differences in velocity variations, but in many cases the direction of the current makes a complete turn around the compass only during the cycle of greater velocity and moves through a limited arc during the cycle of lesser velocity.

21. In representing rotary currents graphically there are three elements to consider—time, velocity, and direction. The data may be plotted with rectilinear coordinates to show the relation of the velocity to time with a separate graph to show the relation of the direction to time; or they may be plotted with polar coordinates to show the relation of velocity and direction with the radii vectores at specified time intervals which are indicated on the graph. The plotting of velocities with rectilinear coordinates is similar to that used for reversing currents, except that for the rotary currents all velocities are considered as positive regardless of direction.

22. The polar coordinate system is most generally used for plotting mean values where the current has been referred to hours of the daily or semidaily tidal cycle, the initial references usually being the times of high and low water or the principal current phases at some standard station. In its simplest form such a graph approximates an ellipse in shape. Figure 10 represents the mean semidiurnal tidal current at Nantucket Shoals Lightship with the radii vectores referred to the hours of the tide at Boston. The letters *"H"* and *"L"* signify respectively the times of high and low water at Boston Each radius vector indicates by its length and direction the velocity and direction of the current at the hour designated. Figure 11 represents the mixed type of current at

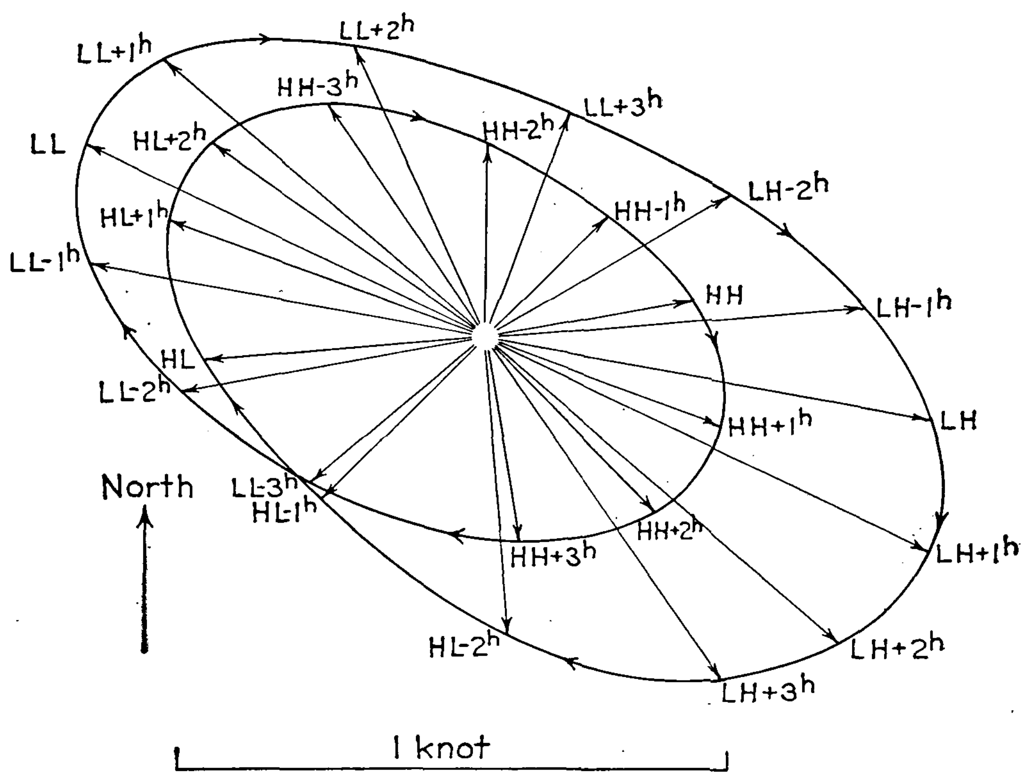

FIGURE 11.—Mean current curve for Swiftsure Bank Lightship, referred to tides at Astoria.

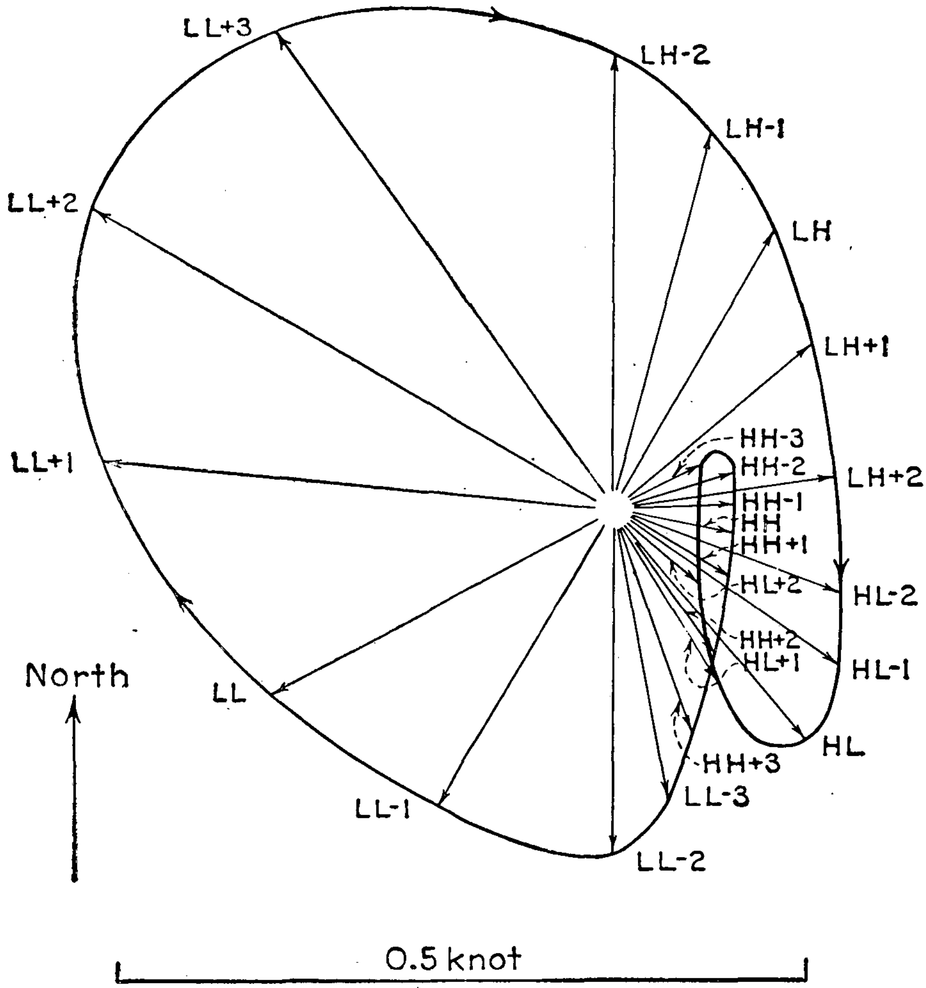

FIGURE 12.—Mean current curve for San Francisco Lightship, referred to tides at San Francisco.

Swiftsure Bank Lightship which is located off the entrance to the Strait of Juan de Fuca. In this graph the radii vectores are referred to the times of the tides at Astoria, Oregon, separate references being made to higher high water (*HH*), lower low water (*LL*), lower high water (*LH*), and higher low water (*HL*). The graph shows two loops covering the tidal day and illustrates the diurnal inequality in current velocity.

23. Figure 12 represents the mean current at San Francisco Lightship which is located about 10 miles offshore from the entrance to San Francisco Bay. In this graph the secondary loop is comparatively small and indicates a change of direction of the current through a limited arc rather than around the entire circle. The current is greatly modified by changes in the declination of the moon and for the time of the equatorial tides the graph would show the two loops nearly equal in size with the current swinging entirely around the compass twice during the day. At the time of the tropic tides, the secondary loop would become very small or vanish altogether so that the current becomes practically diurnal and requires all day to swing entirely around the compass.

24. When a nontidal current is combined with a rotary tidal current, both the velocity and direction of the latter are affected. This is graphically illustrated by

Figure 13. Let *ABCD* be the current curve of a simple rotary tidal current with the origin of the coordinates at *O*. Then *OA*, *OB*, *OC*, etc. will represent the velocity and direction of the tidal current at different intervals of time. Let the nontidal current be represented in velocity and direction by the line *O′O*. Then lines drawn from *O′* to *A*, *B*, *C*, etc., will indicate by their lengths and directions the resultant currents corresponding respectively to the tidal currents *OA*, *OB*, *OC*, etc. It will be noted that the shape of the current ellipse is not changed by the introduction of the nontidal current, but the origin *O* is shifted to a position *O′* in a direction opposite to that of the nontidal current and by an amount representing its velocity. If the velocity of the nontidal current exceeds that of the tidal current, the origin *O* will be shifted to a position *O″* outside of the ellipse. In this case the resultant current will not veer entirely around the compass, but its direction will vary within an arc limited by tangents drawn from *O″* to the ellipse.

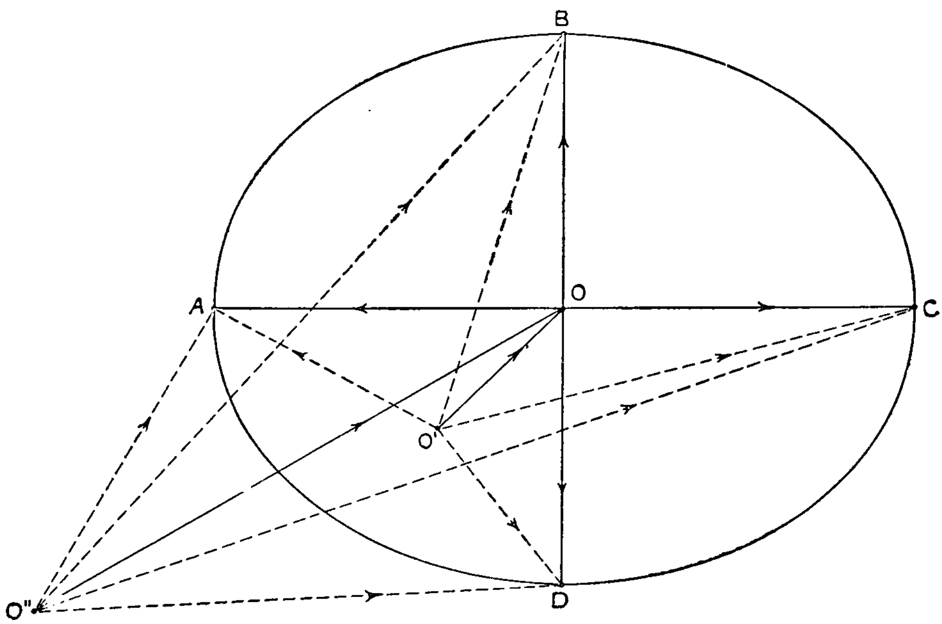

FIGURE 13.—Effect of nontidal current on rotary tidal current.

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Instruments for Observing

Current Pole and Log Line

25. The simplest form of apparatus for observing currents consists of the current pole and log line. By means of this apparatus both velocity and direction of the surface currents may be obtained. The current pole in general use is about 3 inches in diameter and 15 feet long; a shorter pole is used for shoal water. The pole is weighted at the lower end to float upright with the top about one foot out of water. Sheet lead or an iron weight cast in rings is used for this purpose and the weight may be changed to adapt the pole for observations in waters of different densities.

26. The *log line,* which is attached to the current pole, is about three-sixteenths inch in diameter and several hundred feet in length. It is carried on a reel that is mounted on a stand. The line is graduated in such a manner that the velocity of the current expressed in knots and tenths is indicated directly by the amount of line which is carried out by the current pole in a specified interval of time. The time interval generally adopted is 60 seconds, and since a current with a velocity of one knot (6,080 feet per hour) will carry the log line a distance of 1/60 of 6,080 or 101.33 feet per minute, the unit graduations of the line are spaced at 101.33 feet. Subdivisions for tenths of a knot are spaced at 10.1$\dot{3}$ feet.

27. The unit graduations are marked by pieces of cotton string in which knots are tied, the number of knots in any string indicating the velocity of the current expressed in knots or nautical miles per hour. The initial point or zero of the graduations should be marked in a distinctive manner. The subdivisions for tenths of knots are marked by pieces of oiled string according to the following scheme: For each of the fractions 0.1, 0.2, 0.3, and 0.4, a single string with one, two, three, and four knots respectively; for the fraction 0.5, a double string without knots; and for each of the fractions 0.6, 0.7, 0.8, and 0.9, a double string with one, two, three, and four knots respectively. The line should be wet when graduated and when in use.

28. The *stray line* is an ungraduated portion of line between the current pole and the initial graduation of the log line. The stray line should have a length of about 100 feet to permit the pole to attain a position beyond the effect of the disturbed waters in the wake of the vessel before beginning to measure the velocity of the current. That portion of the stray line attached directly to the current pole and used to lift the latter out of the water should be somewhat larger and stronger than the log line itself.

29. **Observing with current pole and log line.**—A stop watch is now generally used in fixing the duration of run for the current pole. With the pole in the water and everything in readiness at the appointed time for taking the observation, the stray line is paid out and as the zero or initial point of the graduated part of the line passes a fixed reference mark on the vessel, the stem of the stop watch is pressed. The paying out of the graduated line is then continued until 1 minute has elapsed. The line is then stopped and the velocity of the current in knots and tenths read directly from the graduation nearest the reference mark on the vessel and the reading entered in a record

book. The direction of the current as indicated by the position of the current pole is determined by compass, pelorus, or sextant angles as will be explained later.

30. For a very strong current, a 30-second run may be used instead of a full minute, and in this case the velocity is double that read directly from the log line. For a very weak current, the line may be allowed to run 2 minutes, in which case the velocity is one-half as great as read directly from the line. Care must be taken not to pay out the line faster than the pole can take it away. In a very weak current, trouble may be experienced because of the sinking bight in the log line. Corks fastened at each tenth of a knot graduation have sometimes been used to eliminate this trouble

Compass

31. There are two types of compasses now in use for the independent determination of direction—the *magnetic* and the *gyro.* The magnetic compass, which has been in common use for a great many years, is actuated by a magnet or group of magnets and indicates direction relative to the earth's magnetic poles but is subject to errors arising from local attractions which will be explained later. The magnetic compass is in general use on the smaller vessels that are usually employed in taking current observations. The gyro compass, which is a more elaborate and modern invention, is actuated by a rapidly spinning rotor which tends to place its axis of rotation parallel to the earth's axis of rotation. This compass, therefore, indicates direction relative to the true meridian and is subject only to small corrections depending upon latitude, course, and speed of the vessel. The larger and more modern vessels are usually equipped with gyro compasses.

32. Either type of compass has a compass card, circular in shape, with circumference graduated to indicate direction. These graduations may be either in *degrees of azimuth* or in *points of the compass*, or in both degrees and points. In modern times there is a tendency towards the use of degrees of azimuth reckoned clockwise through 360° entirely around the circle, with north taken as 0° or the initial point of the reckoning. In the older magnetic compasses preference was given to the designation of direction by points. There are 32 such points in the entire circumference, these points being spaced 11¼° apart; each point is usually subdivided into quarters. The naming of these points in order is called *boxing the compass.* The *cardinal points* are the four principal compass points—north, east, south and west. The *intercardinal points* are the points midway between the cardinal points and are northeast, southeast, southwest and northwest. The names of all of the points and quarter-points with corresponding azimuth to the nearest whole degree are shown in Table 1.

33. The *azimuth circle* is a fitting for a compass employed in taking bearings and consists essentially of a pair of sight vanes at the extremities of the diameter of a ring that revolves concentrically with the compass bowl with the line of sight always passing through the vertical axis of the compass. A system of mirrors and prisms brings into the field of view of the observer the compass reading corresponding to the direction of the line of sight.

34. **Variation of compass.**—The variation of the compass, also called magnetic declination, is the difference between true north as determined by earth's axis of rotation and magnetic north as determined by the earth's magnetism. The variation is designated as east or positive when the earth's magnetism deflects the magnetic needle

TABLE 1.—*Points of compass with corresponding azimuths to nearest whole degree*

Compass point	Azimuth	Compass point	Azimuth	Compass point	Azimuth	Compass point	Azimuth
	°		°		°		°
North	0	East	90	South	180	West	270
N. ¼ E.	3	E. ¼ S.	93	S. ¼ W.	183	W. ¼ N.	273
N. ½ E.	6	E. ½ S.	96	S. ½ W.	186	W. ½ N.	276
N. ¾ E.	8	E. ¾ S.	98	S. ¾ W.	188	W. ¾ N.	278
N. x E.	11	E. x S.	101	S. x W.	191	W. x N.	281
N. x E. ¼ E.	14	ESE. ¾ E.	104	S. x W. ¼ W.	194	WNW. ¾ W.	284
N. x E. ½ E.	17	ESE. ½ E.	107	S. x W. ½ W.	197	WNW. ½ W.	287
N. x E. ¾ E.	20	ESE. ¼ E.	110	S. x W. ¾ W.	200	WNW. ¼ W.	290
NNE.	22	ESE.	112	SSW.	202	WNW.	292
NNE. ¼ E.	25	SE. x E. ¾ E.	115	SSW. ¼ W.	205	NW. x W. ¾ W.	295
NNE. ½ E.	28	SE. x E. ½ E.	118	SSW. ½ W.	208	NW. x W. ½ W.	298
NNE. ¾ E.	31	SE. x E. ¼ E.	121	SSW. ¾ W.	211	NW. x W. ¼ W.	301
NE. x N.	34	SE. x E.	124	SW. x S.	214	NW. x W.	304
NE. ¾ N.	37	SE. ¾ E.	127	SW. ¾ S.	217	NW. ¾ W.	307
NE. ½ N.	39	SE. ½ E.	129	SW. ½ S.	219	NW. ½ W.	309
NE. ¼ N.	42	SE. ¼ E.	132	SW. ¼ S.	222	NW. ¼ W.	312
NE.	45	SE.	135	SW.	225	NW.	315
NE. ¼ E.	48	SE. ¼ S.	138	SW. ¼ W.	228	NW. ¼ N.	318
NE. ½ E.	51	SE. ½ S.	141	SW. ½ W.	231	NW. ½ N.	321
NE. ¾ E.	53	SE. ¾ S.	143	SW. ¾ W.	233	NW. ¾ N.	323
NE. x E.	56	SE. x S.	146	SW. x W.	236	NW. x N.	326
NE. x E. ¼ E.	59	SSE. ¾ E.	149	SW. x W. ¼ W.	239	NNW. ¾ W.	329
NE. x E. ½ E.	62	SSE. ½ E.	152	SW. x W. ½ W.	242	NNW. ½ W.	332
NE. x E. ¾ E.	65	SSE. ¼ E.	155	SW. x W. ¾ W.	245	NNW. ¼ W.	335
ENE.	68	SSE.	158	WSW.	248	NNW.	338
ENE. ¼ E.	70	S. x E. ¾ E.	160	WSW. ¼ W.	250	N. x W. ¾ W.	340
ENE. ½ E.	73	S. x E. ½ E.	163	WSW. ½ W.	253	N. x W. ½ W.	343
ENE. ¾ E.	76	S. x E. ¼ E.	166	WSW. ¾ W.	256	N. x W. ¼ W.	346
E. x N.	79	S. x E.	169	W. x S.	259	N. x W.	349
E. ¾ N.	82	S. ¾ E.	172	W. ¾ S.	262	N. ¾ W.	352
E. ½ N.	84	S. ½ E.	174	W. ½ S.	264	N. ½ W.	354
E. ¼ N.	87	S. ¼ E.	177	W. ¼ S.	267	N. ¼ W.	357

east of true north, and as west or negative if the deflection is west of true north. The magnitude of the variation usually differs considerably in different localities and also changes to some extent from year to year. The amount of the variation in different localities is shown by compass roses on the charts published by the Coast and Geodetic Survey, which also include statements of the annual change. The relation between the true azimuth and magnetic azimuth may be expressed by the following formula:

True azimuth = magnetic azimuth + variation of compass.

35. **Deviation of compass.**—This term is applied to the error in a ship's magnetic compass arising from the attraction of the magnetic metal in the ship itself. If the magnetic needle is deflected to the right of the magnetic north, the deviation is said to be east or positive; if deflected to the left, the deviation is west or negative. The deviation applied according to sign to the compass bearing of an object gives its magnetic bearing. Each compass on the ship may be affected differently and the deviation usually differs for each heading of the ship. Some compasses are compensated for deviation, but if this has not been done, a deviation card should be prepared showing the amount of error for different headings of the ship. In general practice the deviation

is obtained for each 15° rhumb of ship's heading by compass. Placing the vessel on different headings to obtain these deviations is called "swinging the ship."

36. There are a number of methods for swinging ship. The range method described here has been successfully employed in our work. This method requires the selection of two objects on shore which are definitely located on the chart and which are so situated as to be clearly visible from the ship. To form a sensitive range, the front object should be as near as possible, while the back object should be at a distance. The selected range should be located at a place where it will be convenient to carry out the ship swing without being in the way of traffic. The procedure is to place the ship on a heading corresponding to one of the 15° rhumbs and come up on range slowly. When in line with the two objects on shore, a compass bearing of the range is observed. The difference obtained by subtracting this compass bearing from the known magnetic bearing of the range is the deviation corresponding to the ship's head at the time of the observation. The operation is repeated for headings corresponding to other 15° rhumbs.

37. If a ship on a current station is anchored with a single anchor and is free to swing with the current, the following method for preparing a deviation table may be employed. Although more time is required to obtain the deviations for all the required headings, the work can be carried on simultaneously with the current observations at the station. The method requires three or more objects on shore which can be used to determine the location of the ship by sextant angles and a reference object upon which to take bearings. The positions of these objects must be plotted on a chart. Two observers are necessary, one to determine the position of the ship by sextant angles as it swings into different headings, and the other to note the ship's head by compass and at each 15° rhumb to take a compass bearing to the reference object. The position of the ship being plotted for each observation, the true and magnetic bearings of the reference object can be readily obtained. By subtracting the simultaneous compass bearing from the magnetic bearing the corresponding deviation is obtained. With this method the observations at times must be taken very hurriedly when a strong current swings the vessel rapidly through any of its headings.

38. With either method of swinging ship it is desirable that the results be checked by plotting. This may be done on cross section paper using the ship's compass headings as abscissas and the corresponding deviations as ordinates. The plotted points should fall into a fairly smooth curve and any outstanding irregularity should be checked by additional observations. The final results are to be recorded in a deviation table, a form for which will be found in the front part of the book (Form 270) provided for the record of current observations. In this table the magntic heading of the ship is obtained by applying the deviation according to sign to the compass heading of the ship.

39. In addition to the variation and deviation described above, a compass may be subject to error due to local attractions arising from extraneous influences in the vicinity of the vessel, especially when a ship is in port or in close proximity to other vessels. Local attraction may be encountered in certain shallow waters of the sea with underlying mineral deposits. In general it is not necessary to take into consideration this source of error in connection with current observations. The effect of such local conditions that might exist in the area where the ship is being swung may be expected to be included in the deviation error. Disregarding local attractions, the relation of magnetic and true azimuth to compass bearing may be expressed by the following formulas:

Magnetic azimuth = compass bearing + deviation.

True azimuth = compass bearing + deviation + variation.

40. **Direction of current by compass.**—The compass may be used either independently or in connection with the pelorus to obtain the direction of the current. When used independently, the compass equipped with an azimuth circle is mounted in the stern of the vessel. Immediately after a velocity observation has been taken with a current pole and log line, the sights of the azimuth circle are directed toward the pole and the bearing read from the compass and recorded. Necessary corrections are afterwards applied for deviation and variation. When the pelorus is used, its reading must be combined with a compass reading of the ship's head as explained in paragraph 130.

Pelorus

41. While the most modern type of pelorus is a somewhat elaborate instrument, the pelorus used in taking current observations is a simple disk about 8 inches in diameter and graduated clockwise for every 5 or 10 degrees. In conformity with the usual practice it should be mounted rigidly on the vessel with the 0° mark forward and the diameter through this mark parallel to the keel of the boat. Sometimes only the forward half of the disk is graduated, beginning with 270° and extending through 0° to 90°. If the vessel is anchored so that it is free to swing with the current, a single pelorus in the stern is sufficient. This should be installed in a position to allow the current line to swing through as large an unobstructed sector as possible. If the vessel is moored fore and aft so that it cannot swing, a second pelorus mounted forward is also necessary.

42. **Observing with pelorus.**—The pelorus is used in connection with the ship's compass and with the current pole and log line to determine the direction of the current. Immediately after the velocity observation the log line is stretched across the center of the pelorus and a reading taken where the line intersects the forward arc of the instrument. This reading, usually taken to the nearest 5°, is then entered in the record book (Form 270 or 270a). The compass reading of the ship's head for the same time must also be recorded. In general, for observations taken from the stern of the vessel the current pole will be aft of the beam and for observations taken from the forward pelorus the pole will be forward of the beam. There may be occasional exceptions, and these should be carefully noted in the record. Also, when there is more than one pelorus on the vessel, the record should be clear as to which pelorus is in use at any time. The computations for obtaining the actual current direction from the pelorus reading are explained in paragraph 130.

Sextant

43. Aside from its use as an instrument of navigation, the sextant is used in current observations to determine the location of the station occupied and also in determining the direction of the current. The sextants generally used in connection with current surveys are of lighter construction than those used for navigation and are read only to minutes. The sextant is designed to measure the angle between two objects by bringing into coincidence rays of light received directly from one and by reflection from the other, the measure depending upon the angle between two reflecting surfaces. One of these surfaces is fixed and is known as the "horizon mirror," and the other,

which is known as the "index mirror," is attached to the head of an index bar that is free to turn on a pivot. The index bar is provided with a clamp and tangent screw for accurate setting and carries a vernier that may be moved over a fixed graduated arc of a circle. The construction of the instrument is such that the angle being measured is twice as great as the angle between the two mirrors, and the scale of the instrument is graduated accordingly. Thus an arc of one-fourth of a circle is graduated and marked for 180°. The instrument is equipped with a telescope which may be used when sighting upon distant objects.

44. To measure the angle between two objects the observer looks at the one on the left over the top of the horizon mirror and moves the index bar until the reflection of the right-hand object appears in the horizon mirror directly under the left-hand object, the clamp and tangent screw being used to secure a fine setting. The angle may then be read directly from the graduated scale. When used to determine the position of the vessel, angles are measured between three fixed objects whose positions are known and plotted on a chart. When used to determine the direction of the current, it is necessary to have a reference object whose bearing from the vessel is known. Then, immediately after a velocity observation has been taken with current pole and log line, the angle between the reference object and the current pole is measured and entered in the record with the letter *"R"* or *"L"* according to whether the current pole is to the right or left of the reference object.

45. The principal adjustments of the sextant which may require attention in the field consist in placing the two mirrors perpendicular to the plane of the instrument and in placing them parallel to each other when the vernier reads zero. The position of the index mirror is first checked by holding the instrument so that the reflection of the graduated arc can be seen in this mirror and then, moving the index arm slowly, observe if the arc and its reflection appear to form a continuous and unbroken arc. If not, the inclination of the mirror should be corrected by an adjusting screw provided for the purpose. For the adjustment of the horizon mirror set the index arm at zero. Then, holding the sextant in a vertical position, sight at the sea horizon and observe if the horizon and its image in the horizon mirror coincide; if not, correct by means of the screw at the side of the mirror. Next, rotate the instrument about 45° and see if the horizon and its image remain in coincidence; if not, correct with the screw at the back of the mirror. As the latter correction may disturb the previous one, the operation should be repeated until the horizon and its image in the horizon mirror remain in coincidence for every position of the instrument as it is rotated.

Bifilar Direction Indicator

46. The bifilar current indicator is an instrument which has been used to determine the direction of subsurface currents. It consists essentially of a pipe with rudder attached to one end, suspended horizontally by two wires from a bar which is free to turn in azimuth by virtue of a ball-bearing joint at its connection with an outrigger or davit on a vessel. A triple form of the indicator, which was used to determine simultaneously the direction of the current at three different depths, is described in Coast and Geodetic Survey Special Publication No. 124, *Instructions for Tidal Current Surveys*. Because of the difficulty of managing the apparatus from a vessel in rough water, its use has been discontinued.

Price Current Meter

47. The Price current meter (fig. 14) was originally designed by Assistant Engineer W. G. Price, Corps of Engineers, U. S. Army. It is designed to measure the velocity of the current but not its direction. The instrument consists essentially of a wheel made of a number of conical cups which is free to rotate with the current and indicates velocity by the rapidity of the rotation. An electrical connection enables an observer with an earphone to count the number of revolutions during any interval of time, the corresponding velocity of the current being afterwards determined by means of a rating table. It may also be electrically connected with an automatic recording device.

48. The meter wheel shaft, also known as the cup shaft, has at its lower end a bearing which rests upon a pivot point set in the supporting yoke. The upper end of the shaft extends into the contact chamber which is secured in the upper part of the yoke and in which electrical contacts are made as the shaft is rotated. Provisions are made to register each individual turn of the shaft for comparatively weak currents or to register each 5 turns for the stronger currents.

49. For the single-count device an eccentric on the upper part of the cup shaft contacts on each revolution a small wire spring extending from a plug screwed into the contact chamber. For the penta-count device, the shaft is provided with a worm gear which engages a gear wheel in the contact chamber. Projections on the gear-wheel

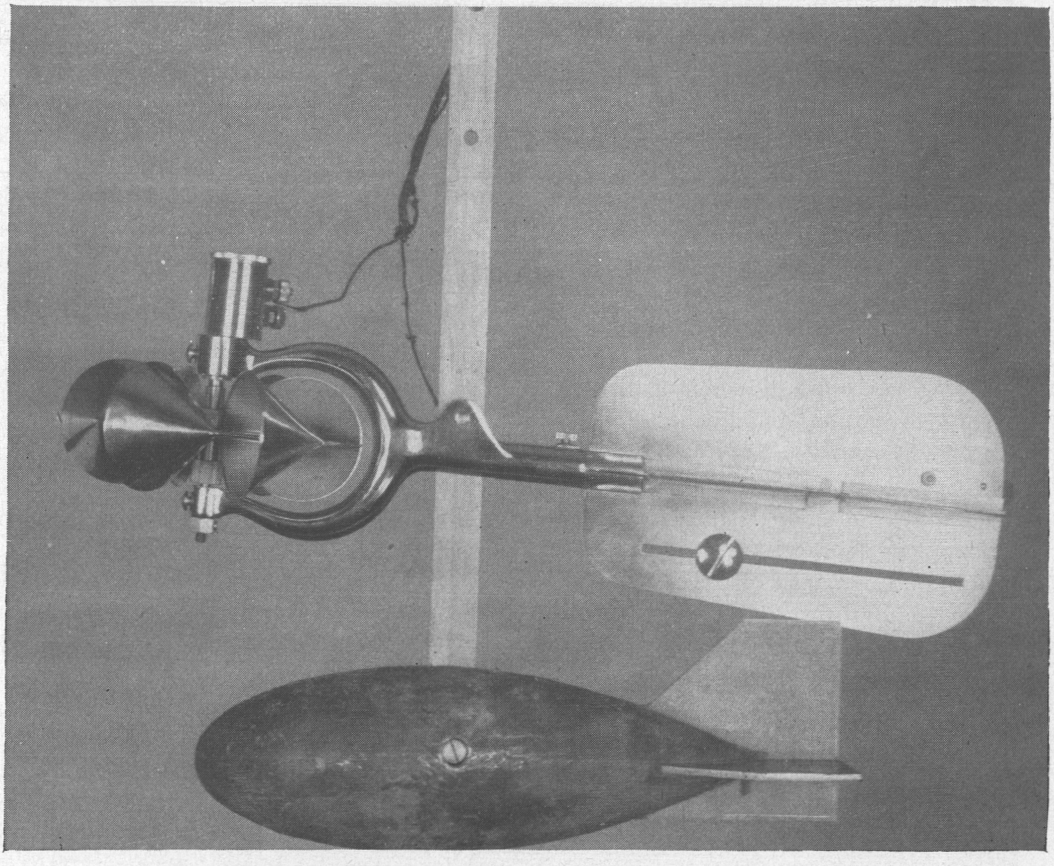

FIGURE 14.—Price current meter.

shaft contact a wire spring similar to the one used for the single-count device. One of these contacts is made for every 5 revolutions of the cup shaft. The eccentric and worm gear are both on the cup shaft, the eccentric being above the worm gear. The contact chamber is provided with two contact plugs, each with a wire contact spring. The upper spring contacts the eccentric for the single-count operation and the lower spring contacts the projections on the gear-wheel shaft for the penta-count operation. Either device is made operative as desired by connecting the proper plug with one of the wires of the electric circuit of the registering device. The other wire is grounded to the supporting yoke of the instrument.

50. The meter is provided with two tail vanes set at right angles, one in a horizontal plane and the other in a vertical plane. The vanes may be separated when the instrument is dismantled for packing. The vanes with their stem balance the head and also keep the axis of the meter parallel to the direction of the current. On one of the vanes there is a slot carrying a weight that can be adjusted to balance the meter. The meter is supported by a flat rod or stem that passes through a slot in the yoke and is secured by a bolt which permits some movement in a vertical plane so that the axis of the meter may retain a direction parallel to the direction of the current, although the supporting stem itself may be carried out of the vertical by the force of the current against the instrument as a whole. Attached to the lower end of the supporting stem is a torpedo-shaped weight to assist in holding the instrument at a desired depth. At the upper end of the stem is an arrangement for attaching a cable.

51. When in use the meter is supported by a cable containing 3 insulated wires. One of these is a stranded steel wire designed to support the instrument and attached weight. The other two are copper wires used to complete an electric circuit between the instrument and an earphone used by the observer. A small battery is connected in the circuit, and when this circuit is made and broken by the revolution of the meter wheel, audible clicks in the earphone can be counted by an observer.

52. **Installation of meter.**—In taking meter observations from a boat, a beam is rigged outboard so that when the apparatus is raised or lowered it will clear the side of the vessel. As it is the usual practice to take observations at several depths at the same station, frequent changes in the height of the instrument are necessary. To accomplish this conveniently it has been found advantageous to suspend the meter from a cable which is reeled on the drum of a hand-sounding machine. The end of the current cable is passed through a hole drilled through the face of the sounding-machine drum to a connecting plug which is made fast in one of the holes in the web of the reel. The reel may be rotated to raise or lower the meter, and when it is at the desired depth the earphone and battery are plugged in, thus completing the electric circuit.

53. Since in strong currents there is a tendency for the meter and current cable to trail out or depart from a vertical line, it has been found desirable to have the meter slide up and down a second cable that is held vertically by a 200-pound weight attached to its extremity (fig. 15). The weight is raised or lowered by means of a small hand winch. After the weight has been lowered to a depth below the lowest point at which observations are to be taken at the station, it may be left in this position until all the observations at the station have been completed. Shackles are used to hold the meter close to the cable supporting the heavy weight. The meter itself may then be raised or lowered as desired without changing the position of the large weight. The current cable and the cable supporting the weight pass over separate sheaves fastened to the beam supporting the apparatus. The sheave through which the current cable passes may contain a registering dial to show the depth to which the meter is lowered.

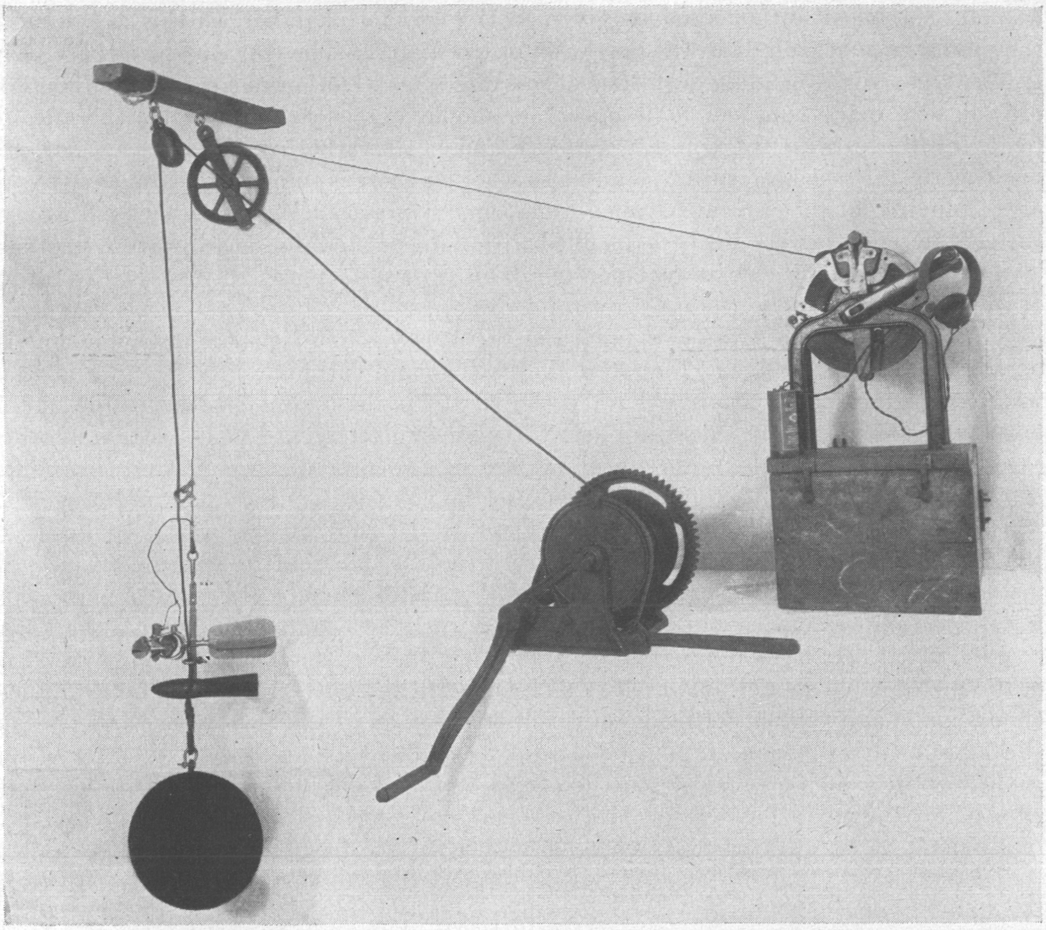

FIGURE 15.—Installation of Price current meter.

54. **Taking the meter apart.**—To take the meter apart remove in order the tail vanes, the contact chamber, and the pivot point, all of which are secured by set screws which must first be loosened. When removing the contact chamber care should be taken to let the cup shaft turn freely, so that the worm gear can disengage from the teeth of the gear wheel without injury. By first unscrewing the cap from the chamber the gear wheel can be seen during the operation. A slight twisting of the chamber will aid in its removal. Next unscrew the upper stem of the cup shaft and the cups may then be lifted out of the yoke. When reassembling the meter, the cups should be placed so that they will rotate counterclockwise with the current and the pivot point should be adjusted to allow a slight vertical movement of the cup shaft.

55. **Care of meter.**—The meter should be carefully handled at all times and the bearings kept clean and oiled so that the meter wheel will spin freely without appreciable resistance. The lower cup-shaft bearing especially should be carefully dried and oiled immediately after use whenever the meter is to remain idle longer than a few hours. If the cups become bent, they may be pressed into shape with a piece of wood or metal with a round smooth end. Care should be taken to avoid any heavy jar on the earphone which might affect the magnetization of the pole pieces. Set screws should be kept tight to avoid the loss of any part when the meter is in the water.

56. Special attention must be given to the contact chamber, as this is the most common source of trouble in the operation of the meter. The contact springs are very slender and a slight bending or misplacement might result either in a continuous contact or failure to make contact. The operation should be checked from time to time by removing the cap on the contact chamber and noting whether definite contacts are made as the meter wheel is rotated and also whether there is sufficient clearance to avoid any grounding of the current between the normal contacts. When the meter is in use, the contact chamber should be kept filled with light or medium oil to prevent any salt water from attacking the contact points. This does not appreciably affect the rating of the meter and experience has proven its value.

57. To locate the cause of a failure in the electric circuit that is not immediately obvious, proceed as follows: First test the battery and earphone in a circuit and note whether distinct clicks are heard when the circuit is made and broken at one of the battery terminals. If no clicks are heard, try a new battery and, if necessary, another earphone. If both battery and earphone are in good operating condition, introduce the meter into the circuit; connect one wire to the yoke of the instrument and the other wire successively to each of the contact plugs in the contact chamber. In this case the circuit may be made and broken by rotating the cup shaft of the meter. If the meter is all right, a click will be heard for each turn of the cup shaft when connection is with the upper contact plug, or for each 5 turns when connection is with the lower contact plug. If the meter is found to be operating satisfactorily, the electric wires of the meter cable should be placed in a circuit with the battery and earphone and the circuit made and broken by bringing together the ends of the two cable wires. If no clicks are heard, the cable should be carefully examined for any break in either of the copper wires. Such a break is most likely to be found near either end of the cable or at a point known to have received an exceptionally sharp bend. When in use it is recommended that waterproof grease be applied to the terminals of the cable at the connections with the meter as a precaution against the shorting of the current through the frame of the instrument, especially when operating in deep water. If the signals are inclined to be weak, it is advisable to wrap the bare cable terminals and contact plugs with waterproof tape before applying the grease.

58. The suspension of the meter on a metal stem attached to the supporting cable is designed so that the axis of the meter can move vertically as well as horizontally in order to keep parallel with the direction of the current. Before being placed in the water the vertical movement should be checked and the balance weight on the tail vane adjusted to eliminate any tendency to tip in either direction.

59. **Automatic recording device.**—An automatic recording device for use with the Price current meter, which was developed by the United States Engineers, is described in an article entitled "Measuring Currents in New York Harbor," by Harold E. Libby, published in the *Military Engineer* for September–October 1932. The device (fig. 16) replaces the earphone and consists of an electric accumulator relay and a recorder. An operating battery of about 3 volts is in one circuit with the current meter and the electro-magnet of the relay, and in another circuit with an electro-magnet in the recorder, the latter circuit being opened and closed by the action of the relay.

60. The recorder contains a circular time chart about 10 inches in diameter which is rotated by clockwork and a recording pen operated by an electro-magnet. With the electric circuit open, the pen traces the circumference of a circle about 8 inches in diameter, but each time the circuit is closed, a short outward stroke is made through the action of the electro-magnet on the pen arm. The frequency of these contact

marks indicates the velocity of the current. The speed at which the time chart rotates may be regulated by the clock movement, but for general purposes a speed of one revolution in 6 hours is recommended. This gives a time scale of 1° of arc for each minute of time and will necessitate the changing of the chart each 6 hours. The record is preferably made on blank paper, and if stock charts ruled for other purposes are furnished, the blank side may be used for these records. The exact times of the beginning and end of the record must be carefully noted on each chart and intermediate times, preferably each hour, should also be indicated both as a check and as a convenience in tabulation.

61. The accumulator relay serves to reduce the number of electrical contacts in the circuit to the recorder. Each electrical contact in the current meter, representing

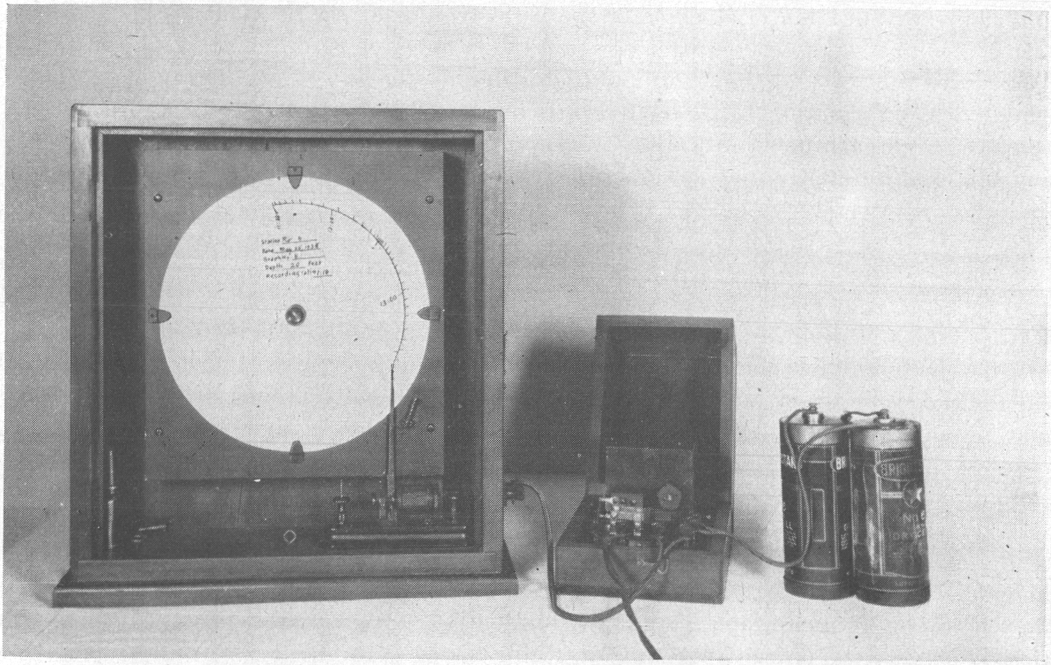

FIGURE 16.—Automatic recorder for Price current meter.

either one or five turns of the meter wheel according to whether the single-count or penta-count contact spring is in circuit, actuates the electro-magnet in the relay and moves a ratchet wheel forward one step. Interchangeable cams may be keyed to an extension of the ratchet wheel shaft and provide for the making and breaking of the circuit to the recorder after any desired number of contacts in the meter. For currents with velocity of less than 5 knots, a cam giving one contact in the recorder for each 10 contacts in the meter is recommended. With this cam a recording ratio of 1:10 is secured when the single-count contact spring of the meter is in circuit and a recording ratio of 1:50 when the penta-count contact spring is in circuit. The recording ratio of 1:10 may be used for very weak currents, but for velocities of more than 1 knot the contact marks on the recording chart will tend to merge together and become indistinguishable from each other unless movement of the chart itself is also speeded up. For the same reason the recording ratio of 1:50 is not, in general, satisfactory for velocities greater than 5 knots. For larger velocities cams giving smaller recording ratios will be necessary. It is important that the recording ratio used for the record shall be clearly stated on each chart. The cam in the accumulator relay should be turned to its zero position each time a new chart is installed on the recorder in order that the first contact mark will correctly indicate the full accumulated count from the time of the installation.

62. **Rating table.**—All Price current meters in use by this Survey are calibrated from time to time by the National Bureau of Standards and formulas are furnished which indicate the velocity of the current in terms of the number of revolutions of the meter wheel in a specified interval of time. From these data rating tables may be prepared which will give directly in a convenient tabular form the velocity corresponding to the number of revolutions of the meter wheel. The manufacture of the Price meter has now become so standardized that a single rating table may be prepared which will be applicable without material error to many instruments of this type. The following rating formulas were derived by averaging the ratings for 26 different meters in recent use by this Survey and they may be used generally for any of the instruments of this type unless information to the contrary is received. It is the general practice of the office to check each new calibration of any meter with the standard table in order that any material difference may be taken into account. The rating formulas follow:

Let V=velocity of current in knots, and
N=number of revolutions of the meter wheel per minute.
Then $V=0.0216\ N+0.021$ when N is less than 30 and
$V=0.0219\ N+0.012$ when N is greater than 30.

Rating tables (Tables 2 and 3) based upon the above formulas are given on pages 48, 49.

63. Different methods may be employed for the interpretation of the graphs of the automatic recorder. Table 3, which has been especially prepared for the purpose, may be conveniently used when the recording ratio is either 1:10 or 1:50. For the purposes of this table the contact marks in any 12-minute (0.2 hr.) period are counted and the number used as the argument for entering the table. The corresponding tabular velocity will be the average velocity over the 12-minute period and may be attributed to the middle of the period. Similar tables may be readily prepared to provide for a period of any other length and for any other recording ratio. The period for the count may be taken at such a length that the number of contact marks will directly express the velocity of the current without any table. For example, if a 11-minute period is taken when the recording ratio is 1:50, the number of contact marks occurring in this period will be substantially the same as the velocity expressed in tenths of a knot. If the recording ratio is 1:10, the number of contact marks in a 2.2-minute period will express the velocity in tenths of a knot, and the number of contact marks in a 22-minute period will give the velocity in hundredths of a knot.

Ekman Current Meter

64. The Ekman current meter (figs. 17 and 18) was developed by Dr. V. Walfrid Ekman, a Swedish scientist, who explains the instrument in an article entitled "An Improved Type of Current Meter," which was published in the *Hydrographic Review* for November 1932. It is also explained in the British *Admiralty Manual of Hydrographic Surveying* (1948) page 314. The manufacture of this meter has not been as completely standardized as that of the Price meter and the following description refers

especially to meter No. 110 (C. & G. S. No. 172), which is now in the possession of this Bureau. The maximum current velocity for which Ekman current meter No. 110 can be used successfully is 1.8 knots. Attempts to measure greater velocities with this particular meter may result in damage to the instrument. It is recommended that its use be limited to velocities of 1.5 knots or less. The instrument is more complicated than the Price meter and is designed to indicate both the velocity and direction of the current.

65. In this instrument the meter wheel, which is called the screw, has inclined blades after the pattern of a screw propeller, and the number of revolutions is recorded on dials in the instrument itself. It is therefore necessary to raise the meter out of the water after each observation in order to read the dials. There are two dials which

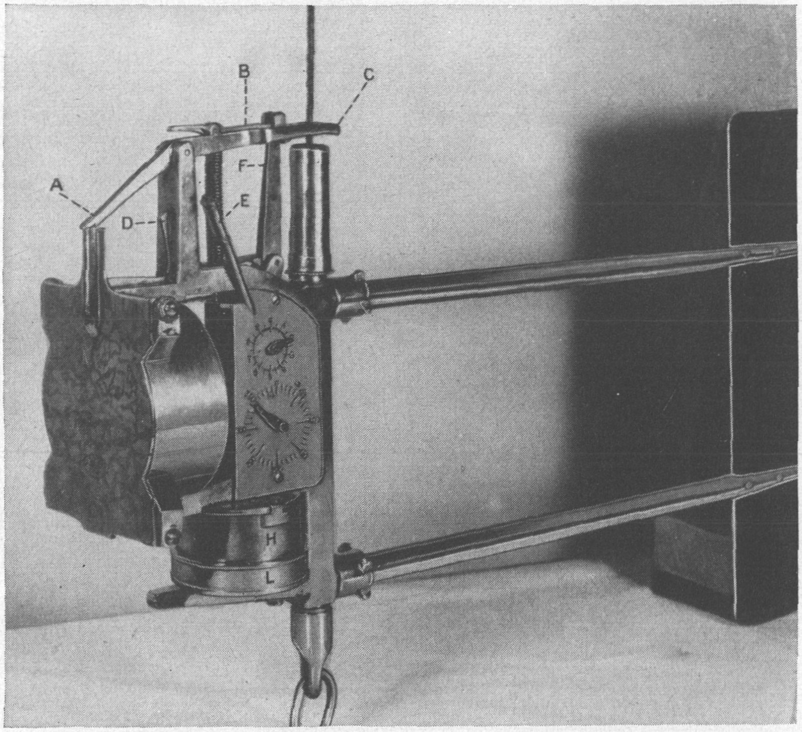

FIGURE 17.—Ekman current meter with shutters closed.

provide for a count up to 4,000 revolutions of the screw. The pointer of the upper dial makes one revolution for each hundred revolutions of the screw and the pointer of the lower dial makes one revolution for each 4,000 revolutions of the screw. The numbers on the dials are in reverse order to give decreasing readings so that the number of revolutions of the screw in any interval of time may be obtained by subtracting the final reading from the initial reading. It will be noted that the numbers inscribed on the dials refer to tens of units and require an annexed cipher to give the true number of revolutions of the screw.

66. A locking device is provided to keep the screw from turning when the instrument is being lowered or raised in the water. The stopper is a small lever inside the protecting ring around the screw. It is movable vertically and stops the rotation of the screw by coming between the blades. The position of the stopper is controlled by

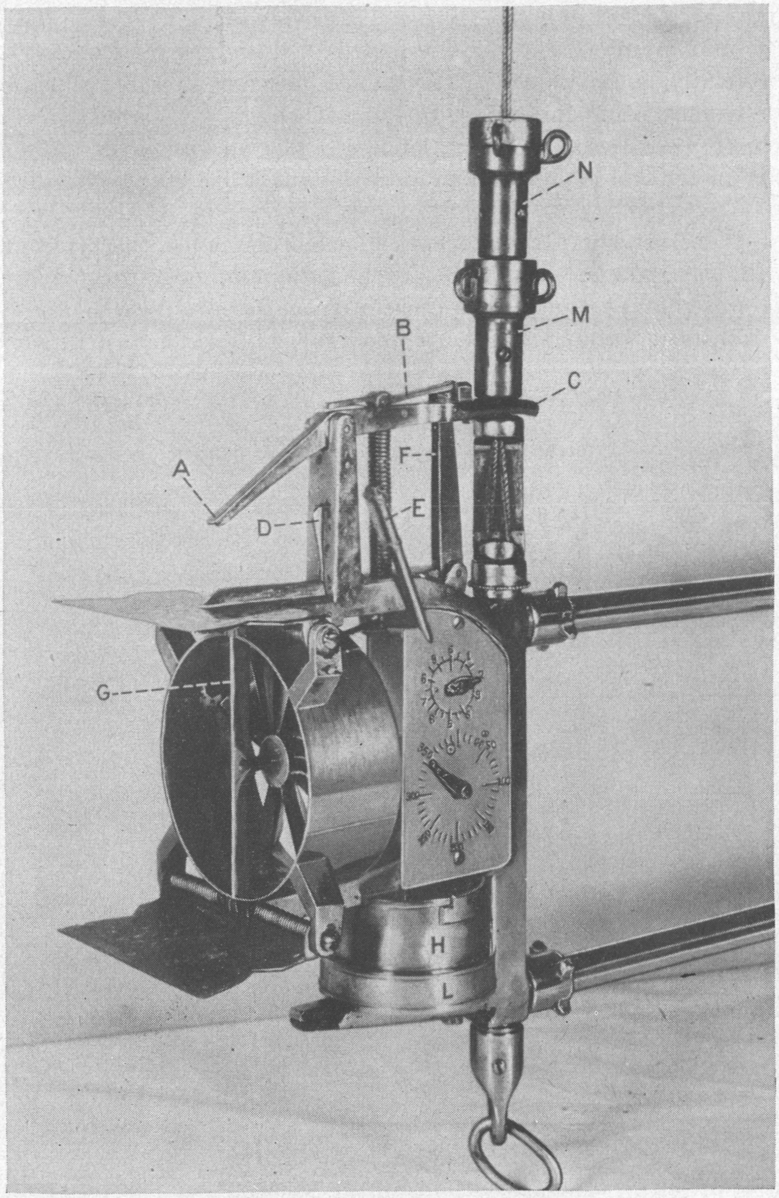

FIGURE 18.—Ekman current meter with shutters open.

the position of the locking lever (*C*) which is movable vertically on a bearing at the top of the instrument. There are two separate devices for holding the locking lever in the position necessary to keep the screw from turning.

67. The first device for holding the locking lever is used in setting the instrument before lowering it into the water for an observation, and consists of placing the outer end of the lever (*A*) against the upper edge of the upper shutter in front of the protecting ring around the screw, the two shutters being first closed. After the instrument is lowered into the water, this device is released by letting a weight, known as the messenger (*M*), slide down the supporting cable. When the messenger strikes the inner end of the locking lever, the latter releases the shutters which automatically fly open by

the action of springs, and also releases the stopper and permits the screw to rotate with the current.

68. The second device for stopping the rotation of the screw, for use at the conclusion of the measurement of the current, is a twin-spring lever (*F*) extending upward near the inner end of the locking lever. When the latter receives a blow from a second messenger (*N*) dropped by the observer, it is forced down and caught by the twin-spring lever which holds it in the locked position until the meter is raised to the surface. When the meter is being set preparatory to taking an observation, the twin-spring lever must be pressed toward the supporting cable and secured by the ratchet (*B*) so that it will remain inoperative until after the first messenger has been dropped. The first messenger releases the ratchet and permits this lever to resume its normal position ready to function as soon as the second messenger is dropped. The messengers weigh approximately one-half pound each and are designed so that they can be readily attached to the cable on which they slide freely.

69. For obtaining the direction of the current, the meter is provided with a compass needle (fig. 19) of magnetized rods which carries a small chute or grooved arm extending from the center to the south end of the needle. From a guide tube above the center of the needle small bronze balls are dropped one at a time and roll along the

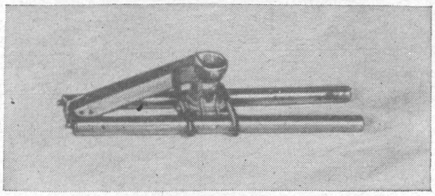

FIGURE 19.—Compass needle of Ekman current meter.

chute until they drop off at the south end. In the bottom of the compass box (*H*) there are 36 holes separated by radial partitions and below this compass box there is a receptacle (*L*) containing 36 compartments corresponding to the 36 holes above. As the meter swings with the changing direction of the current, different compartments of the receptacle are brought under the south end of the compass chute, and the particular compartment into which any ball rolls will indicate the direction of the current at that time.

70. Each compartment represents 10° of azimuth. The zero or north compartment, which is distinguished by being colored red, provides for an arc extending from 5° west of north to 5° east of north; and when the receptacle is fitted into the meter, this compartment is on the side furthest from the vane of the instrument. The compartments themselves are not marked by numbers. After the meter is taken from the water, the receptacle is removed from the instrument and placed in a circular graduated frame (fig. 20) with divisions numbered counterclockwise from 0 to 35. When fitted in the frame the red or north compartment of the receptacle is adjacent to the 0 graduation of the frame. A ball in any compartment then indicates a current having an approximate azimuth corresponding to the number on the frame with a cipher annexed. For example, a ball in compartment No. 1 indicates a current flowing approximately N. 10° E., or between the limits N. 5° E. and 15° E. A ball in compartment No. 35 indicates a current flowing approximately N. 10° W.

71. The bronze balls are kept in a magazine consisting of a tube (*E*) which leads to a drum in the gear box of the instrument. This drum rotates as the meter operates,

878447°—50——3

making one turn for each hundred turns of the screw. Around the circumference of the drum there are three pits, each of which, when passing the magazine, carries away the lowest ball and, after a half revolution of the drum, drops it into the guide tube leading to the compass box. Thus there are three balls deposited in the compass box for each hundred revolutions of the screw.

72. **Instructions for use.**—Because of the complicated construction of the meter special care is required in the handling. It should be kept clean and well oiled and should be examined frequently to see that all movable parts work freely. Special attention must be given to the tubes that convey the direction balls to the compass box, as these sometimes become clogged so that the balls cannot pass through. In order to clean these tubes it is necessary to remove the gear wheels from the dial box and insert a slender wire to free the tubes of any obstruction.

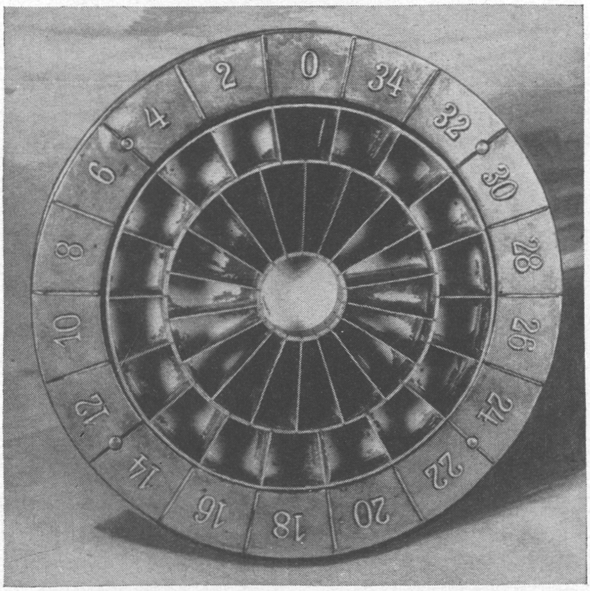

FIGURE 20.—Graduated frame with compass-ball receptacle from Ekman current meter.

73. When the meter is not in use, the compass needle and the screw should be removed from the instrument. Special care must be taken in handling the screw to avoid any injury to it. To insert the screw and shaft; release the bar (*G*), which carries the forward bearing, by pushing on the catch (*D*). Insert the worm end of the shaft through the hole in the gear box and secure the bar (*G*).

74. To place the needle in the compass box; remove the receptacle (*L*) by pressing the spring catch on the bottom of the supporting bracket. Remove the compass box (*H*) by pressing the catch on the bottom of the frame just above and forward of (*H*). Pry up the cover of the compass box and set the needle on the pivot point. In replacing the cover, the bevel of the slot for prying off the cover should face downward, and the small lug on the box should fit into the small notch on the cover.

75. A 15-pound streamlined counter-weight preferably of the *Columbus* type should be used with the Ekman meter. The small weight supplied with meter No. 110 is inadequate.

76. The vane or tail is attached to the main part of the meter by two brass tubes. The tubes are secured to the vane with left-handed screws and are afterwards fastened

to the main part of the instrument by right-handed unions, which are pulled tight with a key.

77. When preparing to take an observation, the meter should be checked to see that the screw turns freely and that the bronze balls are deposited regularly according to the speed with which the screw is rotated. The receptacle below the compass box should be emptied of any balls it may contain and the magazine filled if necessary. The dial readings should be recorded or the pointers turned to zero. The dial pointers are adjustable, being held on their shafts by friction, but frequent adjustments may cause the pointers to become loose and drop off. Except at the beginning of the work, the pointers should not be changed. The practice of letting the last dial reading of each measurement become the initial reading for the following measurement affords some check against any large error that might be made in the reading and also is the most convenient method for doing the work.

78. Before placing the meter in the water the two front shutters are closed and secured by the end of the locking lever. This also locks the screw so that it cannot turn until released by the first messenger. The twin-spring lever must be pressed towards the supporting cable and secured by the ratchet provided for the purpose. This is important and if not done, the screw will not be released when the messenger is dropped.

79. After the meter has been lowered to the depth at which an observation is to be taken, one of the messengers is attached to the cable and allowed to slide down, the time of release being recorded. After the lapse of any specified time interval that has been selected for the purpose (a 10-minute interval is frequently used), a second messenger is dropped. The meter is then drawn to the surface and the dials read and recorded. The receptacle containing the deposited bronze balls is removed from the instrument and placed in the graduated reading frame. The direction of the current as indicated by the compartment containing the balls is recorded. Balls may be found in more than one compartment and in this case the average direction as indicated by the compartment containing a preponderance of the balls is taken. When it is desired to resume observations with a minimum delay, an extra receptacle may be used and the meter can then be returned to the water immediately after the dial reading has been taken and the instrument reset.

80. **Rating table.**—Each meter must be calibrated before using in order to determine the relation of the velocity of the current to the speed of rotation of the meter wheel or screw. In the Ekman meter this relation will depend largely upon the shape and pitch of the blades of the screw. Each meter is usually provided with an extra screw which must be calibrated separately. The rating formulas given below were determined from Bureau of Standards calibrations of Ekman current meter No. 110, using screws Nos. 219 and 220.

Let V=velocity of current in knots, and
N=number of revolutions of the screw per minute.
Then $V=0.0110N+0.020$ for screw No. 219 and
$V=0.0116N+0.020$ for screw No. 220.

The above formulas were used in the construction of Table 4 on page 50. Although this table is prepared for an observational period of 1 minute, it can be used with equal convenience if the observational period covers 10 minutes by simply entering the table with a number one-tenth as great as given by the meter. In general it will be better to use the 10-minute time interval for this meter.

Radio Current Meter*

81. The radio current meter was developed by Capt. Elliott B. Roberts of the Coast and Geodetic Survey, and has been used for a number of years with satisfactory results. It is designed to measure both velocity and direction. It normally requires the use of considerable auxiliary equipment but has the very decided advantage that it can be operated from an anchored buoy thus obviating the necessity of maintaining a vessel and crew at each current station during the entire period of observations at the station.

82. In the radio current meter a rotating impeller is actuated by the current. The impeller is connected through a magnetic drive to an enclosed interior mechanism which makes and breaks an electric circuit by means of two contacting devices. One makes a contact at each fifth turn of the impeller, the frequency of these contacts serving as a measure of current velocity; the other makes a contact at each tenth turn of the impeller. The first contacting device is connected with a built-in magnetic compass; the second is fixed relative to the meter body. The devices are so arranged that when the instrument is heading south both contacts will occur at the same time. When the meter heads in any other direction, the time relation between the two sets of contacts changes with the meter heading. This time relation, therefore, serves as a measure of the direction of the current.

83. In operation, the meter is suspended from an anchored buoy. The buoy houses a radio transmitter, complete with batteries, which is connected electrically with the meter and with an antenna mounted on the buoy. The contacts made within the meter are thus relayed as radio signals by the transmitter to a receiving station.

84. The receiving station may be either aboard ship or on land. It is equipped with a suitable radio receiver, a chronometer which furnishes the time reference for the signals, and a chronograph for recording the time in seconds and the radio signals.

85. From the chronograph tape the number of seconds between velocity contacts is determined and the corresponding velocity is taken from a rating table prepared from a calibration of the meter. The direction is read directly from the tape by means of a converging scale having graduations from 0 to 360 degrees. The zero- and 360-degree graduations are placed upon adjacent velocity marks and the direction read on the direction mark. Direction marks are distinguishable by the double time interval. There is a direction mark between every other pair of velocity marks.

83. The buoy used with the radio current meter is specially designed for that purpose. It is described in detail in the radio current meter operating manual. The problem of anchoring the buoy has been given considerable study some of the results of which are shown graphically in Figures 22 and 23. Figure 22 shows the length of 7 x 7 x 3/16 (3/16 inch in diameter having 7 strands of 7 wires each) stainless steel cable required for anchoring the 80-inch buoy in different depths and current velocities. The limiting condition shown by the dashed curve is the greatest anchoring depth possible in the given current velocity. Figure 23 shows similar data for a 120-inch buoy using 7 x 7 x 1/4 stainless steel cable. The procedures followed in planting and recovering the buoys are discussed in paragraphs 105–109.

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*The original model of this instrument has been employed in a number of current surveys. The methods of use are described in detail in *Roberts Radio Current Meter Operating Manual.* An improved Model II, now available, is described in a revised (1950) edition of the Manual.

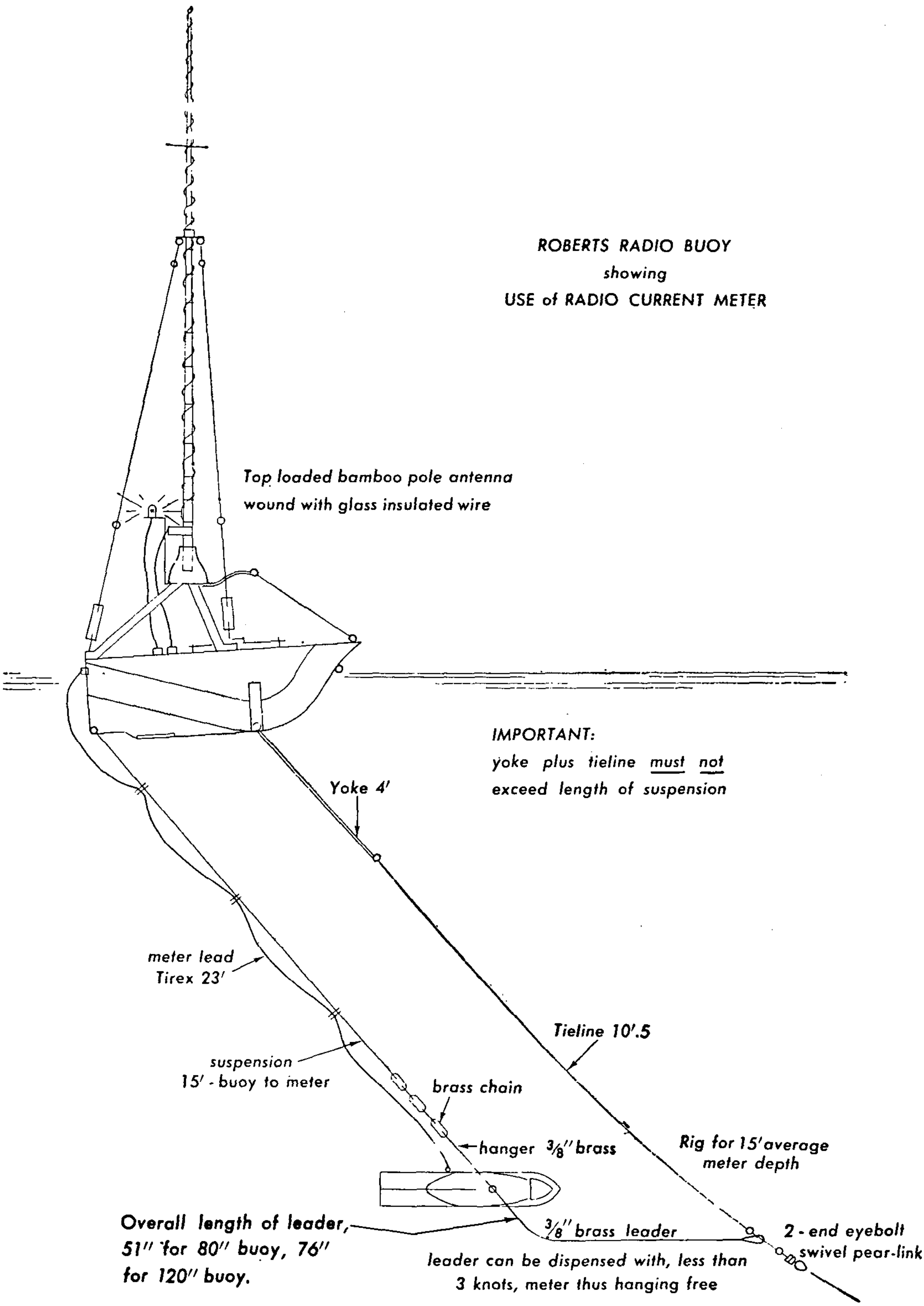


FIGURE 21.—Radio buoy and use of radio current meter.

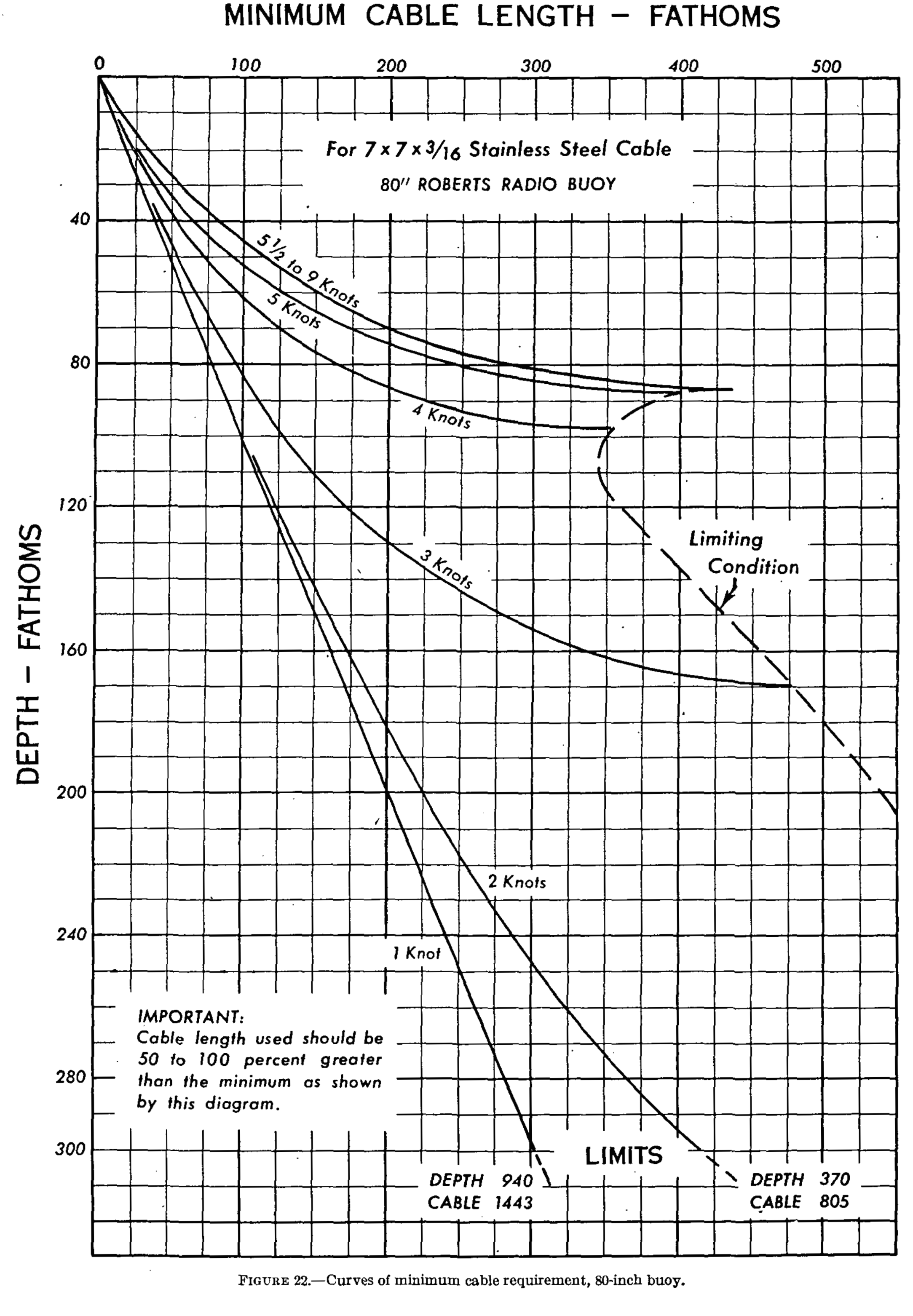


FIGURE 22.—Curves of minimum cable requirement, 80-inch buoy.

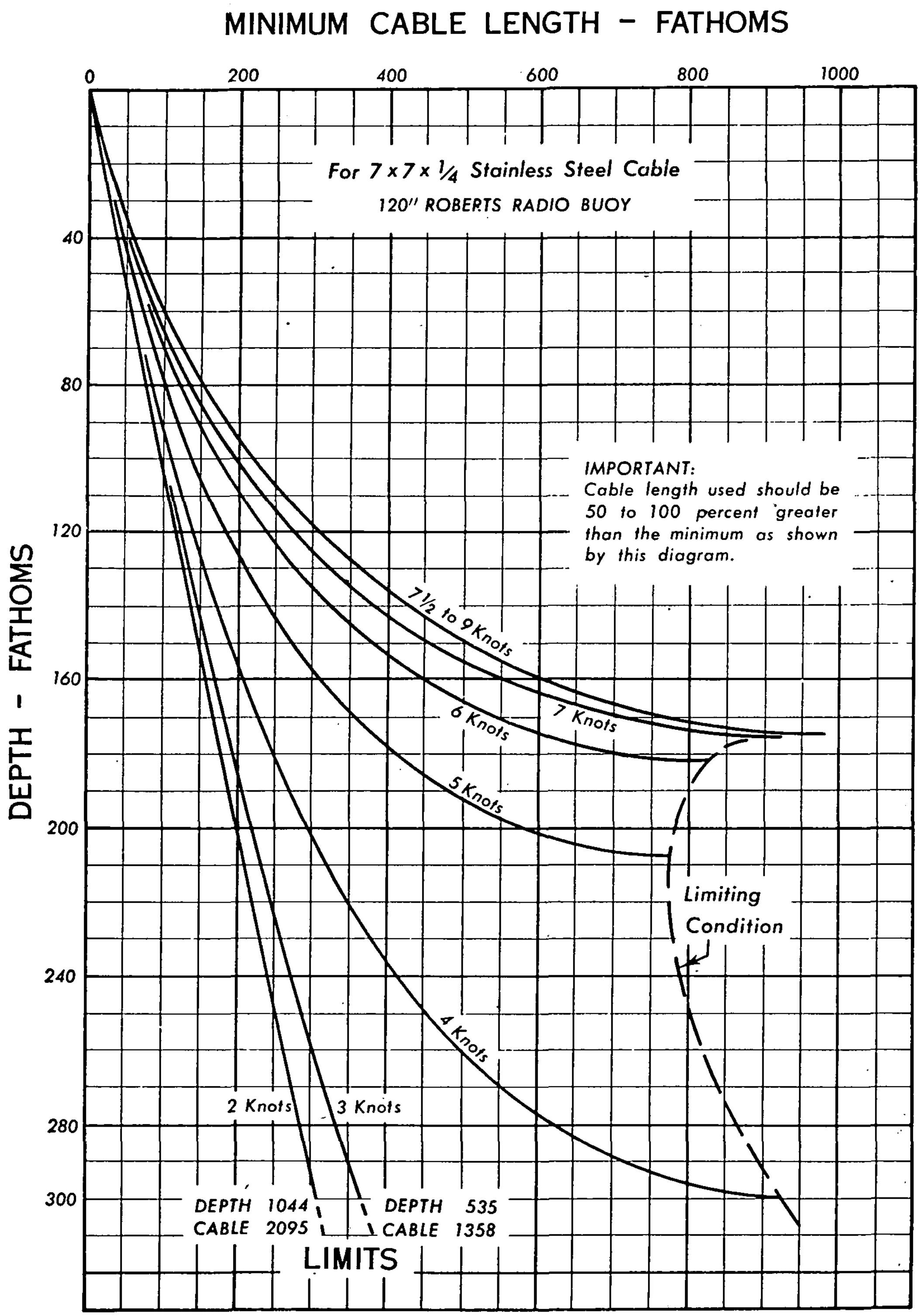


FIGURE 23.—Curves of minimum cable requirement, 120-inch buoy.

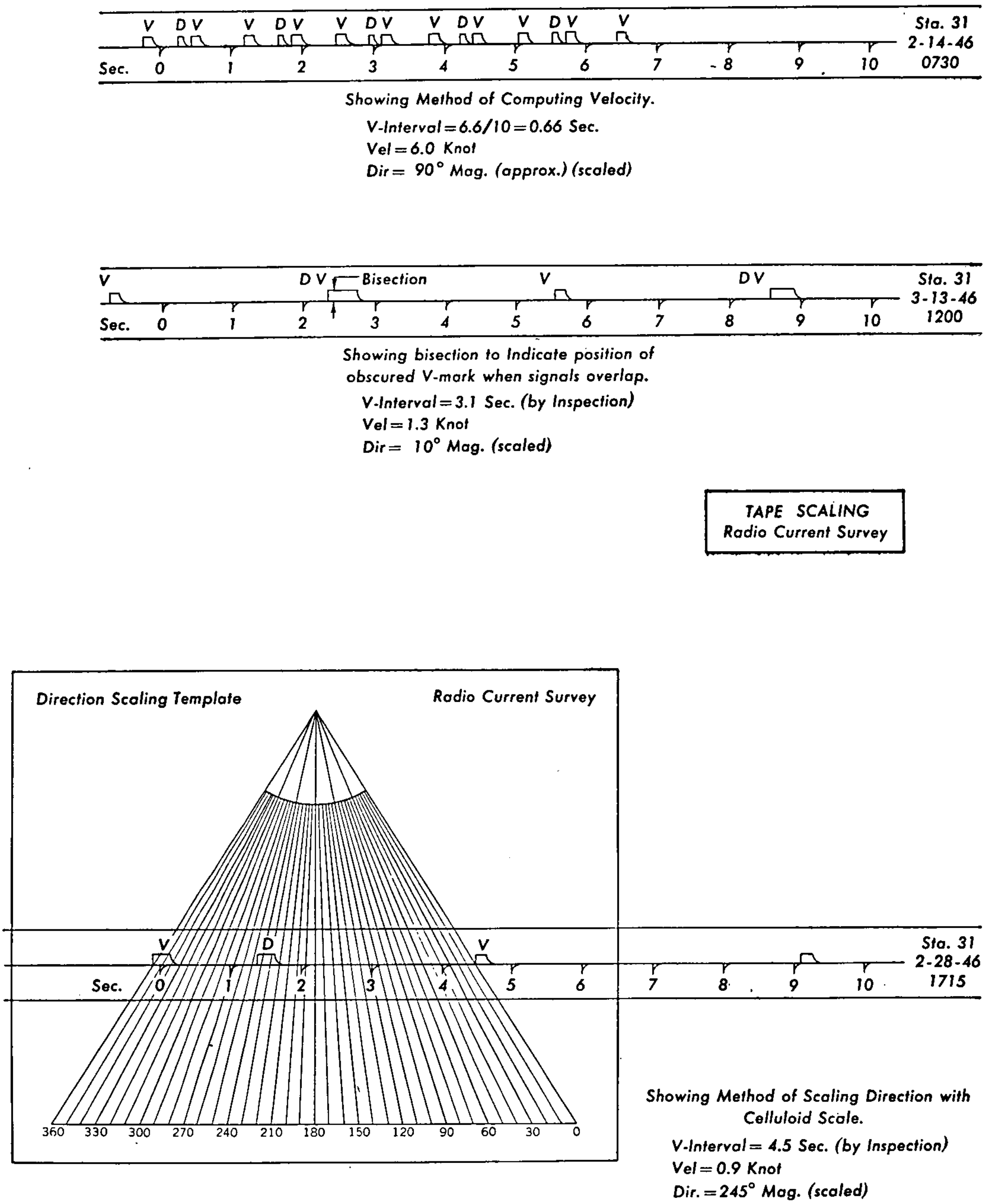
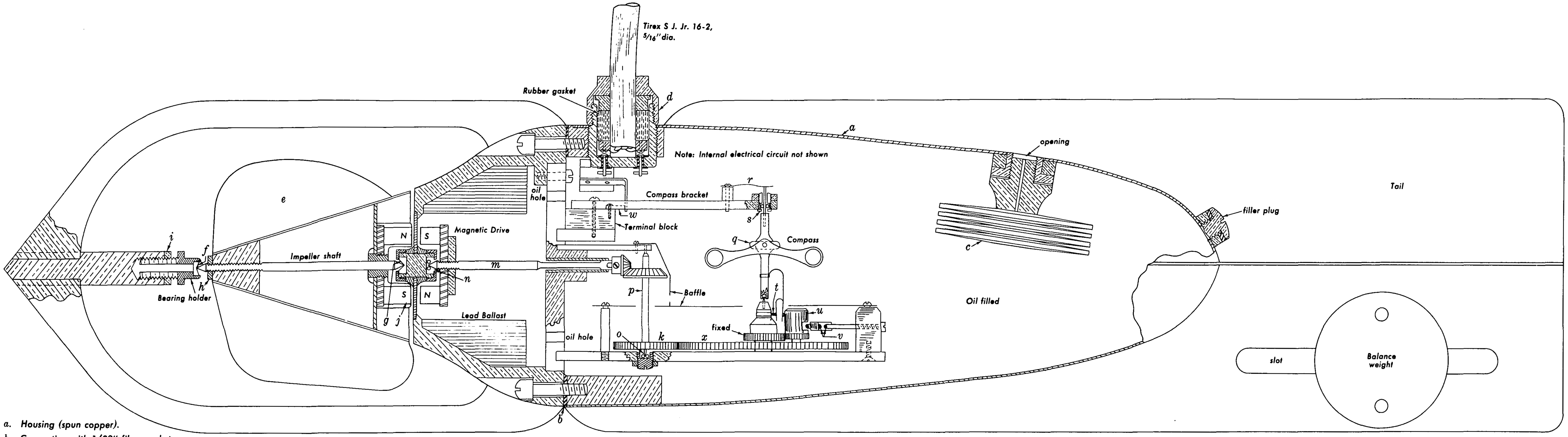


FIGURE 24.—Tape scaling, radio current meter.



a. Housing (spun copper).
b. Connection with 1/32" fiber gasket.
c. Expansion chamber, bellows type, nickel silver.
d. Water and oil proof cable attachment fitting.
e. Impeller.
f. g. Impeller bearings, lignum vitae.
h. Impeller adjustment locknut.
i. Forward bearing holder locknut.
j. Case containing impeller part of magnetic drive.
k. Transmission gear.
m. Drive shaft.
n. Drive shaft thrust bearing,
o. Transmission spindle lower bearing,
p. Transmission spindle.
q. Compass cardan ring.
r. Spring contact clip.
s. Compass upper guide bearing,
t. Velocity contact point.
u. Planetary contactor.
v. Direction contact points.
w. Terminal block lugs.
x. Base gear.

Scale - Inches

1 ½ 0 1 2 3 4 5 6

U. S. COAST AND GEODETIC SURVEY

ROBERTS RADIO CURRENT METER

Sketch Showing Mechanical Arrangement

FIGURE 25.—Radio current meter, original model.

878447 O - 50 (Face p. 34) No. 1

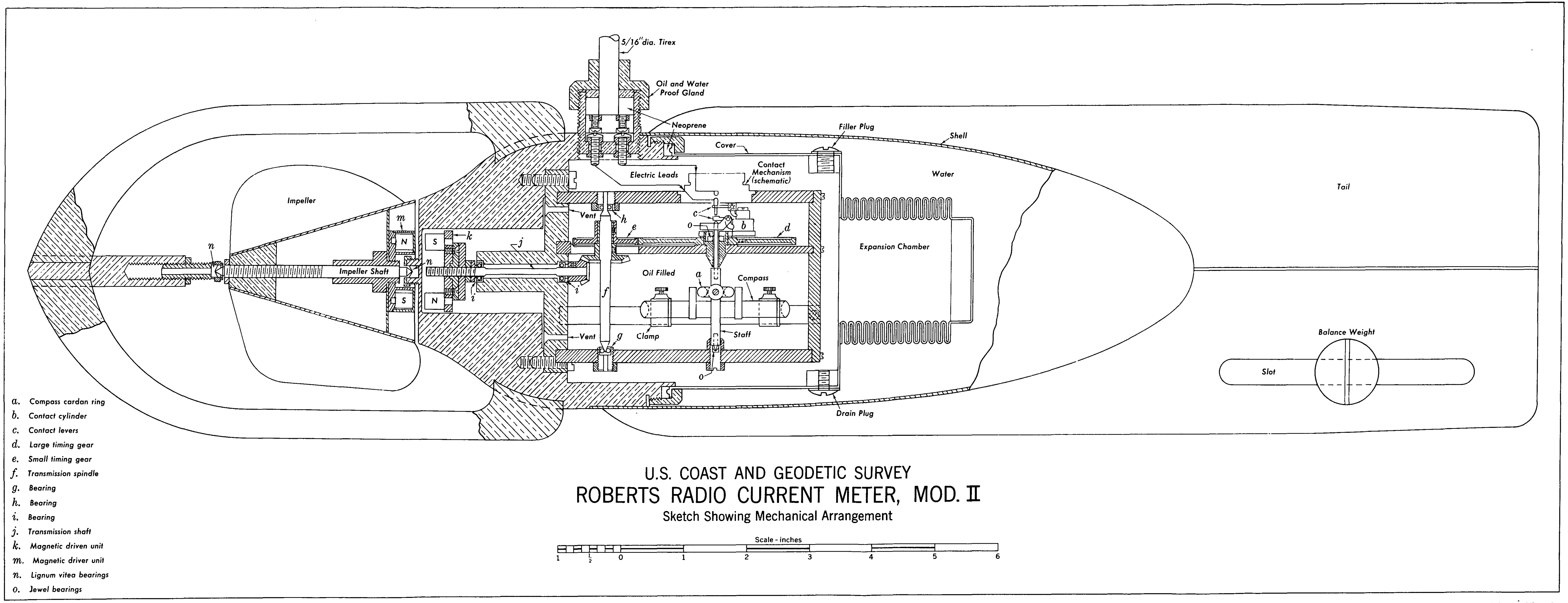


FIGURE 26.—Radio current meter, improved model.

878447 O - 50 (Face p. 34) No. 2

87. **Rating table.**—Results of calibrations of radio current meters in use by this Survey show sufficient uniformity to justify the use of a single rating table for all the radio current meters now on hand. From Bureau of Standards calibrations of eight of the instruments, a rating formula, representing the average of the eight calibrations, has been derived. The rating formula follows:

Let V=velocity of current in knots and
N=number of seconds between velocity contacts

Then $V=\frac{3.9795}{N}+0.041$

The above formula was used in the construction of Table 5 on page 50. This table may be used for any radio current meter now in use by this Bureau.

Pettersson Current Meter

88. The Pettersson current meter, originally designed by Prof. O. Pettersson and later modified by Dr. Hans Pettersson, has been used to a limited extent by this Bureau. It is complicated and weighs about 200 pounds. The meter is designed to give a photographic record of both the velocity and the direction of the current and will operate automatically without an attendant for about 2 weeks. The recording apparatus is contained in a watertight cylinder, below which is an anemometer wheel that is actuated by the current. The movement of the anemometer wheel is transmitted to the recording apparatus inside the cylinder by means of a magnetic drive.

89. The cylinder contains a tiny camera with a roll of film that is moved by clockwork, a small electric lamp with batteries, a glass velocity disk with numerals inscribed near the outer edge, a glass compass disk carrying two magnetic needles and inscribed with numerals to indicate direction, and a system of reducing gears connecting with the velocity disk. At intervals of 30 minutes the electric lamp is automatically flashed and a picture is taken showing numerals on each of the two disks. The numeral on the compass disk indicates the direction of the current at the time the picture was taken, and the numeral on the velocity disk indicates the accumulated revolutions of this disk resulting from the rotation of the anemometer wheel. The difference between two successive readings of the velocity disk, as interpreted by a rating table, will give the average velocity of the current for the half-hour period between the light flashes. A detailed description of this meter with instructions pertaining to its use is contained in Coast and Geodetic Survey Special Publication No. 124, *Instructions for Tidal Current Surveys*. A description by Dr. Hans Pettersson will be found in the *Quarterly Journal* of the Royal Meteorological Society (London), vol. XLI, No. 173, January 1915.

Free Floats

90. In some narrow passages where the current is swift, it may be impracticable to anchor a boat to observe the currents by the usual means. A method of securing observations in such cases is to establish two parallel ranges on shore at approximate right angles to the stream, measuring and recording the distance between the ranges. Floats are then thrown into the stream at regular intervals and allowed to drift by the ranges while observers equipped with stop watches and stationed at the ranges observe the time of passage from one range to the other.

91. Two types of floats have been used, depending upon whether they are thrown from the shore or dropped from a boat at some distance from shore. In the first case, strips of 2-inch by 2-inch lumber about 18 inches long may be used advantageously. Their visibility is increased by wrapping them in cloth. If the float is to be dropped at a considerable distance from shore, something larger will be necessary. Such a float may consist of two horizontal crosspieces about 3 feet in length and an upright about 4 feet long, the material being 2-inch by 2-inch lumber. A small piece of cloth attached to the top will aid the visibility, but should not be so large as to cause the movement of the float to be materially affected by the wind.

92. The velocity of the current may be determined from the distance between the ranges and the time necessary for the float to travel this distance by means of the following formula:

$$\text{Velocity in knots} = \frac{\text{distance between ranges in feet}}{\text{time to travel distance in seconds}} \times 0.592$$

When the same ranges are used for a large number of observations, the computation of the velocities will be facilitated by a table prepared from the above formula.

Current Surveys

93. Systematic tidal current surveys of the principal waterways of the country, which involve considerable expense and equipment, are undertaken from time to time. Several vessels are employed and a number of stations are occupied. One station is selected as a primary or control station to be maintained throughout the entire period of the survey. At the secondary stations observations have frequently been limited to 2 or 3 tidal days, but longer series are greatly to be desired, especially at points where the current is of considerable importance Whenever practicable, observations at important points should cover a period of not less than 2 weeks and preferably a full lunar month.

Selection of Stations

94. Previous to the field work, the office prepares a plan for the survey which includes the proposed current stations plotted on a large scale chart. This preliminary selection of stations is based upon the requirements for general information and also upon any special purpose for which the survey is being undertaken. Stations located in harbor entrances and in main channels are especially important for the purposes of navigation, but stations located in secondary channels and at different points in the cross section of a stream will also supply information relating to the general circulation of the water in a harbor which is of special value to engineers.

95. After the survey party has reached the working grounds, it may be found impracticable on account of local conditions to occupy each station as plotted in the office. Traffic conditions or very swift currents may make the occupation of a station too hazardous, or the presence of a submarine cable, a pipe line, or an unsuitable bottom may preclude anchoring altogether. In such cases the chief of party should ascertain if there is a more suitable location available. While current observations are usually taken from a floating vessel they may be taken also from a fixed support such as a bridge or a platform supported by piles. Observations taken from a fixed support, being free from the effects of the pitching and tossing of a vessel, are in general to be preferred.

Organization and Equipment

96. A current survey party usually consists of a number of units so that several stations can be occupied simultaneously. The number of units will depend upon circumstances. A typical party consisting of four units requires four boats for observing and one tender to carry supplies and enable the chief of party to keep in close contact with all of the units. In general, each unit is organized with a personnel of 6 observers and a cook, one of the observers being a junior officer who is also in charge of the entire unit. As the work is carried on both day and night, it has been found convenient to have 4-hour watches with two observers on each watch, one of whom is held responsible for the work during the watch.

97. The selection of the floating equipment will depend upon the locality and upon the availability of vessels for hire. Among the factors to be considered are the strength of current, liability to danger of collision, exposure to heavy seas, sleeping accommodations required, ground tackle necessary, and deck space available for setting up gear. For harbor work the observing vessels need have little power but the tender should have a speed of 8 knots or more to enable the work to be carried on efficiently. In a waterway where the currents have considerable velocity and dense traffic introduces a factor of danger from collision, a flat-bottom barge which may be towed from station to station by the tender may be found desirable; while in other waterways where the currents are moderate and the traffic light, a power launch 60 to 75 feet long and capable of housing the complement of the unit may be found more economical. In some sheltered locations smaller boats may be used if other provisions for housing the observers can be conveniently made.

98. Standard instrumental equipment for observing includes current poles, log lines, current meters, stop watches, compasses, peloruses, and sextants. Necessary drawing instruments include three-arm protractors for plotting positions. A sufficient number of spare instruments and parts must be provided to insure against any interruption to the observations as a result of loss or the failure of an instrument to function. Sheaves, reels, and winches for handling the observing apparatus, and the equipment necessary for navigating and anchoring the boat and for feeding and housing the observing party must also be provided. When installing equipment on the observation units, all operating gear should be placed so as to reduce to a minimum any lost motion in setting out gear after anchoring on station. As far as possible gear should be under cover so that it may be kept dry and the observations carried on without interruption in rainy weather. After the party has arrived on the working grounds, the compasses which are to be used by the several observing units must be checked for deviation and tables of corrections prepared. (See pars. 35–38.)

Operating Procedure From an Anchored Vessel

99. Each observing unit proceeds as near as practicable to its assigned station. When possible the vessel should be anchored fore and aft so that its position will remain as nearly fixed as possible without swinging with the current. This is especially important in narrow waterways where a small change in position might mean a considerable difference in the current. When this mooring is impracticable and a single anchor is used, the chain should be as short as possible to maintain position without dragging.

100. After the vessel has been moored, its exact position must be determined. This may be done by compass bearings, by sextant angles or by radar. By the first method at least 2 charted reference objects are necessary and by the second method there must be 3 or more such objects. When practicable the reference objects should be selected so that the angles subtended will be fairly large, as angles less than 30° cannot usually be expected to give strong positions. When the position of the station is to be determined by sextant angles, it must be kept in mind that this method will fail if the station occupied happens to lie in the circumference of a circle that also passes through all the reference objects. The bearings or angles must be immediately recorded in the current record book, and the position of the station plotted on a chart or work sheet.

101. The general plan for observing the currents is covered by the instructions furnished to the chief of party. The usual procedure has been to take half-hourly observations, using the current pole for the surface currents and the Price current meter for the subsurface currents. Other types of meters are sometimes used. Before beginning work, the instruments should be checked to see that they are in good order. The distance between the graduation marks on the log line must be measured and any material error corrected. As this is a matter of considerable importance, a statement pertaining to the verification of the line should be entered in the record. The length of a cotton line of the type generally used varies with moisture conditions. The lines are wet when graduated and must be wet when the graduations are checked as well as when in use.

102. The direction of the surface current is obtained in connection with observations by the current pole. There are three different methods already described which may be employed—by compass direct (par. 40), by pelorus in connection with the ship's compass (par. 42), or by sextant angles to a charted reference object (par. 44). In general, the use of sextant angles is not adapted to continuous day and night observations, since the reference object may frequently be obscured by fog and darkness. This method is, however, of value as an occasional check on the use of pelorus and compass. When a lighthouse is visible, sextant angles to the current pole can be observed during darkness by attaching a lighted flashlight to the current pole.

103. The subsurface observations with the Price meter are usually taken at three depths, which are approximately 2-tenths, 5-tenths, and 8-tenths of the depth of water at the station. If the depth of water at the station is less than 20 feet, meter observations at the 5-tenths depth only are usually sufficient. The meter depths are measured from, and should remain fixed relative to, the water surface. They are not to be varied as the tide rises and falls. When observing at three meter depths the meter is first lowered to the upper depth and held in this position for 1 minute while the revolutions of the meter wheel are counted and recorded. The meter is then lowered successively to the middle and lowest depths and similar observations taken. The observations are then repeated at each depth in reverse order as the meter is drawn upward. As it is a convenience to have the observations taken as near as possible on the exact hour or half-hour, it should be the aim to have the first observation at the upper depth taken as many minutes before the exact hour or half-hour as the repeat observation at the same depth is taken after this time. The average of the two observations at each depth may then be attributed to the exact hour or half-hour. Pole observations if taken by the same observer should follow the first observation at the lowest depth before beginning the repeat observations.

Operating Procedure Using Radio Current Meter and Buoy

104. The general plan of the survey is outlined and the locations at which current observations are to be made are specified in the instructions covering the current survey. Before proceeding to the current stations at which buoys are to be anchored, all meters, transmitters, receivers and other equipment should be carefully adjusted and tested to insure that they are in good operating condition. Each buoy is anchored as near as practicable to the position designated in the instructions.

105. **Anchoring the buoy.**—The details of anchoring the buoy and suspending the meter are shown in Figure 21. If the velocity of the current is expected to be less than

three knots, the meter may be hung free from the buoy without the use of a leader. Observations are made at a single depth, which is usually 15 feet below the water surface. The weight of the anchor and the amount of chain and cable to be used will depend upon the depth of water at the proposed location of the current station and the velocity of the current. The minimum lengths of cable required for anchoring in various depths and current velocities are shown on Figures 22 and 23. These figures should be studied and understood before attempting to anchor the buoy. The anchoring equipment and meter are secured to the buoy and arranged on deck so that there will be no fouling of the gear as the mooring cable is payed out.

106. The vessel is maneuvered into position so that the buoy anchor will be ready to drop on the selected location. The buoy is placed in the water and released from the boom cable. The cable is payed out as the buoy clears the vessel which is backed slowly if necessary. In backing extreme care must be observed not to upset the buoy. With buoy streamed and clear and no slack in the cable, the anchor is dropped in the selected location. After the buoy is anchored, its exact position must be determined by the methods described in paragraph 100. All bearings, angles or other observations used in determining the buoy position must be recorded and included in the current record book (Form 270) for that station. The position of the buoy anchor is the location of the current station.

107. As soon as a buoy is anchored and streamed into the current, test observations are secured with receiving equipment to make sure that the station is operating satisfactorily. Thereafter, the velocity and direction of the current are recorded half hourly by radio receiving equipment and chronograph which may be on a vessel or at a shore station. The chronograph tapes should be processed at the receiving station after each half-hourly observation. The velocity and direction are determined as explained in paragraph 85. The velocity in knots and tenths and the true direction in degrees reckoned clockwise from north are tabulated in a copy of Form 270. This copy of form 270 must contain all the data called for in paragraphs 111–113 with the exceptions of the items that obviously are inapplicable to the measurement of currents by the radio current meter.

108. **Recovering the buoy.**—For recovering the buoy a time is selected when the current is weak. The vessel slowly approaches the buoy against the current. As the vessel arrives alongside the buoy, the buoy is caught with a boat hook, secured to a block and raised from the water. The slack in the buoy anchor cable is hauled in by hand and secured to a bitt. The buoy is detached from the cable and attached to a line leading over the bow to the windlass. The meter is detached from the buoy and the buoy secured on deck. During this operation it is important that the ship put no strain on the buoy anchor particularly during the early stages of the operation before the cable is detached from the buoy. In a modification of the recovering procedure, the buoy anchor cable, rather than the buoy, is caught with a boat hook and a loop of the cable with adjacent slack hauled on deck and made fast. Then the cable is detached from the buoy, the buoy raised, the meter detached, buoy and meter secured and anchor cable and anchor hauled aboard with the windlass.

109. A spherical relieving buoy has been used successfully in conjunction with the radio current buoy in the following manner. The buoy was anchored in a depth of 30 fathoms. One end of a 30-fathom, 3-inch manila line was attached to a spherical buoy and the other end to the buoy anchor cable at a position 15 fathoms below the buoy. A 4-foot piece of 2-inch by 4-inch timber was made fast to the manila line at the end attached to the cable. This piece of timber was inserted to prevent winding

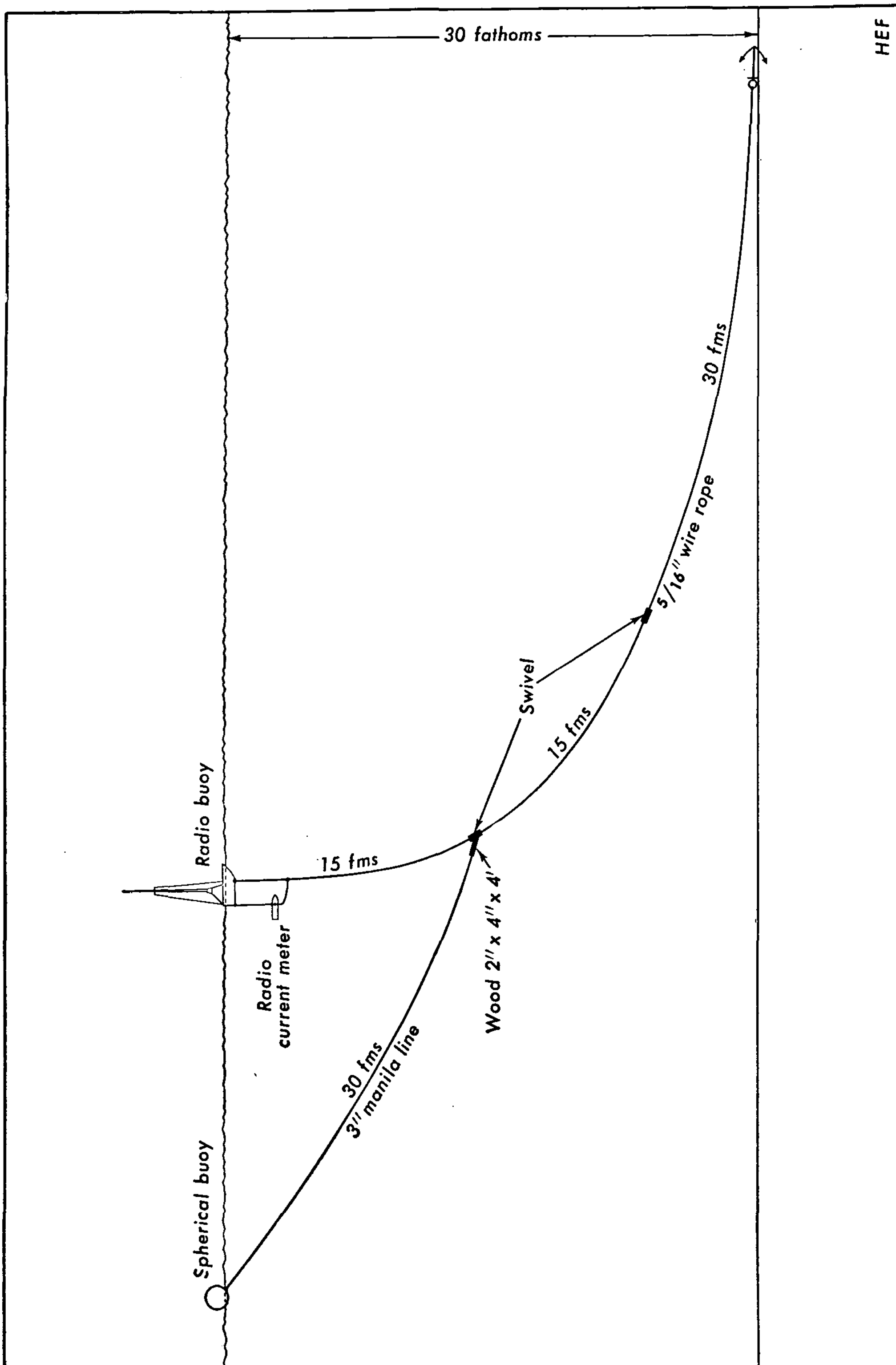


FIGURE 27.—Radio buoy with relieving buoy anchored in depth of 30 fathoms.

of the line around the anchor cable. In planting, the relieving buoy was set out first; then the current buoy with meter was streamed; anchor cable payed out; and finally anchor was dropped as the ship was going astern away from the buoys. In recovering, the relieving and current buoys were kept on line while conning the vessel to pick up the relieving buoy. The relieving line was hauled directly over the bow and the anchor cable was secured temporarily just below the 15-fathom shackle. (See fig. 27) That section of the anchor cable secured to the meter was detached and held until the tackle of the boom was secured to the current buoy, which then was hauled aboard without any strain or difficulty. Use of the relieving buoy also provided a method of observing the surface direction of the current for checking the operation of the meter. Figure 27 shows the method of anchoring the radio current buoy with a relieving buoy.

110. Detailed information relative to the use of the radio current meter and buoy is contained in the Radio Current Meter Operating Manual.

Records

111. Form 270. *Record of Current Observations* is a book especially designed for recording observations taken with the current pole and with the Price current meter. The form may also be adapted for observations taken with other types of meters. General information pertaining to the current station must be entered in the front part of the book. This includes a deviation table for the compass used in the work, and detailed information regarding the kind of time used, apparatus employed, and method of anchoring the vessel. A section of chart or a tracing on which the station is plotted should be pasted on the inside front cover at the beginning of the record. Reference objects used for angles and bearings must be sufficiently well described for identification.

112. The information required for the heading of each page must be supplied. If the vessel is anchored so that it is free to swing, the position angles should be repeated from time to time and recorded with the time of measurement. Such entries may be placed in the column of remarks if there is insufficient space in the heading of the page. Entries made in the several columns must be in accord with the respective headings, the latter being revised if necessary to take account of any variation. The direction and velocity of the wind are to be entered in the columns provided. By common usage, direction of wind signifies the direction *from* which the wind is blowing, and this usage will be followed in recording wind direction. If an anemometer or other means of measuring the wind velocity is available, the fact should be noted with the general information at the beginning of the record. Otherwise the velocity of the wind is to be estimated in statute miles per hour. To assist in this estimate the following scale is provided, the velocities indicated being statute miles per hour (m. p. h.).

	Velocity m. p. h.		*Velocity m. p. h.*
Calm	Less than 1	Moderate gale	32–38
Light air	1–3	Fresh gale	39–46
Light breeze	4–7	Strong gale	47–54
Gentle breeze	8–12	Whole gale	55–63
Moderate breeze	13–18	Storm	64–75
Fresh breeze	19–24	Hurricane	Above 75
Strong breeze	25–31		

113. Any unusual condition that might affect the current or any information that would be helpful in the interpretation of the record should be entered in the column of remarks. The observer should place his initials in the last column which is provided for this purpose. If the record for any station covers more than one book, the volumes are to be numbered in order, the total number of volumes being indicated on the cover of the first book and the close of the series noted on the last volume. In general, more than one station will not be recorded in a single book unless there are a number of very short series of observations in the same general area.

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Observations at Lightships

114. Through the cooperation of the Coast Guard arrangements are made from time to time for current observations to be taken by the officers and crews of lightships while on their regular stations. These observations are taken hourly with a 15-foot current pole and log line, using a stop watch for timing the run-out of the pole and a pelorus for determining the direction of the current.

115. **Pelorus.**—The pelorus is described in paragraphs 41–42. The instrument is to be mounted in the stern of the vessel with the 0° mark forward or inboard and with the line through this mark and the center of the instrument either exactly in the fore-and-aft line of the vessel or exactly parallel to it.

116. **Current pole and log line.**—Descriptions of these instruments will be found in paragraphs 25–30. The log line should be marked for an observational interval of 60 seconds, the distance between the marks for the whole knots being 101 feet 4 inches and the distance between the marks for the tenths of a knot, 10 feet 1.6 inches. There should be not less than 80 feet of stray line. The log line must be checked occasionally, the measurement being made when the line is wet, and any error in the distance between marks noted in the record book. If the line has been broken, it must be carefully re-marked after repairs and a note to that effect entered in the record book. A spare pole and line should be kept aboard the lightship at all times so that an occasional loss of these items will not interrupt the current record.

117. **Record book.**—Form 270a, *Hourly Current Observations*, has been especially designed for recording the hourly current observations taken on lightships. Each record book is to contain the observations for a single calendar month. The name of the station with the names of the master and observers and the period of time covered by the record should be written on the front cover. After the completion of the record for any month, the book is to be mailed at the first opportunity to the Director, Coast and Geodetic Survey, Washington, D. C. Official envelopes with printed address will be provided for the purpose. A copy of the deviation card for the ship's compass should be forwarded with the first record book for the station and with the record book following a change of lightships at the station or a compass adjustment. All current-observing equipment, including record books and instructions, should be transferred to the relieving lightship when there is a change of lightships at a station.

118. **Time used.**—Correct time is of great importance and each record book must have a statement on the first page telling the kind of time used and whether Standard or Daylight Saving time is followed. The clock or watch used for the observations should be checked frequently by radio time signals.

119. **Observing velocity.**—Have everything in readiness a little before the hour, and exactly on the hour start paying out the stray line. When the initial mark of the graduated portion of the log line passes some fixed reference point (a mark on the taffrail is convenient), press the stem of the stop watch. Continue to pay out the line for exactly 1 minute, taking care not to pay it out faster than the pole can carry it away; then check the line and read the velocity of the current to the nearest tenth of a knot as indicated by the mark on the line nearest to the fixed reference point. The number of knots and tenths must be immediately recorded in their respective

columns in the record book. In the event that other duties have prevented taking the observation on the exact hour, the observation may be taken as soon thereafter as practicable, but the time in the record book must be changed accordingly. Thus, if an observation is taken 10 minutes past 2, the corresponding hour in the first column of the record book should be changed to read "2:10."

120. **Observing direction.**—Immediately after the velocity has been recorded, stretch the log line across the center of the pelorus and read the graduation where the line intersects the forward half of the disk, that is between 270° and 360° or between 0° and 90°. This reading is to be taken to the nearest 5° and entered in the record book in the column provided for the purpose. The ship's head by standard compass must then be immediately recorded in the book. Attention is called to the fact that the pelorus reading is to be taken from the forward half of the disk regardless of whether the pole has been carried astern of the vessel or has drifted forward of the beam. In the latter case the note "Pole forward" must be inserted in the column of remarks. If the pole has drifted so close to the side of the vessel that a pelorus reading is impossible this should be noted in the record.

121. **Additional information.**—The direction from which the wind is blowing as determined by the ship's compass and its velocity in miles per hour are to be recorded each hour. The velocity of the wind may be estimated if there is no instrument available for a direct measurement. The scale given in paragraph 112 will be found helpful in making such an estimate. Any unusual condition of the sea or any other fact that may be of assistance in understanding the record should be recorded in the column of remarks. In the last column the observer should sign his name.

Reduction of Current Records

122. On receipt of the field records in the office, it is necessary to check and interpret the data. The forms most commonly used for recording the original observational data are Form 270 *Record of Current Observations* and Form 270a *Hourly Current Observations*. The first is for general use and provides for both pole and meter observations. The latter was designed especially for hourly pole observations at lightships. When an automatic recording device is used with the Price current meter, the record consists of a series of graphs on circular charts. Records from the radio current meter consist of chronograph-tape tracings together with the field interpretation of those tracings tabulated in copies of Form 270. Current records supplied by other organizations may be in various manuscript forms.

Record of Current Velocity

123. In the work of this Bureau, velocity of the current is usually expressed in knots, or nautical miles per hour, and this unit is generally indicated in the forms used in connection with the work. If velocities have been expressed in any other unit, care must be taken to have all papers marked accordingly. For convenience, reduction processes may be carried on with the original units used for the observations, but the final current velocities should be expressed in knots. The factor 0.592 applied to velocities given in feet per second, or the factor 0.0194 applied to velocities in centimeters per second, will convert these velocities to knots.

124. When observations have been taken with a current pole and line, the latter being suitably graduated, the velocities in knots and decimals are entered by the observer directly in the record book (Form 270 or 270a). When a Price current meter is used with earphone, the observer enters directly in Form 270 the number of revolutions of the meter wheel in a specified interval of time. The corresponding velocities are afterwards obtained by means of rating table (Table 2) and entered in the column provided for the purpose in the same form. The rating table is directly applicable if the standard observational interval of 60 seconds has been used for the observations, but may be adapted to another observational interval by the use of an appropriate factor. For example, if an observational interval of 30 seconds has been used, the number of revolutions should be doubled before entering the table.

125. For the interpretation of the graphs from the recording device sometimes used with the Price current meter, the following procedure involving the use of Table 3 is recommended when the contact ratio is either 1:10 or 1:50. Prepare a curved scale covering a little more than 1 hour of the graphic record and divide it into 12-minute (0.2 hr.) spaces. In the middle of the first space make a distinctive mark which will be applied to the beginning of each hour in the graphic record. The first 12-minute space will then cover an interval from 6 minutes before the hour to 6 minutes after the hour and the average velocity for the period may be attributed to the exact hour. Also, the successive 12-minute periods may be taken as representative of the exact fractional parts 0.2, 0.4, 0.6, and 0.8 of the hour.

126. The beginning of each hour should be indicated on the graph. If this has not already been done by the observer, the hour marks must be inserted by the tabulator, who will determine their position from such time notes as have been recorded. Next, apply the scale successively to the different hours of the graph and count the number of contact marks in each 12-minute space. These are to be recorded directly in the third column of Form 270 and the heading of the column revised to read "Number of contacts." In the following column note the time interval of 12 minutes and also indicate whether the contact ratio of the automatic recorder was 1:10 or 1:50.

TABLE 2.—*Rating table for Price current meter for 60-second time interval*

Rev.	Knots	Rev.	Knots	Rev.	Knots	Rev.	Knots	Rev.	Knots
1	0.04	46	1.02	91	2.00	136	2.99	305	6.69
2	.06	47	1.04	92	2.03	137	3.01	310	6.80
3	.09	48	1.06	93	2.05	138	3.03	315	6.91
4	.11	49	1.09	94	2.07	139	3.06	320	7.02
5	.13	50	1.11	95	2.09	140	3.08	325	7.13
6	.15	51	1.13	96	2.11	141	3.10	330	7.24
7	.17	52	1.15	97	2.14	142	3.12	335	7.35
8	.19	53	1.17	98	2.16	143	3.14	340	7.46
9	.22	54	1.19	99	2.18	144	3.17	345	7.57
10	.24	55	1.22	100	2.20	145	3.19	350	7.68
11	.26	56	1.24	101	2.22	146	3.21	355	7.79
12	.28	57	1.26	102	2.25	147	3.23	360	7.90
13	.30	58	1.28	103	2.27	148	3.25	365	8.01
14	.32	59	1.30	104	2.29	149	3.28	370	8.12
15	.34	60	1.33	105	2.31	150	3.30	375	8.22
16	.37	61	1.35	106	2.33	155	3.41	380	8.33
17	.39	62	1.37	107	2.36	160	3.52	385	8.44
18	.41	63	1.39	108	2.38	165	3.63	390	8.55
19	.43	64	1.41	109	2.40	170	3.74	395	8.66
20	.45	65	1.44	110	2.42	175	3.84	400	8.77
21	.47	66	1.46	111	2.44	180	3.95	405	8.88
22	.50	67	1.48	112	2.46	185	4.06	410	8.99
23	.52	68	1.50	113	2.49	190	4.17	415	9.10
24	.54	69	1.52	114	2.51	195	4.28	420	9.21
25	.56	70	1.54	115	2.53	200	4.39	425	9.32
26	.58	71	1.57	116	2.55	205	4.50	430	9.43
27	.60	72	1.59	117	2.57	210	4.61	435	9.54
28	.63	73	1.61	118	2.60	215	4.72	440	9.65
29	.65	74	1.63	119	2.62	220	4.83	445	9.76
30	.67	75	1.65	120	2.64	225	4.94	450	9.87
31	.69	76	1.68	121	2.66	230	5.05		
32	.71	77	1.70	122	2.68	235	5.16		
33	.73	78	1.72	123	2.71	240	5.27		
34	.76	79	1.74	124	2.73	245	5.38		
35	.78	80	1.76	125	2.75	250	5.49		
36	.80	81	1.79	126	2.77	255	5.60		
37	.82	82	1.81	127	2.79	260	5.71		
38	.84	83	1.83	128	2.82	265	5.82		
39	.87	84	1.85	129	2.84	270	5.92		
40	.89	85	1.87	130	2.86	275	6.03		
41	.91	86	1.90	131	2.88	280	6.14		
42	.93	87	1.92	132	2.90	285	6.25		
43	.95	88	1.94	133	2.92	290	6.36		
44	.98	89	1.96	134	2.95	295	6.47		
45	1.00	90	1.98	135	2.97	300	6.58		

Obtain the velocities corresponding to the number of contacts from the rating table and enter in the fifth column of the form. The times given in the first column should refer to the middle of each observational period, which will be an exact hour or an exact fifth of an hour. For another method of interpreting the graphic record without the rating table see paragraph 63. Table 2 is also applicable if the number of revolutions of the meter wheel per minute is first obtained by multiplying the number of contacts by the denominator of the contact ratio and then dividing by the number of minutes in the period covered by the count.

127. When the Ekman current meter is used, the number of turns of the meter screw in a specified interval of time is determined by the difference between dial readings taken at the beginning and end of the time interval. The observer is expected to record in a suitable note book these dial readings with the times of the observations. The difference between successive dial readings obtained by subtracting each reading from the one that precedes it (dial readings decrease with operation of meter) may then be entered in Form 270 together with the period covered by the observation. The time of the observation should be entered in the first column of the form. As each observation usually covers a number of minutes, that given in the record may be either the middle of the period or should indicate both beginning and end of the observation. Next, the velocity of the current for each observation is obtained by a suitable formula or rating table (par. 80). Table 4 has been prepared for use with meter No. 110. This rating table provides directly for a 1-minute observational interval, but when the period of observations covers a number of minutes, as is generally the case with the Ekman meter, the number of revolutions of the meter screw should be divided by the number of minutes covered by the observation to obtain the average for 1 minute which is used in entering the table.

128. It will be noted (par. 65) that the limit of the accumulated count of the Ekman meter is 4,000 revolutions, after which the instrument begins to repeat. In obtaining differences between successive dial readings, this fact must be kept in mind. Usually there will be little danger of misinterpreting the record on this account pro-

TABLE 3.—*Rating table for Price current meter for graphs from automatic recording device*

Contacts during 12-minute period	Velocity		Contacts during 12-minute period	Velocity		Contacts during 12-minute period	Velocity		Contacts during 12-minute period	Velocity	
	Recording ratio 1:10	Recording ratio 1:50		Recording ratio 1:10	Recording ratio 1:50		Recording ratio 1:10	Recording ratio 1:50		Recording ratio 1:10	Recording ratio 1:50
	Knots	*Knots*		*Knots*	*Knots*		*Knots*	*Knots*		*Knots*	*Knots*
1	0.04	0.1	16	0.31	1.5	31	0.58	2.8	46	0.85	4.2
2	.06	.2	17	.33	1.6	32	.60	2.9	47	.87	4.3
3	.08	.3	18	.34	1.7	33	.62	3.0	48	.89	4.4
4	.09	.4	19	.36	1.7	34	.63	3.1	49	.90	4.5
5	.11	.5	20	.38	1.8	35	.65	3.2	50	.92	4.6
6	.13	.6	21	.40	1.9	36	.67	3.3	51	.94	4.7
7	.15	.7	22	.42	2.0	37	.69	3.4	52	.96	4.8
8	.16	.7	23	.44	2.1	38	.70	3.5	53	.98	4.8
9	.18	.8	24	.45	2.2	39	.72	3.6	54	1.00	4.9
10	.20	.9	25	.47	2.3	40	.74	3.7	55	1.01	5.0
11	.22	1.0	26	.49	2.4	41	.76	3.8	56	1.03	5.1
12	.24	1.1	27	.51	2.5	42	.78	3.8	57	1.05	5.2
13	.26	1.2	28	.52	2.6	43	.80	3.9	58	1.07	5.3
14	.27	1.3	29	.54	2.7	44	.81	4.0	59	1.09	5.4
15	.29	1.4	30	.56	2.7	45	.83	4.1	60	1.11	5.5

TABLE 4.—*Rating table for Ekman current meter (applicable to meter No. 110) for 1-minute time interval*

Rev.	Screw No. 219	Screw No. 220	Rev.	Screw No. 219	Screw No. 220	Rev.	Screw No. 219	Screw No. 220	Rev.	Screw No. 219	Screw No. 220	Rev.	Screw No. 219	Screw No. 220
	Knots	*Knots*		*Knots*	*Knots*		*Knots*	*Knots*		*Knots*	*Knots*		*Knots*	*Knots*
10	0. 13	0. 14	40	0. 46	0. 48	70	0. 79	0. 83	100	1. 12	1. 18	130	1. 45	1. 53
20	. 24	. 25	50	. 57	. 60	80	. 90	. 95	110	1. 23	1. 30	140	1. 56	1. 64
30	. 35	. 37	60	. 68	. 72	90	1. 01	1. 06	120	1. 34	1. 41	150	1. 67	1. 76

vided each dial reading is always subtracted from the *preceding* reading, the latter being increased by 4,000 when less than the following reading. However, if the observational interval is long and the current velocity large, the total number of revolutions of the meter screw during a single observational interval may exceed 4,000, a fact which might not be immediately obvious in the record itself except by inference based upon a general knowledge of the approximate current velocity to be expected at the time. For example, if the observational interval used is 30 minutes, a count of 4,000 by meter will represent an average of 133 revolutions per minute which in the rating table indicates a velocity of about 1½ knots. If it is known that the current velocity is approximately 1½ knots and the count during the 30-minute interval indicates a much smaller velocity, it may be assumed that 4,000 revolutions should be added to the count. A longer observational interval will increase the possibility of exceeding this limit, while a shorter interval will make less likely the need for taking this matter into account.

TABLE 5.—*Rating table for Roberts radio current meter*

Contact interval	Velocity	Contact interval	Velocity	Contact interval	Velocity	Contact interval	Velocity
Seconds	*Knots*	*Seconds*	*Knots*	*Seconds*	*Knots*	*Seconds*	*Knots*
36 –20	0. 2	2. 63–2. 48	1. 6	1. 32–1. 29	3. 1	0. 88–0. 87	4. 6
19 –12. 9	. 3	2. 47–2. 33	1. 7	1. 28–1. 24	3. 2	. 86– . 85	4. 7
12. 8– 9. 8	. 4	2. 32–2. 20	1. 8	1. 23–1. 21	3. 3	. 84– . 83	4. 8
9. 7– 7. 9	. 5	2. 19–2. 09	1. 9	1. 20–1. 17	3. 4	. 82	4. 9
		2. 08–1. 99	2. 0	1. 16–1. 14	3. 5	. 81– . 78	5. 0
7. 8– 6. 6	. 6	1. 98–1. 89	2. 1	1. 13–1. 11	3. 6	. 77– . 76	5. 2
6. 5– 5. 7	. 7	1. 88–1. 81	2. 2	1. 10–1. 08	3. 7	. 75– . 73	5. 4
5. 6– 5. 0	. 8	1. 80–1. 73	2. 3	1. 07–1. 05	3. 8	. 72– . 71	5. 6
4. 9– 4. 4	. 9	1. 72–1. 66	2. 4	1. 04–1. 02	3. 9	. 70– . 68	5. 8
4. 3–3. 95	1. 0	1. 65–1. 59	2. 5	1. 01–1. 00	4. 0	. 67– . 66	6. 0
3. 94–3. 59	1. 1	1. 58–1. 53	2. 6	0. 99–0. 97	4. 1	. 65– . 64	6. 2
3. 58–3. 30	1. 2	1. 52–1. 47	2. 7	. 96– . 95	4. 2	. 63– . 62	6. 4
3. 29–3. 05	1. 3	1. 46–1. 42	2. 8	. 94– . 93	4. 3	. 61– . 60	6. 6
3. 04–2. 83	1. 4	1. 41–1. 37	2. 9	. 92– . 91	4. 4	. 59	6. 8
2. 82–2. 64	1. 5	1. 36–1. 33	3. 0	. 90– . 89	4. 5	. 58– . 57	7. 0

For reference to this table see par. 87.

Record of Current Direction

129. By direction of current is meant the direction toward which the water moves. It is convenient to express this in degrees of azimuth as reckoned clockwise from the north. For short series of observations it is the general practice to reduce the direction of each individual observation to the true azimuth, this reduction being made on

Form 270. For the long series of observations at lightships, which are recorded on Form 270a, it is usually more convenient to take the magnetic azimuth for the individual observations, the computation of the true azimuth being deferred until final means have been obtained and then any necessary correction for compass variation applied. For a discussion of compass variation and deviation see paragraphs 34–39.

130. When the pelorus has been used to obtain the direction of the current pole, the true or magnetic direction of the current may be obtained by one of the following formulas.

TRUE DIRECTION OF THE CURRENT

=pelorus+ship's head+deviation+variation±180° (pole aft of beam)

=pelorus+ship's head+deviation+variation (pole forward of beam)

MAGNETIC DIRECTION OF CURRENT

=pelorus+ship's head+deviation±180° (pole aft of beam)

=pelorus+ship's head+deviation (pole forward of beam)

In order that the above formulas may be applicable, it is important that the pelorus shall have been mounted as described in paragraph 41 and that it has been read on the forward half of the disk in accordance with the instructions in paragraph 42. The pelorus reading must therefore be between 270° and 360° or between 0° and 90°. The ship's head must be expressed in degrees of azimuth as read from the ship's compass. If the ship's head has been recorded in points of the compass as is sometimes done, the equivalent azimuth readings may be taken from Table 1 on page 15. The compass deviation and variation are considered as positive when east and negative when west and should have the corresponding sign when used in the above formulas. If the ship's compass has been completely compensated for deviation, this term becomes zero.

131. In the above formulas it will be noted that the angle ±180° must be applied if the current pole is aft of the vessel's beam when taking the observation, but is not included when the current pole is forward of the beam. It is therefore essential that the record kept by the observer should indicate clearly the position of the pole. If observations are being taken from a vessel anchored so that it is free to swing with the current as is usually the case with lightships, the current pole will, in general, move astern unless an opposing wind prevents the vessel from tailing with the current. With the vessel so anchored, it may usually be assumed that the pole is aft of the beam unless the observer specifically records otherwise. When the vessel is moored fore and aft so that it cannot swing with the current and is provided with two peloruses, one forward and the other aft, it is expected that the observer will alternate in the use of these instruments according to the direction of the current. In general, the pole will be ahead of the beam when the forward pelorus is in use and astern of the beam when the aft pelorus is in use, but there will be a number of exceptions. Special care is therefore required on the part of the observer to indicate not only the particular pelorus in use, but also to have the record clear as to whether the pole was forward or aft of the beam at the time of any observation. If the observer reports the changes between flood and ebb, it will aid in the later interpretation of the record in the office.

132. If the bearing of the current pole has been taken directly by compass, corrections for deviation and variation only are required to obtain the true direction of the current; or, if the magnetic direction only is needed, the correction for deviation alone is sufficient. If the direction of the current pole is measured by a sextant angle from a charted reference object, the corresponding true direction of the current is obtained by applying this angle to the true bearing of the reference object from the

observing vessel, the sextant angle being added if measured to the right of the reference object and subtracted if measured to the left.

133. The direction of subsurface currents as indicated by the Ekman current meter may for convenience be recorded directly in Form 270 in the column provided for direction of pole, but such entries must be suitably marked with a reference to an explanatory note. A correction for compass variation will be required to obtain the true azimuth of the current, but corrections for deviation are usually disregarded as the instrument itself is constructed mainly of nonmagnetic substances and there are practical difficulties in determining with any degree of accuracy the effect of the proximity of the observing vessel.

Reversing Currents

134. For a discussion of reversing currents see paragraphs 6–18. In the nonharmonic reduction of these currents, the results usually sought are (*a*) times of strength of flood, strength of ebb, and slack waters as referred to the moon's transit; (*b*) mean velocity of current at times of strength of flood and strength of ebb; (*c*) mean azimuth of current at times of strength of flood and strength of ebb; and (*d*) velocity and azimuth of nontidal current. Besides referring the times of the current phases to the moon's transit as a standard reference for all places, comparisons are also made, with tide or current phases at certain selected primary stations. This may be done both as an intermediate step in the reduction and to obtain differences which can be conveniently used with regular predictions for the primary station. On the Atlantic coast of the United States where the diurnal inequality in the tides is relatively small, the reductions are usually carried on without any distinction between morning and afternoon tidal cycles; but on the Pacific coast where the diurnal inequality is relatively large, a distinction is usually made if there are sufficient observations to develop this inequality. Following are described the several steps in the nonharmonic reduction of reversing currents.

135. **Plotting reversing currents.**—Observed velocities are plotted on cross-section paper with times as abscissas and the velocities as ordinates. Cross-section paper printed from plate 3391, with the 24 hours of the day at the top, is recommended for the purpose. The velocity scale usually adopted is one knot for each principal division (about 0.6 inch) of the form, with each subdivision representing one-tenth of a knot. Other velocity scales may be used, however, when more suitable.

136. A horizontal line representing zero velocity is to be ruled across the form with black ink. Flood velocities are to be plotted above this line as positive ordinates and ebb velocities below the line as negative ordinates, using ink for this plotting. If the direction of any observed current differs greatly from the normal flood and ebb movement, the plotted velocity point should be encircled to indicate a lack of definiteness. Several days of record may often be plotted on a single sheet if the zero velocity line for successive days is lowered by an amount sufficient to keep the plottings separate. When the velocities have been measured by pole near the surface and by meter at several subsurface depths, it is frequently advantageous to use a sheet for each day, plotting the pole velocities near the top of the sheet and the meter velocities below in order of depth.

137. Curves are now drawn with pencil to follow as near as practicable the general trend of the plotted velocity points. A single point standing apart from the general

trend of all the points, or a point that has been encircled to indicate some uncertainty in the observation, may be disregarded when drawing the curves. With the above exceptions, the departure of the curve from the plotted points of observed velocities should in general not exceed 0.2 knot by the scale that is used. In general, it is desirable to have the curve pass through the points of observed maximum flood and ebb velocities unless these are clearly erroneous.

138. In some cases it is necessary or desirable to depart somewhat from the procedure outlined above for drawing the velocity curves. Plottings for some localities show such roughness, due to surge or other conditions, that a curve following the general trend will unavoidably depart more than 0.2 knot from many of the plotted velocity points including the points of largest flood and ebb velocities. Many plottings form curves smooth enough for the purpose at hand when the points are connected successively by straight lines. This method may be used for all reversing-current velocity curves; a smooth curve being drawn if it is needed for preparing the tabulations described in succeeding paragraphs or for other purposes.

139. When sub-surface velocities are observed with a meter that does not record the direction of the current, it is sometimes possible to infer the direction from surface observations with current pole, especially in passageways where the current floods and ebbs with considerable regularity. In this case the velocities may be plotted in the manner already described, with the flood above the zero line and the ebb below it. If, however, there is considerable uncertainty in the direction of the sub-surface currents, it is best to plot all velocities above the zero line, noting the fact on the plotting.

140. In addition to the velocity curves it usually is desirable to include on the plotting sheet the current directions observed at the times the velocities were measured and a notation of wind conditions during the observations. The current directions in degrees are tabulated in a horizontal column above the velocity curve each direction on the same vertical line as the corresponding velocity point; or if desired the directions may be plotted below the velocity curve using the same horizontal time scale as for the velocity plotting, and a suitable vertical direction scale. The wind note should state briefly the general direction and velocity of the wind and indicate the times of changes in direction or velocity.

141. **Tabulation of strengths and slacks.**—Form 451 (fig. 28) is used for this tabulation. The times of flood and ebb strengths and slack waters are taken from plotted curves and entered in the form to the nearest tenth of an hour, the 24-hour system being used in recording the hour of the day. Attention is to be given to the general trend of the curve when selecting the time of the strength of current, the aim in general being to bisect the horizontal chord that represents a velocity about 0.1 knot less than the maximum velocity as read on a smooth curve. The practice of picturing mentally a smoothed curve and selecting the time of strength from the curve thus pictured is satisfactory and labor saving when the curve formed by the plotted points is reasonably smooth. If there is considerable roughness a smooth curve should be drawn.

142. The rule given below for selecting the time of a current strength from an unsmoothed curve is helpful, particularly if the selecting is done by an inexperienced worker.

> Mark with pencil near the zero-velocity line to the nearest tenth of an hour the following three times each of which is an approximation to the time of strength:
>
> (1) The time midway between the preceding and following slack waters.

(2) The time midway between the ends of the horizontal chord which represents one-half the largest observed velocity.

(3) The time of the largest observed velocity, or if the largest velocity was observed more than once the time midway between the first and last observations of that velocity.

The three times are readily determined by the use of spacing dividers. The average of the three times is the time of current strength sought.

143. The time selected for each current strength is indicated on the curve sheet by a check mark placed just above the flood loop or below the ebb loop of the velocity curve. The times thus marked should be scanned for validity by an experienced worker and any necessary adjustments made before tabulating. The intersection of the curve

Form 451
Rev. Sept., 1931
DEPARTMENT OF COMMERCE
U. S. COAST AND GEODETIC SURVEY

CURRENTS: FLOOD, EBB, AND SLACK

Lat. 32° 05.2'N

Station: Savannah (0.5 Mi. N 42° W of City Hall Dome), Savannah R., Ga. Long. 81° 05.9'W

Acc. No. T 1863 Party of E. F. Hicks, Jr. Plotted on Chart No. 440 Station No. 19

Times referred to ~~Obs.~~ Pred. Tides at Tybee Light, Ga. Time Meridians: (This Sta.) 75° W

Velocities corrected for ~~Obs.~~ range Pred. ~~vel.~~ at Tybee Light, Ga. f = 6.80/6.87 = 0.99 (Ref. Sta.) 75° W

Pole Average Depth 7 feet

DATE Year 1934	HW., LW.	TIME OF—				CURRENT INTERVALS				STR. OF FLOOD		STR. OF EBB	
		Slack Before F.	Strength of Flood	Slack Before E.	Strength of Ebb	Slack Before F.	Strength of Flood	Slack Before E.	Strength of Ebb	Direct ~~Mag.~~ True	Velocity	Direct ~~Mag.~~ True	Velocity
mo. d	h.	h.	h.	h.	h.	h. L+	h. H−	h. H+	h. L−	°	knots	°	knots
May 7	2.3 8.8	11.5			(8.0)	2.7			0.8			(140)	(1.8)
	14.9 21.2	---	13.7	16.5	19.2	---	1.2	1.6	2.0	322	1.4	143	2.0
8	3.3 9.7	0.0	2.4	5.0	8.9	2.8	0.9	1.7	0.8	319	1.2	141	2.0
	16.0 22.3	12.3	15.2	17.6	20.4	2.6	0.8	1.6	1.9	320	1.8	142	2.0
9	4.3 10.6	1.1	3.2	6.2	10.1	2.8	1.1	1.9	0.5	323	1.4	145	2.0
	16.9 23.2	13.3	15.5	18.8	22.0	2.7	1.4	1.9	1.2	314	1.6	140	2.0
10	5.2 11.4	2.1	4.3	7.0	---	2.9	0.9	1.8	---	319	1.2	---	---
				Sums		16.5	6.3	10.5	7.2	1917	8.6	851	11.8
				Divisors		6	6	6	6	6	6	6	6
				Means		+2.75	−1.05	+1.75	−1.20	320	1.43	142	1.97
Gr. Intervals, reference station						6.66	0.34	0.34	6.66				
"	"	this station				9.41	11.71	2.09	5.46		1.41c		1.95c
Mean current hour (MCH)							11.82						

Computation of mean current hour

Slack before flood	9.41 + 3.10	= 12.51 hours
Strength of flood		= 11.71 "
Slack before ebb	2.09 − 3.10 + 12.42	= 11.41 "
Strength of ebb	5.46 + 6.21	= 11.67 "
Sum		47.30 "
Mean current hour		11.82 "

Velocity reduction

Best known mean range of tide at reference station		6.80 feet
Range for observational period at reference station		6.87 "
Reduction factor for tidal current	f = 6.80/6.87 =	0.99
Observed tidal current at this station	= ½(1.43 + 1.97) =	1.70 knots
Corrected tidal current	= 1.70 x 0.99 =	1.68 "
Nontidal current	= ½(1.43 − 1.97) =	−0.27 "
Corrected flood current	= 1.68 − 0.27 =	1.41c "
Corrected ebb current	= 1.68 + 0.27 =	1.95c "

FIGURE 28.—Form 451, Flood, ebb, and slack referred to tides.

with the line of zero velocity will in general be taken as the time of slack water; but if the velocity remains near zero for a considerable period of time, the time of slack may be taken at the middle of the period during which the velocity is less than 0.1 knot.

144. The velocity of the current at the time of each strength is also taken from the plotted curve and entered in the form to the nearest tenth of a knot. This value will usually be the actual observed maximum velocity unless a smoothed curve has been drawn in which case it will be the maximum velocity indicated by the smoothed curve.

145. The direction of the current at the time of each strength is to be taken directly from the original record (Form 270) or from the plotting sheet and will usually be expressed in true azimuth. If the series of observations does not exceed 3 days, it is recommended that the direction for each strength be taken as the average of the 3 observed directions nearest the time of the strength. For longer series, the single observed direction nearest the time of the strength may be used provided it is consistent with the generally prevailing direction for the particular phase of current.

146. Sometimes a nontidal current may be strong enough to overcome the tidal flow in one direction as explained in paragraphs 10–11. The current then flows continuously in the same direction throughout the tidal cycle with a velocity varying between maximum and minimum without coming to a slack. When tabulating a record of this kind, the minimum velocity may be tabulated as a negative velocity of opposite phase and the time of its occurrence as the time of the strength of that phase. The direction of such minimum velocity, however, should be enclosed in parentheses as it will not be comparable with the direction of the current of positive velocity of the same phase. There being no intervening slack water, the corresponding spaces in Form 451 are to be left vacant or filled with dashed lines.

147. **Double phases.**—In some places the current may be characterized by a double flood or a double ebb as illustrated in Figure 4. When tabulating currents of this type it is recommended that Form 451 be modified so as to separate the phases applying to the flood period and the ebb period as illustrated in Figure 29. In the example, both flood and ebb have a double maximum, but in other cases it may be found that only one of the strengths is doubled. At the time of the minimum strength the direction of the current may reverse itself, in which case the velocity is to be tabulated with a negative sign. Only a single column is provided for the direction of the current during either the flood or ebb period. The direction to be entered is the one applicable to the greatest velocity occurring during the period.

148. **Weak reversing currents.**—When a reversing current is weak and irregular the times of the several current phases are not well defined and considerable uncertainty will exist in any attempt to select the times of the individual strengths and slacks. In such cases it is desirable to tabulate the observed velocities and directions at hourly or half-hourly intervals as referred to the times of the high and low waters at a reference station. The method of tabulation is similar to that used for rotary currents and is described in paragraphs 164–165. The average velocity for each hourly or half-hourly group is plotted and a mean velocity curve drawn through the plotted points. The times of the several current phases as referred directly to the high and low waters at the reference station are taken from this curve of mean velocities and entered in Form 451 in the columns of current intervals. The current velocities at the times of flood and ebb strength may also be taken from the same curve. The average direction of the current for the time of each strength may be obtained by interpolating between the hourly or half-hourly group averages.

Form 451
Rev. Sept., 1931
DEPARTMENT OF COMMERCE
U. S. COAST AND GEODETIC SURVEY

CURRENTS: FLOOD, EBB, AND SLACK

Lat. 41° 23.4'N

Station: Edgartown Harbor (0.3 mi. S 77° E of Church Tower), Mass. Long. 70° 30.5'W

Acc. No. T-2114 Party of E. F. Hicks, Jr. Plotted on Chart No. 1209 Station No. 19

Times referred to ~~Obs.~~ Pred. Tides at Boston (Commonwealth Piers), Mass. Time Meridians: (This Sta.) 75° W

Velocities corrected for ~~Obs.~~ range Pred. ~~vel.~~ at Boston, Mass. f = 9.40/11.33 = 0.83 (Ref. Sta.) 75°

Pole Average Depth 7 feet

DATE Year 1934	HW., LW.	TIME OF— Slack	Strength	Slack	Strength	CURRENT INTERVALS Slack	Strength	Slack	Strength	Direct True	Velocity	Direct	Velocity
mo. d	h.	h.	h. (1st)	h. (min.)	h. (2nd)	h.	h. (1st)	h. (min.)	h. (2nd)	°	knots (1st)	knots (min.)	knots (2nd)
	LW		Flood	Period		L+	L+	L+	L+				
Sept.24	5.4	---	(7.2)	10.1	12.0	---	1.8	4.7	6.6	258	(1.6)	0.0	0.8
	17.9	18.2	19.6	22.2	---	0.3	1.7	4.3	---	244	1.5	-0.1	---
25	6.2	6.5	8.0	10.2	0.3	0.3	1.8	4.0	6.4	244	1.6	-0.2	0.8
	18.7	19.1	20.3	23.5	12.5	0.4	1.6	4.8	6.3	251	1.4	-0.1	0.9
26	7.0	7.2	8.8	11.5	1.0	0.2	1.8	4.5	6.3	251	1.4	-0.1	0.8
	19.5	20.0	21.3	---	13.5	0.5	1.8	---	6.5	260	1.2	---	0.8
27	7.7	8.0	---	0.5	2.0	0.3	---	5.0	6.5	---	---	-0.2	1.0
				Sums		2.0	10.5	27.3	38.6	1508	8.7	-0.7	5.1
				Divisors		6	6	6	6	6	6	6	6
				Means		0.33	1.75	4.55	6.43	251	1.45	-0.12	0.85
Greenwich LW interval, reference station						9.94	9.94	9.94	9.94				
Greenwich intervals, this station						10.27	11.69	14.49	16.37		1.21c	-0.10c	0.71c
								2.07	3.95				
	HW		Ebb	Period		H+	H+	H+	H+				
Sept.24	11.7												
	---	12.5	13.5	14.5	16.1	0.8	1.8	2.8	4.4	87	1.0	0.4	1.2
25	0.2	1.0	1.7	3.2	4.4	0.8	1.5	3.0	4.2	84	0.8	0.2	0.9
	12.5	13.3	14.2	15.1	16.8	0.8	1.7	2.6	4.3	78	1.0	0.4	1.4
26	1.0	1.6	2.6	4.0	5.5	0.6	1.6	3.0	4.5	71	0.8	0.0	0.7
	13.2	14.0	15.0	16.1	18.1	0.8	1.8	2.9	4.9	76	1.0	0.4	1.0
27	1.8	2.7	3.4	5.0	6.0	0.9	1.6	3.2	4.2	80	0.8	-0.2	0.8
				Sums		4.7	10.0	17.5	26.5	476	5.4	1.2	6.0
				Divisors		6	6	6	6	6	6	6	6
				Means		0.78	1.67	2.92	4.42	79	0.90	0.20	1.00
Greenwich HW interval, reference station						3.77	3.77	3.77	3.77				
Greenwich intervals, this station						4.55	5.44	6.69	8.19		0.75c	0.16c	0.83c

Velocity reduction

Best known mean range of tide at reference station.................... 9.40 feet
Range for observational period at reference station.................. 11.33 "
Reduction factor for tidal current.................. f = 9.40/11.33 = 0.83

	Flood			Ebb		
Observed velocities............	1.45	-0.12	0.85	-0.90	-0.20	-1.00
Mean of above, nontidal current	0.01	0.01	0.01	0.01	0.01	0.01
Observed tidal current.........	1.44	-0.13	0.84	-0.91	-0.21	-1.01
Reduction factor...............	0.83	0.83	0.83	0.83	0.83	0.83
Corrected tidal current........	1.20	-0.11	0.70	-0.76	-0.17	-0.84
Nontidal current...............	0.01	0.01	0.01	0.01	0.01	0.01
Corrected velocities...........	1.21c	-0.10c	0.71c	-0.75c	-0.16c	-0.83c

FIGURE 29.—Form 451, Flood, ebb, and slack for double phases

149. **Inferred values.**—When tabulating strengths and slacks for the purpose of reduction it is desirable in general to have an even number of items for each current phase in order to partially balance the effect of any diurnal inequality either in the time or in the velocity of the current. This is especially important for very short series of observations and for localities where the diurnal inequality is relatively large. To accomplish this purpose it is usually better to infer an additional phase item rather than reject an observation already obtained, especially in a very short series. Sometimes when the observations have commenced just after, or have terminated just before, one of the principal phases, the plotted velocity curves may be easily extended to include the needed extra item. Inferred values may also be obtained by comparison with predicted currents at a reference station or with simultaneous observations at some other current station. A value roughly inferred from the sequence of the other observations at the same station may be used when necessary. Inferred values should be enclosed in parentheses to distinguish them from the actual observations.

150. **Time comparison.**—The times of the current phases at the station for which the reduction is being made (the subordinate station) may be referred either to the corresponding phases at a current reference station or to the times of high and low water at a tidal reference station. If no suitable reference station is available, the current phases may be referred directly to the moon's transits. In general, predictions for the reference station are to be preferred to actual observations. This is especially true when the currents are referred to times of high and low water, since irregularities in observed tides arising from meteorological causes may have no counterpart in observed current velocities.

151. **Reference to tides.**—Figure 28 illustrates a reduction with reference to a tide station. The times of the high and low waters at the reference station are taken to the nearest tenth of an hour and entered in the column provided in Form 451. Differences between the times of the tide and the current phases are obtained and entered in the columns of current intervals, the symbol *H* or *L* at the top of each column indicating whether the reference is to a high or low water. The signs (+) and (−) are used to indicate whether the current follows or precedes the tide to which it is referred. Usually the current will be referred to the nearest high or low water, but all references in any one column must be to like phases of the tide in order to be comparable. In case that one tidal phase is much better defined than the other, it is permissible to refer all the currents to that phase rather than using both high and low water. In localities where there is considerable diurnal inequality it is desirable that the greater flood strength and greater ebb strength be referred to the lower low water and the higher high water rather than to the lesser tides. The columns of differences are summed and averaged, the means being usually carried to two decimal places.

152. **Greenwich intervals.**—By referring the several current phases at all stations to the times of the moon's transit of the meridian of Greenwich, the results are directly comparable, and relations between the times of the current in different localities may be obtained simply by taking the differences between their Greenwich intervals. After having obtained the average difference between each current phase and the tidal phase at the reference station as described in the preceding paragraph, this difference is applied to the Greenwich interval for the tidal phase to which it is referred in order to obtain the corresponding Greenwich current interval. A multiple of the tidal period 12.42 hours may be included or rejected when necessary. The *mean current hour* (*MCH*) is the Greenwich interval for the flood strength as modified by the intervals for the other current phases. It is computed by taking the average of the intervals for the following

modified phases: flood strength, slack before flood increased by 3.10 hours, slack after flood decreased by 3.10 hours, and ebb strength increased or decreased by 6.21 hours. Before taking the average the several items must be made comparable by the addition or rejection of the tidal period 12.42 hours when necessary.

153. **Reference to currents.**—When the current phases at the subordinate station are referred to the corresponding phases at a current reference station, the latter may be tabulated in Form 451 below the tabulations for the subordinate station as illustrated in Figure 30. Differences are obtained between the times of the observed currents at the subordinate station and the times of the corresponding currents at the reference station, the difference being considered as positive or negative according to whether the current at the subordinate station is later or earlier than at the reference station. The differences are then averaged for each phase of the current. Next, the Greenwich intervals for the several current phases at the subordinate station are obtained by applying the average differences to the corresponding Greenwich intervals for the reference station. The mean current hour may then be obtained in the manner described in the preceding paragraph.

154. A double flood or double ebb may be referred to either tides or currents. In the example in Figure 29, the phases of the flood period are referred to low water and the phases of the ebb period to high water at the reference station. The average difference for each group is obtained and applied to the Greenwich interval of the tide phase to which it is referred.

155. **Velocity reduction factor.**—The velocity of the observed tidal current may be reduced to a mean value by the application of a factor derived from the tidal range or the current velocity at the reference station. When the reference is to a tide station, the reduction factor is obtained by dividing the best determined mean range of tide at the reference station by the range for the period covered by the observations at the current station. If the current at the subordinate station is chiefly hydraulic, the square root of the factor as computed above is taken as the reduction factor. When a current reference station is used, the reduction factor is obtained by dividing the best determined average velocity at the reference station by the average velocity for the period covered by the observations.

156. The reduction factor obtained by either of the above methods is to be applied only to the tidal portion of the observed current. In simple cases the tidal current is obtained by taking the half sum of the average observed flood and ebb velocities at their strengths, and the nontidal part of the current is obtained by taking the half difference of these velocities. After the reduction factor has been applied to the tidal current it is recombined with the nontidal part to obtain the corrected flood and ebb velocities, which are usually indicated in the reduction forms by the letter "*c*." It will be noted that the nontidal current will be in the flood or ebb direction according to whether the observed flood or ebb velocity is the stronger. In recombining the nontidal current with the tidal current it will be added for the direction in which it is acting and substracted for the opposite direction.

157. A more general method of applying the reduction factor, which is applicable when the observations include double flood or double ebb strengths, is described as follows: Considering all velocities in the flood direction as positive and all velocities in the ebb direction as negative, find the nontidal current by taking the algebraic mean of these velocities. The sign of the result will indicate whether this current is in the flood or ebb direction. Subtract algebraically the nontidal current from each of the observed velocities and multiply the remainders by the reduction factor. Restore

Form 451
Rev. Sept., 1931
DEPARTMENT OF COMMERCE
U. S. COAST AND GEODETIC SURVEY

CURRENTS: FLOOD, EBB, AND SLACK

Station: Channel west of Onslow Island, Savannah River, Ga. Lat. 32° 08.8'N Long. 81° 08.4'W

Acc. No. T 1863 Party of E. F. Hicks, Jr. Plotted on Chart No. 440 Station No. 23

Times referred to ~~Obs.~~ Pred. Currents at Savannah River Entrance Time Meridians: (This Sta.) 75° W

Velocities corrected for ~~Obs. range~~ Pred. vel. at Savannah River Entrance f = 2.00/2.05 = 0.98 (Ref. Sta.) 75° W

Pole Average Depth 7 feet

DATE Year 1934	HW., LW.	TIME OF— Slack Before F.	TIME OF— Strength of Flood	TIME OF— Slack Before E.	TIME OF— Strength of Ebb	CURRENT INTERVALS Slack Before F.	CURRENT INTERVALS Strength of Flood	CURRENT INTERVALS Slack Before E.	CURRENT INTERVALS Strength of Ebb	STR. OF FLOOD Direct ~~Mag.~~ True	STR. OF FLOOD Velocity	STR. OF EBB Direct ~~Mag.~~ True	STR. OF EBB Velocity
mo. d	h.	h.	h.	h.	h.	h.	h.	h.	h.	°	knots	°	knots
May 14			(7.7)	9.5						(20)	(0.6)		
		17.5	19.9	22.5	13.6					23	1.1	210	1.4
15		6.5	8.4	10.5	2.7					21	0.6	209	1.5
		18.0	20.4	23.0	14.4					25	1.0	209	1.5
16		7.0	8.9	11.0	3.5					22	0.6	210	1.4
		18.5	20.6	23.5	15.1					19	1.0	212	1.3
17		7.8			3.5							209	1.3
								Sums		130	4.9	1259	8.4
								Divisors		6	6	6	6
								Means		22	0.82	210	1.40
											0.80c		1.38c
			Savannah River Entrance for comparison										
						Time differences							
						+	+	+	+				
May 14			5.7	9.2			2.0	0.3			1.8		
		15.9	18.1	22.0	12.7	1.6	1.8	0.5	0.9		2.1		2.4
15		4.5	6.4	9.7	1.3	2.0	2.0	0.8	1.4		1.7		2.3
		16.6	18.8	22.6	13.4	1.4	1.6	0.4	1.0		2.1		2.3
16		5.2	7.2	10.2	2.0	1.8	1.7	0.8	1.5		1.6		2.2
		17.4	19.6	23.2	14.1	1.1	1.0	0.3	1.0		2.0		2.1
17		6.0			2.7	1.8			0.8				2.0
				Sums		9.7	10.1	3.1	6.6		11.3		13.3
				Divisors		6	6	6	6		6		6
				Means		1.62	1.68	0.52	1.10		1.88		2.22
Greenwich intervals, reference station						8.11	10.22	1.72	4.86				
"	"		this station			9.73	11.90	2.24	5.96				
Mean current hour (MCH)							12.12						

Velocity reduction

Best known mean current velocity at reference station................	2.00	knots
Velocity for observational period at reference sta. $\frac{1}{2}(1.88 + 2.22)$	= 2.05	"
Reduction factor for tidal current................. 2.00/2.05	= 0.98	
Observed tidal current at this station = $\frac{1}{2}(0.82 + 1.40)$	= 1.11	knots
Corrected tidal current = 1.11 x 0.98	= 1.09	"
Nontidal current = $\frac{1}{2}(0.82 - 1.40)$	= -0.29	"
Corrected flood current = 1.09 - 0.29	= 0.80c	"
Corrected ebb current = 1.09 + 0.29	= 1.38c	"

FIGURE 30.—Form 451, Flood, ebb, and slack referred to currents.

the nontidal current by adding it algebraically to the products. The results will be the corrected velocities with the sign in each case indicating the direction of flow. (See fig. 29.)

158. **Direction of current.**—When obtaining the mean direction of the current for flood or ebb strength, care is to be taken not to include in the calculation an individual value that differs by an excessive amount from the apparent general average. Such a value should be encircled and omitted from the sum. Individual directions approximating north should be made comparable by the addition or rejection of 360° when necessary.

Rotary Currents

159. The plotting of the original observed velocities, a procedure preliminary to the tabulation of reversing currents, is usually omitted when tabulating rotary currents. If such plottings are desired for checking purposes, it is recommended that all velocities be plotted as positive ordinates regardless of the direction of the current with a separate plotting for directions when needed. As rotary currents are usually weak and irregular, the most satisfactory preliminary treatment is to resolve the observed velocities into north and east components. Reductions may, however, be carried on without such resolution if the observed periodic changes are fairly regular. Rotary currents with the movement principally along a single axis may be treated as reversing currents.

160. **Resolution of velocities.**—The resolutions are usually made along a north-and-south and an east-and-west axis, the component velocities in the north and the east directions being taken as positive and those in the opposite directions as negative. The resolved values are designated as north and east components, and in order to avoid negative readings in the tabulations, a constant (usually 3 knots) is added to all resolved velocities. The resolution may be accomplished by multiplying each observed velocity by the cosine of its direction to obtain the north component and by the sine of its direction to obtain its east component. Resolutions may be made to accord with either true or magnetic north.

161. The work of resolving the current velocities is facilitated by the use of Table 6 which was specially prepared for the purpose. This table contains the north and east components of each tenth of a knot velocity from 0.1 knot to 3.0 knots inclusive for each 5 degrees of direction from 0 degrees to 355 degrees. To avoid negative values a constant of 3.0 knots is included in each component velocity given in the table. Each group of four figures represents a north and an east component each expressed in knots and tenths, the first two figures being the north component and the last two the east component. Decimal points are omitted in the body of the table. Thus, the north and east components of a velocity of 0.5 knot setting 25 degrees are found, on the line marked "0.5" and in the column headed "25°", to be 3.5 knots and 3.2 knots respectively. If the direction of the velocity to be resolved is not a multiple of 5 degrees the nearest direction that is such a multiple should be used in entering the table. Taking the directions to the nearest 5 degrees for this purpose will not affect the accuracy of results which are averages of a number of observations. For the hourly observations taken at lightships, the resolved velocities are entered directly in the columns provided in Form 270a which is used for recording these observations. In other cases, special provisions must be made for recording the resolved values.

TABLE 6.—*North and east component velocities*

[Constant of 3 knots added]

Knots	0°	5°	10°	15°	20°	25°	30°	35°	40°	45°	50°	55°	Knots
0.1	3130	3130	3130	3130	3130	3130	3130	3131	3131	3131	3131	3131	0.1
.2	3230	3230	3230	3231	3231	3231	3231	3231	3231	3131	3132	3132	.2
.3	3330	3330	3331	3331	3331	3331	3332	3232	3232	3232	3232	3232	.3
.4	3430	3430	3431	3431	3431	3432	3332	3332	3333	3333	3333	3233	.4
.5	3530	3530	3531	3531	3532	3532	3432	3433	3433	3434	3334	3334	.5
.6	3630	3631	3631	3632	3632	3533	3533	3533	3534	3434	3435	3335	.6
.7	3730	3731	3731	3732	3732	3633	3634	3634	3534	3535	3435	3436	.7
.8	3830	3831	3831	3832	3833	3733	3734	3735	3635	3636	3536	3537	.8
.9	3930	3931	3932	3932	3833	3834	3834	3735	3736	3636	3637	3537	.9
1.0	4030	4031	4032	4033	3933	3934	3935	3836	3836	3737	3638	3638	1.0
1.1	4130	4131	4132	4133	4034	4035	4036	3936	3837	3838	3738	3639	1.1
1.2	4230	4231	4232	4233	4134	4135	4036	4037	3938	3838	3839	3740	1.2
1.3	4330	4331	4332	4333	4234	4235	4136	4137	4038	3939	3840	3741	1.3
1.4	4430	4431	4432	4434	4335	4336	4237	4138	4139	4040	3941	3841	1.4
1.5	4530	4531	4533	4434	4435	4436	4338	4239	4140	4141	4041	3942	1.5
1.6	4630	4631	4633	4534	4535	4537	4438	4339	4240	4141	4042	3943	1.6
1.7	4730	4731	4733	4634	4636	4537	4538	4440	4341	4242	4143	4044	1.7
1.8	4830	4832	4833	4735	4736	4638	4639	4540	4442	4343	4244	4045	1.8
1.9	4930	4932	4933	4835	4836	4738	4640	4641	4542	4343	4245	4146	1.9
2.0	5030	5032	5033	4935	4937	4838	4740	4641	4543	4444	4345	4146	2.0
2.1	5130	5132	5134	5035	5037	4939	4840	4742	4644	4545	4446	4247	2.1
2.2	5230	5232	5234	5136	5138	5039	4941	4843	4744	4646	4447	4348	2.2
2.3	5330	5332	5334	5236	5238	5140	5042	4943	4744	4646	4447	4349	2.3
2.4	5430	5432	5434	5336	5338	5240	5142	5044	4845	4747	4548	4450	2.4
2.5	5530	5532	5534	5436	5439	5341	5242	5044	4946	4848	4649	4450	2.5
2.6	5630	5632	5635	5537	5439	5441	5343	5145	5047	4848	4750	4551	2.6
2.7	5730	5732	5735	5637	5539	5441	5344	5245	5147	4949	4751	4552	2.7
2.8	5830	5832	5835	5737	5640	5542	5444	5346	5148	5050	4851	4653	2.8
2.9	5930	5933	5935	5838	5740	5642	5544	5447	5249	5151	4952	4754	2.9
3.0	6030	6033	6035	5938	5840	5743	5645	5547	5349	5151	4953	4755	3.0
	180°	185°	190°	195°	200°	205°	210°	215°	220°	225°	230°	235°	
0.1	2930	2930	2930	2930	2930	2930	2930	2929	2929	2929	2929	2929	0.1
.2	2830	2830	2830	2829	2829	2829	2829	2829	2829	2929	2928	2928	.2
.3	2730	2730	2729	2729	2729	2729	2728	2828	2828	2828	2828	2828	.3
.4	2630	2630	2629	2629	2629	2628	2728	2728	2727	2727	2727	2827	.4
.5	2530	2530	2529	2529	2528	2528	2628	2627	2627	2626	2726	2726	.5
.6	2430	2429	2429	2428	2428	2527	2527	2527	2526	2626	2625	2725	.6
.7	2330	2329	2329	2328	2328	2427	2426	2426	2526	2525	2625	2624	.7
.8	2230	2229	2229	2228	2227	2327	2326	2325	2425	2424	2524	2523	.8
.9	2130	2129	2128	2128	2227	2226	2226	2325	2324	2424	2423	2523	.9
1.0	2030	2029	2028	2027	2127	2126	2125	2224	2224	2323	2422	2422	1.0
1.1	1930	1929	1928	1927	2026	2025	2024	2124	2223	2222	2322	2421	1.1
1.2	1830	1829	1828	1827	1926	1925	2024	2023	2122	2222	2221	2320	1.2
1.3	1730	1729	1728	1727	1826	1825	1924	1923	2022	2121	2220	2319	1.3
1.4	1630	1629	1628	1626	1725	1724	1823	1922	1921	2020	2119	2219	1.4
1.5	1530	1529	1527	1626	1625	1624	1722	1821	1920	1919	2019	2118	1.5
1.6	1430	1429	1427	1526	1525	1523	1622	1721	1820	1919	2018	2117	1.6
1.7	1330	1329	1327	1426	1424	1523	1522	1620	1719	1818	1917	2016	1.7
1.8	1230	1228	1227	1325	1324	1422	1421	1520	1618	1717	1816	2015	1.8
1.9	1130	1128	1127	1225	1224	1322	1420	1419	1518	1717	1815	1914	1.9
2.0	1030	1028	1027	1125	1123	1222	1320	1419	1517	1616	1715	1914	2.0
2.1	0930	0928	0926	1025	1023	1121	1220	1318	1416	1515	1614	1813	2.1
2.2	0830	0828	0826	0924	0922	1021	1119	1217	1316	1414	1613	1712	2.2
2.3	0730	0728	0726	0824	0822	0920	1018	1117	1316	1414	1613	1711	2.3
2.4	0630	0628	0626	0724	0722	0820	0918	1016	1215	1313	1512	1610	2.4
2.5	0530	0528	0526	0624	0621	0719	0818	1016	1114	1212	1411	1610	2.5
2.6	0430	0428	0425	0523	0621	0619	0717	0915	1013	1212	1310	1509	2.6
2.7	0330	0328	0325	0423	0521	0619	0716	0815	0913	1111	1309	1508	2.7
2.8	0230	0228	0225	0323	0420	0518	0616	0714	0912	1010	1209	1407	2.8
2.9	0130	0127	0125	0222	0320	0418	0516	0613	0811	0909	1108	1306	2.9
3.0	0030	0027	0025	0122	0220	0317	0415	0513	0711	0909	1107	1305	3.0

TABLE 6.—*North and east component velocities*

[Constant of 3 knots added]

Knots	60°	65°	70°	75°	80°	85°	90°	95°	100°	105°	110°	115°	Knots
0.1	3031	3031	3031	3031	3031	3031	3031	3031	3031	3031	3031	3031	0.1
.2	3132	3132	3132	3132	3032	3032	3032	3032	3032	2932	2932	2932	.2
.3	3233	3133	3133	3133	3133	3033	3033	3033	2933	2933	2933	2933	.3
.4	3233	3234	3134	3134	3134	3034	3034	3034	2934	2934	2934	2834	.4
.5	3234	3235	3235	3135	3135	3035	3035	3035	2935	2935	2835	2835	.5
.6	3335	3335	3236	3236	3136	3136	3036	2936	2936	2836	2836	2735	.6
.7	3436	3336	3237	3237	3137	3137	3037	2937	2937	2837	2837	2736	.7
.8	3437	3337	3338	3238	3138	3138	3038	2938	2938	2838	2738	2737	.8
.9	3438	3438	3338	3239	3239	3139	3039	2939	2839	2839	2738	2638	.9
1.0	3539	3439	3339	3340	3240	3140	3040	2940	2840	2740	2739	2639	1.0
1.1	3640	3540	3440	3341	3241	3141	3041	2941	2841	2741	2640	2540	1.1
1.2	3640	3541	3441	3342	3242	3142	3042	2942	2842	2742	2641	2541	1.2
1.3	3641	3542	3442	3343	3243	3143	3043	2943	2843	2743	2642	2542	1.3
1.4	3742	3643	3543	3444	3244	3144	3044	2944	2844	2644	2543	2443	1.4
1.5	3843	3644	3544	3444	3345	3145	3045	2945	2745	2644	2544	2444	1.5
1.6	3844	3745	3545	3445	3346	3146	3046	2946	2746	2645	2545	2345	1.6
1.7	3845	3745	3646	3446	3347	3147	3047	2947	2747	2646	2446	2345	1.7
1.8	3946	3846	3647	3547	3348	3248	3048	2848	2748	2547	2447	2246	1.8
1.9	4046	3847	3648	3548	3349	3249	3049	2849	2749	2548	2448	2247	1.9
2.0	4047	3848	3749	3549	3350	3250	3050	2850	2750	2549	2349	2248	2.0
2.1	4048	3949	3750	3550	3451	3251	3051	2851	2651	2550	2350	2149	2.1
2.2	4149	3950	3851	3651	3452	3252	3052	2852	2652	2451	2251	2150	2.2
2.3	4250	4051	3852	3652	3453	3253	3053	2853	2653	2452	2252	2051	2.3
2.4	4251	4052	3853	3653	3454	3254	3054	2854	2654	2453	2253	2052	2.4
2.5	4252	4153	3954	3654	3455	3255	3055	2855	2655	2454	2154	1953	2.5
2.6	4353	4154	3954	3755	3556	3256	3056	2856	2556	2355	2154	1954	2.6
2.7	4453	4154	3955	3756	3557	3257	3057	2857	2557	2356	2155	1954	2.7
2.8	4454	4255	4056	3757	3558	3258	3058	2858	2558	2357	2056	1855	2.8
2.9	4455	4256	4057	3858	3559	3359	3059	2759	2559	2258	2057	1856	2.9
3.0	4556	4357	4058	3859	3560	3360	3060	2760	2560	2259	2058	1757	3.0
	240°	245°	250°	255°	260°	265°	270°	275°	280°	285°	290°	295°	
0.1	3029	3029	3029	3029	3029	3029	3029	3029	3029	3029	3029	3029	0.1
.2	2928	2928	2928	2928	3028	3028	3028	3028	3028	3128	3128	3128	.2
.3	2827	2927	2927	2927	2927	3027	3027	3027	3127	3127	3127	3127	.3
.4	2827	2826	2926	2926	2926	3026	3026	3026	3126	3126	3126	3226	.4
.5	2826	2825	2825	2925	2925	3025	3025	3025	3125	3125	3225	3225	.5
.6	2725	2725	2824	2824	2924	2924	3024	3124	3124	3224	3224	3325	.6
.7	2624	2724	2823	2823	2923	2923	3023	3123	3123	3223	3223	3324	.7
.8	2623	2723	2722	2822	2922	2922	3022	3122	3122	3222	3322	3323	.8
.9	2622	2622	2722	2821	2821	2921	3021	3121	3221	3221	3322	3422	.9
1.0	2521	2621	2721	2720	2820	2920	3020	3120	3220	3320	3321	3421	1.0
1.1	2420	2520	2620	2719	2819	2919	3019	3119	3219	3319	3420	3520	1.1
1.2	2420	2519	2619	2718	2818	2918	3018	3118	3218	3318	3419	3519	1.2
1.3	2419	2518	2618	2717	2817	2917	3017	3117	3217	3317	3418	3518	1.3
1.4	2318	2417	2517	2616	2816	2916	3016	3116	3216	3416	3517	3617	1.4
1.5	2217	2416	2516	2616	2715	2915	3015	3115	3315	3416	3516	3616	1.5
1.6	2216	2315	2515	2615	2714	2914	3014	3114	3314	3415	3515	3715	1.6
1.7	2215	2315	2414	2614	2713	2913	3013	3113	3313	3414	3614	3715	1.7
1.8	2114	2214	2413	2513	2712	2812	3012	3212	3312	3513	3613	3814	1.8
1.9	2014	2213	2412	2512	2711	2811	3011	3211	3311	3512	3612	3813	1.9
2.0	2013	2212	2311	2511	2710	2810	3010	3210	3310	3511	3711	3812	2.0
2.1	2012	2111	2310	2510	2609	2809	3009	3209	3409	3510	3710	3911	2.1
2.2	1911	2110	2209	2409	2608	2808	3008	3208	3408	3609	3809	3910	2.2
2.3	1810	2009	2208	2408	2607	2807	3007	3207	3407	3608	3808	4009	2.3
2.4	1809	2008	2207	2407	2606	2806	3006	3206	3406	3607	3807	4008	2.4
2.5	1808	1907	2106	2406	2605	2805	3005	3205	3405	3606	3906	4107	2.5
2.6	1707	1906	2106	2305	2504	2804	3004	3204	3504	3705	3906	4106	2.6
2.7	1607	1906	2105	2304	2503	2803	3003	3203	3503	3704	3905	4106	2.7
2.8	1606	1805	2004	2303	2502	2802	3002	3202	3502	3703	4004	4205	2.8
2.9	1605	1804	2003	2202	2501	2701	3001	3301	3501	3802	4003	4204	2.9
3.0	1504	1703	2002	2101	2500	2700	3000	3300	3500	3901	4002	4303	3.0

TABLE 6.—*North and east component velocities*—Continued

[Constant of 3 knots added]

Knots	120°	125°	130°	135°	140°	145°	150°	155°	160°	165°	170°	175°	Knots
0. 1	3031	2931	2931	2931	2931	2931	2930	2930	2930	2930	2930	2930	0. 1
. 2	2932	2932	2932	2931	2831	2831	2831	2831	2831	2831	2830	2830	. 2
. 3	2833	2832	2832	2832	2832	2832	2732	2731	2731	2731	2731	2730	. 3
. 4	2833	2833	2733	2733	2733	2732	2732	2632	2631	2631	2631	2630	. 4
. 5	2834	2734	2734	2634	2633	2633	2632	2532	2532	2531	2531	2530	. 5
. 6	2735	2735	2635	2634	2534	2533	2533	2533	2432	2432	2431	2431	. 6
. 7	2636	2636	2635	2535	2534	2434	2434	2433	2332	2332	2331	2331	. 7
. 8	2637	2537	2536	2436	2435	2335	2334	2333	2233	2232	2231	2231	. 8
. 9	2638	2537	2437	2436	2336	2335	2234	2234	2233	2132	2132	2131	. 9
1. 0	2539	2438	2438	2337	2236	2236	2135	2134	2133	2033	2032	2031	1. 0
1. 1	2440	2439	2338	2238	2237	2136	2036	2035	2034	1933	1932	1931	1. 1
1. 2	2440	2340	2239	2238	2138	2037	2036	1935	1934	1833	1832	1831	1. 2
1. 3	2441	2341	2240	2139	2038	1937	1936	1835	1834	1733	1732	1731	1. 3
1. 4	2342	2241	2141	2040	1939	1938	1837	1736	1735	1634	1632	1631	1. 4
1. 5	2243	2142	2041	1941	1940	1839	1738	1636	1635	1634	1533	1531	1. 5
1. 6	2244	2143	2042	1941	1840	1739	1638	1537	1535	1534	1433	1431	1. 6
1. 7	2245	2044	1943	1842	1741	1640	1538	1537	1436	1434	1333	1331	1. 7
1. 8	2146	2045	1844	1743	1642	1540	1439	1438	1336	1335	1233	1232	1. 8
1. 9	2046	1946	1845	1743	1542	1441	1440	1338	1236	1235	1133	1132	1. 9
2. 0	2047	1946	1745	1644	1543	1441	1340	1238	1137	1135	1033	1032	2. 0
2. 1	2048	1847	1646	1545	1444	1342	1240	1139	1037	1035	0934	0932	2. 1
2. 2	1949	1748	1647	1446	1344	1243	1141	1039	0938	0936	0834	0832	2. 2
2. 3	1850	1749	1647	1446	1344	1143	1042	0940	0838	0836	0734	0732	2. 3
2. 4	1851	1650	1548	1347	1245	1044	0942	0840	0738	0736	0634	0632	2. 4
2. 5	1852	1650	1449	1248	1146	1044	0842	0741	0639	0636	0534	0532	2. 5
2. 6	1753	1551	1350	1248	1047	0945	0743	0641	0639	0537	0435	0432	2. 6
2. 7	1653	1552	1351	1149	0947	0845	0744	0641	0539	0437	0335	0332	2. 7
2. 8	1654	1453	1251	1050	0948	0746	0644	0542	0440	0337	0235	0232	2. 8
2. 9	1655	1354	1152	0951	0849	0647	0544	0442	0340	0238	0135	0133	2. 9
3. 0	1556	1355	1153	0951	0749	0547	0445	0343	0240	0138	0035	0033	3. 0
	300°	305°	310°	315°	320°	325°	330°	335°	340°	345°	350°	355°	
0. 1	3029	3129	3129	3129	3129	3129	3130	3130	3130	3130	3130	3130	0. 1
. 2	3128	3128	3128	3129	3229	3229	3229	3229	3229	3229	3230	3230	. 2
. 3	3227	3228	3228	3228	3228	3228	3328	3329	3329	3329	3329	3330	. 3
. 4	3227	3227	3327	3327	3327	3328	3328	3428	3429	3429	3429	3430	. 4
. 5	3226	3326	3326	3426	3427	3427	3428	3528	3528	3529	3529	3530	. 5
. 6	3325	3325	3425	3426	3526	3527	3527	3527	3628	3628	3629	3629	. 6
. 7	3424	3424	3425	3525	3526	3626	3626	3627	3728	3728	3729	3729	. 7
. 8	3423	3523	3524	3624	3625	3725	3726	3727	3827	3828	3829	3829	. 8
. 9	3422	3523	3623	3624	3724	3725	3826	3826	3827	3928	3928	3929	. 9
1. 0	3521	3622	3622	3723	3824	3824	3925	3926	3927	4027	4028	4029	1. 0
1. 1	3620	3621	3722	3822	3823	3924	4024	4025	4026	4127	4128	4129	1. 1
1. 2	3620	3720	3821	3822	3922	4023	4024	4125	4126	4227	4228	4229	1. 2
1. 3	3619	3719	3820	3921	4022	4123	4124	4225	4226	4327	4328	4329	1. 3
1. 4	3718	3819	3919	4020	4121	4122	4223	4324	4325	4426	4428	4429	1. 4
1. 5	3817	3918	4019	4119	4120	4221	4322	4424	4425	4426	4527	4529	1. 5
1. 6	3816	3917	4018	4119	4220	4321	4422	4523	4525	4526	4627	4629	1. 6
1. 7	3815	4016	4117	4218	4319	4420	4522	4523	4624	4626	4727	4729	1. 7
1. 8	3914	4015	4216	4317	4418	4520	4621	4622	4724	4725	4827	4828	1. 8
1. 9	4014	4114	4215	4317	4518	4619	4620	4722	4824	4825	4927	4928	1. 9
2. 0	4013	4114	4315	4416	4517	4619	4720	4822	4923	4925	5027	5028	2. 0
2. 1	4012	4213	4414	4515	4616	4718	4820	4921	5023	5025	5126	5128	2. 1
2. 2	4111	4312	4413	4614	4716	4817	4919	5021	5122	5124	5226	5228	2. 2
2. 3	4210	4311	4413	4614	4716	4917	5018	5120	5222	5224	5326	5328	2. 3
2. 4	4209	4410	4512	4713	4815	5016	5118	5220	5322	5324	5426	5428	2. 4
2. 5	4208	4410	4611	4812	4914	5016	5218	5319	5421	5424	5526	5528	2. 5
2. 6	4307	4509	4710	4812	5013	5115	5317	5419	5421	5523	5625	5628	2. 6
2. 7	4407	4508	4709	4911	5113	5215	5316	5419	5521	5623	5725	5728	2. 7
2. 8	4406	4607	4809	5010	5112	5314	5416	5518	5620	5723	5825	5828	2. 8
2. 9	4405	4706	4908	5109	5211	5413	5516	5618	5720	5822	5925	5927	2. 9
3. 0	4504	4705	4907	5109	5311	5513	5615	5717	5820	5922	6025	6027	3. 0

162. In order to find the velocity and direction of the resultant current from its north and east component velocities, the latter must first be freed from the arbitrary constant previously introduced to avoid negative values. The components will then be expressed in their true velocities with positive or negative signs to indicate the actual directions. The velocity of the resultant current will equal the square root of the sum of the squares of the component velocities and its direction will be expressed by the angle whose tangent is the quotient obtained by dividing the east component velocity by the north component velocity. The quadrant for the angle will be determined by the signs of the east and north components which will correspond respectively to those of the sine and cosine of the angle.

163. Table 7 provides a means of readily determining the resultant current from its north and east component velocities. The table contains values representing the velocity and direction of current corresponding to north- and east-component velocities for each hundredth of a knot from 0.01 to 0.60 knot. There is a line for each north-component velocity and a column for each east-component velocity. Of each group of four figures in the body of the table the first two represent the velocity in hundredths of a knot and the last two the direction in degrees measured from north (0° or 360°) or south (180°) according to the following rule which takes into account the signs of the component velocities. If these are both positive the direction will be the same as in the table; if the east component alone is negative, the tabular direction must be subtracted from 360°; if the north component alone is negative, the tabular direction is to be subtracted from 180°; and if both components are negative, the tabular direction is to be added to 180°.

> *Example:* To find the resultant velocity and direction corresponding to a north component velocity of −0.42 knot and an east component velocity of +0.13 knot, Table 7 is entered at the line marked ".42". On this line in the column headed "0.13" it is found that the resultant velocity is 0.44 knot and the tabular direction 17 degrees. Applying the rule just stated for the case where the north component alone is negative we find the actual direction of the resultant current to be 180°−17°=163°. So the current represented by north and east components, −0.42 and +0.13 respectively, has a velocity of 0.44 knot and a direction of 163°.

Specially prepared charts were formerly used both for resolving the observed current velocities and for obtaining the resultant currents. These charts and their use are described in detail on pages 51 and 52 of the first (1938) edition of this manual.

164. **Tabulation of rotary currents.**—Form 768 is used for this tabulation, which consists of grouping hourly or half-hourly current observations according to the high and low water phases at a reference station. If the observed velocities have not been resolved, the actual velocities and corresponding azimuths are entered in the double columns provided in the form, but if the observations have been resolved, the north and east component velocities are tabulated, a constant being included to avoid negative readings. On the Atlantic coast where the diurnal inequality in the tides is relatively small, the groups are usually reckoned from 3 hours before high water to 3 hours after high water and from 3 hours before low water to 3 hours after low water. On the Pacific coast where the diurnal inequality is of considerable importance, separate references are made to the higher high, lower high, higher low, and lower low water. If the current is largely diurnal, references are made to the higher high and lower low waters only. As the type of current varies somewhat in different localities, a special grouping may sometimes be required to meet existing conditions. Sometimes it may

be desirable to make all references to a single phase of the tide if other phases are not well defined. As with the reversing currents, predicted tides are in general to be preferred to observations for the purpose of reference.

165. Observations taken at hourly intervals are to be referred to the nearest whole tidal hour, but when observations have been taken at half-hourly intervals it is often better to use half-hourly groups with reference to the nearest half hour. Currents observed at lightships are usually of the rotary type. Most of the current records reduced by the rotary method are obtained at lightships. After the reference station has been selected and the form prepared with the desired group headings, the usual procedure is first to indicate in the original record by colored pencil the times of the high and low waters to which references are to be made. With these times as guides, the assignment of each observation to its proper group is readily accomplished. Each observation should be tabulated once. When the same observation fulfills the requirements of two groups, it may be included in either group but not in both. An occasional observation not belonging to any of the planned groups should be included in the nearest planned group. If such observations are numerous a rearrangement of the groups may be helpful.

166. **Reduction of rotary currents.**—After the observations have been tabulated as described in the preceding paragraph, the hourly groups are summed and averaged. For series of observations extending over a number of months, it is recommended that the tabulations and reductions be made by calendar months, separate sums and averages being obtained for each month. As these averages include both tidal and nontidal current, the next step is to separate them from each other. When the original observations have been resolved into north and east component velocities, the corresponding components of the nontidal current can be obtained by averaging separately the resolved values for each month or for the period of the observations. For observations taken at lightships, the daily sums may be conveniently entered in Form 270a at the bottom of the page, these sums being afterward brought together to obtain the monthly sums and averages. The velocity and direction of the resultant nontidal current may be obtained from its components by means of Table 7, after rejecting any constant that may have been introduced in the original resolution.

167. The north and east components of the nontidal current are then subtracted algebraically from the corresponding components of the observed current as obtained for each of the hourly groups. The subtraction automatically eliminates any constant introduced in the original resolution since this constant appears in the component averages for both the observed and the nontidal current. The velocity and direction of the resultant tidal current for each of the hourly groups may then be obtained from their components by the method already described. If the observations cover a period of less than 1 month, the reduction factor described in paragraph 155 should be applied to the velocities of the tidal current.

168. **Graphic representation of rotary current.**—The hourly velocities and directions of the rotary current may be represented graphically either by rectilinear or polar coordinates. For rectilinear coordinates the cross-section paper printed from plate 4145 is recommended. Separate graphs with the same time scale are made for velocity and direction. The smallest subdivision of the horizontal ruling is usually taken to represent 0.05 knot in the velocity scale and 5° of azimuth in the direction scale. For the time scale the smallest subdivision of the vertical ruling is taken as the equivalent of 0.2 hour. Along this scale are indicated the times of the tidal phases to which the currents are referred. To promote uniformity in this work it is suggested

TABLE 7.—*Velocities and directions from north and east components*

NORTH	East 0.01	0.02	0.03	0.04	0.05	East 0.06	0.07	0.08	0.09	0.10	East 0.11	0.12	0.13	0.14	0.15	NORTH
0.01	0145	0263	0372	0476	0579	0681	0782	0883	0984	1084	1185	1285	1386	1486	1586	0.01
.02	0227	0345	0456	0463	0568	0672	0774	0876	0977	1079	1180	1281	1381	1482	1582	.02
.03	0318	0434	0445	0553	0659	0763	0867	0969	0972	1073	1175	1276	1377	1478	1579	.03
.04	0414	0427	0537	0645	0651	0756	0860	0963	1066	1168	1270	1372	1473	1574	1675	.04
.05	0511	0522	0631	0639	0745	0850	0954	0958	1061	1163	1266	1367	1469	1570	1672	.05
.06	0609	0618	0727	0734	0840	0845	0949	1053	1156	1259	1361	1363	1465	1567	1668	.06
.07	0708	0716	0823	0830	0936	0941	1045	1149	1152	1255	1358	1460	1562	1663	1765	.07
.08	0807	0814	0921	0927	0932	1037	1141	1145	1248	1351	1454	1456	1558	1660	1762	.08
.09	0906	0913	0918	1024	1029	1134	1138	1242	1345	1348	1451	1553	1655	1757	1759	.09
.10	1006	1011	1017	1122	1127	1231	1235	1339	1342	1445	1548	1650	1652	1754	1856	.10
.11	1105	1110	1115	1220	1224	1329	1332	1436	1439	1542	1645	1647	1750	1852	1954	.11
.12	1205	1209	1214	1318	1323	1327	1430	1434	1537	1640	1643	1745	1847	1849	1951	.12
.13	1304	1309	1313	1417	1421	1425	1528	1532	1635	1638	1740	1843	1845	1947	2049	.13
.14	1404	1408	1412	1516	1520	1523	1627	1630	1733	1736	1838	1841	1943	2045	2047	.14
.15	1504	1508	1511	1615	1618	1622	1725	1728	1731	1834	1936	1939	2041	2043	2145	.15
.16	1604	1607	1611	1614	1717	1721	1724	1827	1829	1932	1935	2037	2139	2141	2243	.16
.17	1703	1707	1710	1713	1817	1819	1822	1925	1928	2030	2033	2135	2137	2239	2341	.17
.18	1803	1806	1809	1813	1916	1918	1921	2024	2027	2129	2131	2234	2236	2338	2340	.18
.19	1903	1906	1909	1912	2015	2018	2020	2123	2125	2128	2230	2232	2334	2436	2438	.19
.20	2003	2006	2009	2011	2114	2117	2119	2222	2224	2227	2329	2331	2433	2435	2537	.20
.21	2103	2105	2108	2111	2213	2216	2218	2221	2323	2325	2428	2430	2532	2534	2636	.21
.22	2203	2205	2208	2210	2313	2315	2318	2320	2422	2424	2527	2529	2631	2632	2734	.22
.23	2302	2305	2307	2310	2412	2415	2417	2419	2521	2523	2526	2628	2629	2731	2733	.23
.24	2402	2405	2407	2409	2412	2514	2516	2518	2621	2623	2625	2727	2728	2830	2832	.24
.25	2502	2505	2507	2509	2511	2613	2616	2618	2720	2722	2724	2826	2827	2929	2931	.25
.26	2602	2604	2607	2609	2611	2713	2715	2717	2819	2821	2823	2925	2927	3028	3030	.26
.27	2702	2704	2706	2708	2710	2813	2815	2817	2818	2920	2922	3024	3026	3027	3129	.27
.28	2802	2804	2806	2808	2810	2912	2914	2916	2918	3020	3021	3023	3125	3127	3228	.28
.29	2902	2904	2906	2908	2910	3012	3014	3015	3017	3119	3121	3122	3224	3226	3327	.29
.30	3002	3004	3006	3008	3009	3111	3113	3115	3117	3218	3220	3222	3323	3325	3427	.30
	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12	0.13	0.14	0.15	
0.31	3102	3104	3106	3107	3109	3211	3213	3214	3216	3318	3320	3321	3423	3424	3426	0.31
.32	3202	3204	3205	3207	3209	3311	3312	3314	3316	3417	3419	3421	3422	3524	3525	.32
.33	3302	3303	3305	3307	3309	3410	3412	3414	3415	3417	3518	3520	3522	3623	3624	.33
.34	3402	3403	3405	3407	3408	3510	3512	3513	3515	3517	3618	3619	3621	3722	3724	.34
.35	3502	3503	3505	3507	3508	3610	3611	3613	3614	3616	3717	3719	3720	3822	3823	.35
.36	3602	3603	3605	3606	3608	3609	3711	3713	3714	3716	3817	3818	3820	3921	3923	.36
.37	3702	3703	3705	3706	3708	3709	3811	3812	3814	3815	3917	3918	3919	4021	4022	.37
.38	3802	3803	3805	3806	3807	3809	3910	3912	3913	3915	4016	4018	4019	4020	4122	.38
.39	3901	3903	3904	3906	3907	3909	4010	4012	4013	4014	4116	4117	4118	4120	4221	.39
.40	4001	4003	4004	4006	4007	4009	4110	4111	4113	4114	4115	4217	4218	4219	4321	.40
.41	4101	4103	4104	4106	4107	4108	4210	4211	4212	4214	4215	4317	4318	4319	4420	.41
.42	4201	4203	4204	4205	4207	4208	4309	4311	4312	4313	4315	4416	4417	4418	4520	.42
.43	4301	4303	4304	4305	4307	4308	4409	4411	4412	4413	4414	4516	4517	4518	4619	.43
.44	4401	4403	4404	4405	4406	4408	4509	4510	4512	4513	4514	4615	4616	4618	4719	.44
.45	4501	4503	4504	4505	4506	4508	4609	4610	4611	4613	4614	4715	4716	4717	4718	.45
.46	4601	4602	4604	4605	4606	4607	4709	4710	4711	4712	4713	4815	4816	4817	4818	.46
.47	4701	4702	4704	4705	4706	4707	4808	4810	4811	4812	4813	4914	4915	4917	4918	.47
.48	4801	4802	4804	4805	4806	4807	4908	4909	4911	4912	4913	4914	5015	5016	5017	.48
.49	4901	4902	4904	4905	4906	4907	4908	5009	5010	5012	5013	5014	5115	5116	5117	.49
.50	5001	5002	5003	5005	5006	5007	5008	5109	5110	5111	5112	5113	5215	5216	5217	.50
.51	5101	5102	5103	5104	5106	5107	5108	5209	5210	5211	5212	5213	5314	5315	5317	.51
.52	5201	5202	5203	5204	5205	5207	5208	5309	5310	5311	5312	5313	5414	5415	5416	.52
.53	5301	5302	5303	5304	5305	5306	5308	5409	5410	5411	5412	5413	5514	5515	5516	.53
.54	5401	5402	5403	5404	5405	5406	5407	5508	5509	5510	5512	5513	5614	5615	5616	.54
.55	5501	5502	5503	5504	5505	5506	5507	5608	5609	5610	5611	5612	5713	5714	5715	.55
.56	5601	5602	5603	5604	5605	5606	5607	5708	5709	5710	5711	5712	5713	5814	5815	.56
.57	5701	5702	5703	5704	5705	5706	5707	5808	5809	5810	5811	5812	5813	5914	5915	.57
.58	5801	5802	5803	5804	5805	5806	5807	5908	5909	5910	5911	5912	5913	6014	6014	.58
.59	5901	5902	5903	5904	5905	5906	5907	6008	6009	6010	6011	6011	6012	6113	6114	.59
.60	6001	6002	6003	6004	6005	6006	6007	6108	6109	6109	6110	6111	6112	6213	6214	.60

TABLE 7.—*Velocities and directions from north and east components*—Con.

NORTH	East					East					East					NORTH
	0.16	0.17	0.18	0.19	0.20	0.21	0.22	0.23	0.24	0.25	0.26	0.27	0.28	0.29	0.30	
0.01	1686	1787	1887	1987	2087	2187	2287	2388	2488	2588	2688	2788	2888	2988	3088	0.01
.02	1683	1783	1884	1984	2084	2185	2285	2385	2485	2585	2686	2786	2886	2986	3086	.02
.03	1679	1780	1881	1981	2081	2182	2282	2383	2483	2583	2683	2784	2884	2984	3084	.03
.04	1676	1777	1877	1978	2079	2179	2280	2380	2481	2581	2681	2782	2882	2982	3082	.04
.05	1773	1873	1974	2075	2176	2277	2377	2478	2478	2579	2679	2780	2880	2980	3081	.05
.06	1769	1871	1972	2072	2173	2274	2375	2475	2576	2677	2777	2877	2978	3078	3179	.06
.07	1766	1867	1969	2070	2171	2272	2372	2473	2574	2674	2775	2875	2976	3076	3177	.07
.08	1863	1965	2066	2167	2268	2269	2370	2471	2572	2672	2773	2873	2974	3075	3175	.08
.09	1861	1962	2063	2165	2266	2367	2468	2569	2669	2770	2871	2872	2972	3073	3173	.09
.10	1958	2060	2161	2162	2263	2365	2466	2567	2667	2768	2869	2970	3070	3171	3272	.10
.11	1955	2057	2159	2260	2361	2462	2563	2564	2665	2766	2867	2968	3069	3169	3270	.11
.12	2053	2155	2256	2258	2359	2460	2561	2662	2763	2864	2965	3066	3067	3168	3268	.12
.13	2151	2153	2254	2356	2457	2558	2659	2661	2762	2863	2963	3064	3165	3266	3367	.13
.14	2149	2251	2352	2454	2455	2556	2658	2759	2860	2961	3062	3063	3163	3264	3365	.14
.15	2247	2349	2350	2452	2553	2654	2756	2757	2858	2959	3060	3161	3262	3363	3463	.15
.16	2345	2347	2448	2550	2651	2653	2754	2855	2956	3057	3058	3159	3260	3361	3462	.16
.17	2343	2445	2547	2648	2650	2751	2852	2954	2955	3056	3157	3258	3359	3460	3460	.17
.18	2442	2543	2545	2647	2748	2849	2851	2952	3053	3154	3255	3256	3357	3458	3559	.18
.19	2540	2642	2643	2745	2846	2848	2949	3051	3152	3153	3254	3355	3456	3557	3658	.19
.20	2639	2640	2742	2844	2845	2946	3048	3049	3150	3251	3352	3453	3454	3555	3656	.20
.21	2637	2739	2841	2842	2944	3045	3046	3148	3249	3350	3351	3452	3553	3654	3755	.21
.22	2736	2838	2839	2941	3042	3044	3145	3246	3347	3349	3450	3551	3652	3653	3754	.22
.23	2835	2936	2938	3039	3041	3142	3244	3345	3346	3447	3549	3550	3651	3752	3853	.23
.24	2934	2935	3037	3138	3140	3241	3343	3344	3445	3546	3547	3648	3749	3850	3851	.24
.25	3033	3034	3136	3137	3239	3340	3341	3443	3544	3545	3646	3747	3848	3849	3950	.25
.26	3032	3133	3235	3236	3338	3339	3440	3541	3543	3644	3745	3746	3847	3948	4049	.26
.27	3131	3232	3234	3335	3437	3438	3539	3540	3642	3743	3744	3845	3946	4047	4048	.27
.28	3230	3331	3333	3434	3436	3537	3638	3639	3741	3842	3843	3944	4045	4046	4147	.28
.29	3329	3430	3432	3533	3535	3636	3637	3738	3840	3841	3942	4043	4044	4145	4246	.29
.30	3428	3430	3531	3632	3634	3735	3736	3837	3839	3940	4041	4042	4143	4244	4245	.30
	0.16	0.17	0.18	0.19	0.20	0.21	0.22	0.23	0.24	0.25	0.26	0.27	0.28	0.29	0.30	
0.31	3527	3529	3630	3632	3733	3734	3835	3937	3938	4039	4040	4141	4242	4243	4344	0.31
.32	3627	3628	3729	3731	3832	3833	3935	3936	4037	4138	4139	4240	4341	4342	4443	.32
.33	3726	3727	3829	3830	3931	3932	4034	4035	4136	4137	4238	4339	4340	4441	4542	.33
.34	3825	3827	3828	3929	3930	4032	4033	4134	4235	4236	4337	4338	4439	4540	4541	.34
.35	3825	3926	3927	4028	4030	4131	4132	4233	4234	4336	4437	4438	4539	4540	4641	.35
.36	3924	4025	4027	4128	4129	4230	4231	4333	4334	4435	4436	4537	4638	4639	4740	.36
.37	4023	4124	4126	4227	4228	4330	4331	4432	4433	4534	4535	4636	4637	4738	4839	.37
.38	4123	4224	4225	4227	4328	4329	4430	4431	4532	4533	4634	4735	4736	4837	4838	.38
.39	4222	4323	4325	4326	4427	4428	4529	4531	4632	4633	4734	4735	4836	4937	4938	.39
.40	4322	4323	4424	4425	4527	4528	4629	4630	4731	4732	4833	4834	4935	4936	5037	.40
.41	4421	4423	4524	4525	4626	4627	4728	4729	4830	4831	4932	4933	5034	5035	5136	.41
.42	4521	4522	4623	4624	4725	4727	4728	4829	4830	4931	4932	5033	5034	5135	5236	.42
.43	4620	4622	4723	4724	4725	4826	4827	4928	4929	5030	5031	5132	5133	5234	5235	.43
.44	4720	4721	4822	4823	4824	4926	4927	5028	5029	5130	5131	5232	5232	5333	5334	.44
.45	4820	4821	4822	4923	4924	5025	5026	5127	5128	5129	5230	5231	5332	5433	5434	.45
.46	4919	4920	4921	5022	5023	5125	5126	5127	5228	5229	5329	5330	5431	5432	5533	.46
.47	5019	5020	5021	5122	5123	5124	5225	5226	5327	5328	5429	5430	5531	5532	5633	.47
.48	5118	5120	5121	5222	5223	5224	5325	5326	5427	5428	5528	5529	5630	5631	5732	.48
.49	5218	5219	5220	5321	5322	5323	5424	5425	5526	5527	5528	5629	5630	5731	5731	.49
.50	5218	5319	5320	5321	5422	5423	5524	5525	5626	5627	5627	5728	5729	5830	5831	.50
.51	5317	5418	5419	5420	5521	5522	5623	5624	5625	5726	5727	5828	5829	5930	5930	.51
.52	5417	5518	5519	5520	5621	5622	5623	5724	5725	5826	5827	5927	5928	6029	6030	.52
.53	5517	5618	5619	5620	5721	5722	5723	5823	5824	5925	5926	5927	6028	6029	6130	.53
.54	5617	5717	5718	5719	5820	5821	5822	5923	5924	6025	6026	6027	6127	6128	6229	.54
.55	5716	5817	5818	5819	5920	5921	5922	6023	6024	6024	6125	6126	6227	6228	6329	.55
.56	5816	5917	5918	5919	5920	6021	6021	6122	6123	6124	6225	6226	6327	6327	6428	.56
.57	5916	5917	6018	6018	6019	6120	6121	6122	6223	6224	6325	6325	6426	6427	6428	.57
.58	6015	6016	6117	6118	6119	6220	6221	6222	6322	6323	6424	6425	6426	6527	6527	.58
.59	6115	6116	6217	6218	6219	6320	6320	6321	6422	6423	6424	6525	6525	6626	6627	.59
.60	6215	6216	6317	6318	6318	6419	6420	6421	6522	6523	6523	6624	6625	6726	6727	.60

TABLE 7.—*Velocities and directions from north and east components*—Con.

NORTH	East					East					East					NORTH
	0.31	0.32	0.33	0.34	0.35	0.36	0.37	0.38	0.39	0.40	0.41	0.42	0.43	0.44	0.45	
0.01	3188	3288	3388	3488	3588	3688	3788	3888	3989	4089	4189	4289	4389	4489	4589	0.01
.02	3186	3286	3387	3487	3587	3687	3787	3887	3987	4087	4187	4287	4387	4487	4587	.02
.03	3184	3285	3385	3485	3585	3685	3785	3885	3986	4086	4186	4286	4386	4486	4586	.03
.04	3183	3283	3383	3483	3583	3684	3784	3884	3984	4084	4184	4285	4385	4485	4585	.04
.05	3181	3281	3381	3482	3582	3682	3782	3883	3983	4083	4183	4283	4383	4484	4584	.05
.06	3279	3379	3480	3580	3680	3681	3781	3881	3981	4081	4182	4282	4382	4482	4582	.06
.07	3277	3378	3478	3578	3679	3779	3879	3980	4080	4180	4280	4381	4481	4581	4681	.07
.08	3276	3376	3476	3577	3677	3777	3878	3978	4078	4179	4279	4379	4479	4580	4680	.08
.09	3274	3374	3475	3575	3676	3776	3876	3977	4077	4177	4278	4378	4478	4578	4679	.09
.10	3372	3473	3473	3573	3674	3774	3875	3975	4076	4176	4276	4377	4477	4577	4677	.10
.11	3370	3471	3572	3672	3773	3873	3973	4074	4174	4175	4275	4375	4476	4576	4676	.11
.12	3369	3469	3570	3671	3771	3872	3972	4072	4173	4273	4373	4474	4574	4675	4775	.12
.13	3467	3468	3568	3669	3770	3870	3971	4071	4172	4272	4372	4473	4573	4674	4774	.13
.14	3466	3566	3667	3768	3868	3969	4069	4070	4170	4271	4371	4472	4572	4672	4773	.14
.15	3464	3565	3666	3766	3867	3967	4068	4168	4269	4369	4470	4570	4671	4771	4772	.15
.16	3563	3663	3764	3865	3865	3966	4067	4167	4268	4368	4469	4569	4670	4770	4870	.16
.17	3561	3662	3763	3863	3964	4065	4166	4266	4367	4367	4467	4568	4668	4769	4869	.17
.18	3660	3761	3861	3862	3963	4063	4164	4265	4365	4466	4566	4667	4767	4868	4868	.18
.19	3658	3759	3860	3961	4062	4162	4263	4263	4364	4465	4565	4666	4766	4867	4967	.19
.20	3757	3858	3959	3960	4060	4161	4262	4362	4463	4563	4664	4765	4765	4866	4966	.20
.21	3756	3857	3958	4058	4159	4260	4360	4361	4462	4562	4663	4763	4864	4964	5065	.21
.22	3855	3955	4056	4057	4158	4259	4359	4460	4561	4661	4762	4762	4863	4963	5064	.22
.23	3953	3954	4055	4156	4257	4357	4458	4459	4559	4660	4761	4861	4962	5062	5163	.23
.24	3952	4053	4154	4255	4256	4356	4457	4558	4658	4759	4860	4860	4961	5061	5162	.24
.25	4051	4152	4153	4254	4354	4455	4556	4557	4657	4758	4859	4959	5060	5160	5161	.25
.26	4050	4151	4252	4353	4453	4454	4555	4656	4756	4857	4958	4958	5059	5159	5260	.26
.27	4149	4250	4351	4352	4452	4553	4654	4755	4755	4856	4957	5057	5158	5258	5259	.27
.28	4248	4349	4350	4451	4551	4652	4653	4754	4854	4955	5056	5056	5157	5258	5358	.28
.29	4247	4348	4449	4550	4550	4651	4752	4853	4953	4954	5055	5155	5256	5357	5457	.29
.30	4346	4447	4548	4549	4649	4750	4851	4852	4952	5053	5154	5254	5255	5356	5456	.30
	0.31	0.32	0.33	0.34	0.35	0.36	0.37	0.38	0.39	0.40	0.41	0.42	0.43	0.44	0.45	
0.31	4445	4546	4547	4648	4748	4849	4850	4951	5052	5152	5153	5254	5354	5455	5555	0.31
.32	4544	4545	4646	4747	4748	4848	4949	5050	5051	5151	5252	5353	5453	5454	5555	.32
.33	4543	4644	4745	4746	4847	4947	5048	5049	5150	5250	5351	5352	5452	5553	5654	.33
.34	4642	4743	4744	4845	4946	5047	5047	5148	5249	5250	5350	5451	5552	5652	5653	.34
.35	4742	4742	4843	4944	4945	5046	5147	5247	5248	5349	5450	5550	5551	5651	5752	.35
.36	4841	4842	4943	5043	5044	5145	5246	5247	5347	5448	5548	5549	5650	5751	5851	.36
.37	4840	4941	5042	5043	5143	5244	5245	5346	5447	5447	5548	5649	5749	5750	5851	.37
.38	4939	5040	5041	5142	5243	5243	5344	5445	5446	5546	5647	5748	5749	5849	5950	.38
.39	5038	5039	5140	5241	5242	5343	5443	5444	5545	5646	5746	5747	5848	5948	6049	.39
.40	5138	5139	5240	5240	5341	5442	5443	5544	5644	5745	5746	5846	5947	5948	6048	.40
.41	5137	5238	5339	5340	5440	5542	5542	5643	5744	5744	5845	5946	5946	6047	6148	.41
.42	5236	5337	5338	5439	5540	5541	5641	5742	5743	5844	5944	5945	6046	6146	6247	.42
.43	5336	5437	5438	5538	5539	5640	5741	5741	5842	5943	5944	6044	6145	6246	6246	.43
.44	5435	5436	5537	5638	5639	5739	5740	5841	5942	5942	6043	6144	6244	6245	6346	.44
.45	5535	5535	5636	5637	5738	5839	5839	5940	6041	6042	6142	6243	6244	6344	6445	.45
.46	5534	5635	5736	5736	5837	5838	5939	6039	6040	6141	6242	6242	6343	6444	6444	.46
.47	5633	5734	5735	5836	5937	5937	6038	6039	6140	6240	6241	6342	6442	6443	6544	.47
.48	5733	5834	5835	5935	5936	6037	6138	6138	6239	6240	6341	6441	6442	6543	6643	.48
.49	5832	5933	5934	6035	6036	6137	6137	6238	6339	6339	6440	6541	6541	6642	6743	.49
.50	5932	5933	6033	6034	6135	6236	6237	6337	6338	6439	6539	6540	6641	6741	6742	.50
.51	6031	6032	6133	6134	6234	6235	6336	6437	6437	6538	6539	6639	6740	6741	6841	.51
.52	6131	6132	6232	6233	6334	6335	6435	6436	6537	6638	6638	6739	6740	6840	6941	.52
.53	6130	6231	6232	6333	6433	6434	6535	6536	6636	6637	6738	6838	6839	6940	7040	.53
.54	6230	6331	6331	6432	6433	6534	6534	6635	6736	6737	6837	6838	6939	7039	7040	.54
.55	6329	6430	6431	6532	6532	6633	6634	6735	6735	6836	6937	6937	7038	7039	7139	.55
.56	6429	6430	6531	6631	6632	6733	6733	6834	6835	6936	6936	7037	7138	7138	7239	.56
.57	6529	6529	6630	6631	6732	6732	6833	6934	6934	7035	7036	7136	7137	7238	7338	.57
.58	6628	6629	6730	6730	6831	6832	6933	6933	7034	7035	7135	7236	7237	7337	7338	.58
.59	6728	6728	6829	6830	6931	6931	7032	7033	7133	7134	7235	7235	7336	7437	7437	.59
.60	6827	6828	6829	6930	6930	7031	7032	7132	7233	7234	7334	7335	7436	7436	7537	.60

TABLE 7.—*Velocities and directions from north and east components*—Con.

NORTH	East					East					East					NORTH
	0.46	0.47	0.48	0.49	0.50	0.51	0.52	0.53	0.54	0.55	0.56	0.57	0.58	0.59	0.60	
0.01	4689	4789	4889	4989	5089	5189	5289	5389	5489	5589	5689	5789	5889	5989	6089	0.01
.02	4688	4788	4888	4988	5088	5188	5288	5388	5488	5588	5688	5788	5888	5988	6088	.02
.03	4686	4786	4886	4986	5087	5187	5287	5387	5487	5587	5687	5787	5887	5987	6087	.03
.04	4685	4785	4885	4985	5085	5186	5286	5386	5486	5586	5686	5786	5886	5986	6086	.04
.05	4684	4784	4884	4984	5084	5184	5285	5385	5485	5585	5685	5785	5885	5985	6085	.05
.06	4683	4783	4883	4983	5083	5183	5283	5384	5484	5584	5684	5784	5884	5984	6084	.06
.07	4781	4882	4982	4982	5082	5182	5282	5382	5483	5583	5683	5783	5883	5983	6083	.07
.08	4780	4880	4981	5081	5181	5281	5381	5481	5582	5682	5782	5882	5982	6082	6182	.08
.09	4779	4879	4979	5080	5180	5280	5380	5480	5581	5681	5781	5881	5981	6081	6181	.09
.10	4778	4878	4978	5078	5179	5279	5379	5479	5580	5680	5780	5880	5980	6080	6181	.10
.11	4777	4877	4977	5077	5178	5278	5378	5478	5578	5679	5779	5879	5979	6079	6180	.11
.12	4875	4976	4976	5076	5177	5277	5377	5477	5577	5678	5778	5878	5978	6079	6179	.12
.13	4874	4975	5075	5175	5275	5376	5476	5576	5676	5777	5777	5877	5977	6078	6178	.13
.14	4873	4973	5074	5174	5274	5375	5475	5575	5675	5776	5876	5976	6076	6177	6277	.14
.15	4872	4972	5073	5173	5273	5373	5474	5574	5674	5775	5875	5975	6076	6176	6276	.15
.16	4971	5071	5172	5272	5272	5373	5473	5573	5673	5774	5874	5974	6075	6175	6275	.16
.17	4970	5070	5170	5271	5371	5472	5572	5672	5773	5873	5973	5973	6074	6174	6274	.17
.18	4969	5069	5169	5270	5370	5471	5571	5671	5772	5872	5972	6072	6173	6273	6373	.18
.19	5068	5168	5268	5369	5369	5470	5570	5670	5771	5871	5971	6072	6172	6272	6372	.19
.20	5067	5167	5267	5368	5468	5569	5669	5769	5870	5970	5970	6071	6171	6271	6372	.20
.21	5165	5166	5266	5367	5467	5568	5668	5768	5869	5969	6069	6170	6270	6370	6471	.21
.22	5164	5265	5365	5466	5566	5667	5667	5767	5868	5968	6069	6169	6269	6370	6470	.22
.23	5163	5264	5364	5465	5565	5666	5766	5867	5967	6067	6168	6168	6268	6369	6469	.23
.24	5262	5363	5463	5564	5664	5665	5765	5866	5966	6066	6167	6267	6368	6468	6568	.24
.25	5261	5362	5462	5563	5663	5764	5864	5965	6065	6066	6166	6266	6367	6467	6567	.25
.26	5361	5461	5562	5562	5663	5763	5863	5964	6064	6165	6265	6365	6466	6466	6567	.26
.27	5360	5460	5561	5661	5762	5862	5963	5963	6063	6164	6264	6365	6465	6565	6666	.27
.28	5459	5559	5660	5660	5761	5861	5962	6062	6163	6263	6363	6464	6464	6565	6665	.28
.29	5458	5558	5659	5759	5860	5960	6061	6061	6162	6262	6363	6463	6563	6664	6764	.29
.30	5557	5657	5758	5759	5859	5960	6060	6160	6261	6361	6462	6462	6563	6663	6763	.30
	0.46	0.47	0.48	0.49	0.50	0.51	0.52	0.53	0.54	0.55	0.56	0.57	0.58	0.59	0.60	
0.31	5556	5657	5757	5858	5958	6059	6159	6160	6260	6361	6461	6561	6662	6762	6863	0.31
.32	5655	5756	5856	5957	5957	6058	6158	6259	6359	6460	6460	6561	6661	6762	6862	.32
.33	5754	5755	5855	5956	6057	6157	6258	6258	6359	6459	6559	6660	6760	6861	6861	.33
.34	5754	5854	5955	6055	6056	6156	6257	6357	6458	6558	6659	6659	6760	6860	6960	.34
.35	5853	5953	5954	6054	6155	6256	6356	6457	6457	6558	6658	6758	6859	6959	6960	.35
.36	5852	5953	6053	6153	6254	6255	6355	6456	6556	6657	6757	6758	6858	6959	7059	.36
.37	5951	6052	6152	6153	6253	6354	6455	6555	6556	6656	6757	6857	6957	7058	7058	.37
.38	6051	6051	6152	6252	6353	6453	6454	6554	6655	6755	6856	6956	6957	7057	7158	.38
.39	6050	6150	6251	6351	6352	6453	6553	6654	6754	6755	6855	6956	7056	7157	7257	.39
.40	6149	6250	6250	6351	6451	6552	6652	6653	6754	6854	6954	7055	7055	7156	7256	.40
.41	6248	6249	6349	6450	6551	6551	6652	6752	6853	6953	6954	7054	7155	7255	7356	.41
.42	6248	6348	6449	6549	6550	6651	6751	6852	6852	6953	7053	7154	7254	7255	7355	.42
.43	6347	6448	6448	6549	6649	6750	6750	6851	6951	7052	7152	7153	7253	7354	7454	.43
.44	6446	6447	6547	6648	6749	6749	6850	6950	7051	7051	7152	7252	7353	7453	7454	.44
.45	6446	6546	6647	6747	6748	6849	6949	7050	7050	7151	7251	7352	7352	7453	7553	.45
.46	6545	6646	6646	6747	6847	6948	6949	7049	7150	7250	7251	7351	7452	7552	7653	.46
.47	6644	6645	6746	6846	6947	6947	7048	7148	7249	7249	7350	7450	7551	7551	7652	.47
.48	6644	6744	6845	6946	6946	7047	7147	7248	7248	7349	7449	7550	7550	7651	7751	.48
.49	6743	6844	6944	6945	7046	7146	7147	7247	7348	7448	7449	7549	7650	7750	7751	.49
.50	6843	6943	6944	7044	7145	7146	7246	7347	7447	7448	7548	7649	7749	7750	7850	.50
.51	6942	6943	7043	7144	7144	7245	7346	7446	7447	7547	7648	7648	7749	7849	7950	.51
.52	6941	7042	7143	7143	7244	7344	7445	7446	7546	7647	7647	7748	7848	7949	7949	.52
.53	7041	7142	7242	7243	7343	7444	7444	7545	7646	7646	7747	7847	7948	7948	8049	.53
.54	7140	7241	7242	7342	7443	7443	7544	7644	7645	7746	7846	7947	7947	8048	8148	.54
.55	7240	7241	7341	7442	7442	7543	7643	7644	7744	7845	7846	7946	8047	8147	8147	.55
.56	7239	7340	7441	7441	7542	7642	7643	7743	7844	7844	7945	8046	8146	8146	8247	.56
.57	7339	7440	7540	7541	7641	7642	7742	7843	7943	7944	8044	8145	8145	8246	8346	.57
.58	7438	7539	7540	7640	7741	7741	7842	7942	7943	8043	8144	8145	8245	8345	8346	.58
.59	7538	7539	7639	7740	7740	7841	7941	7942	8042	8143	8144	8244	8345	8345	8445	.59
.60	7637	7638	7739	7739	7840	7940	7941	8041	8142	8143	8243	8244	8344	8445	8545	.60

that there shall be provided for each graph a basic Greenwich transit time scale reckoned from the time of the moon's transit over the meridian of Greenwich. Along this basic scale may be indicated according to the Greenwich intervals the times of the tidal phases. All velocities are plotted as positive regardless of direction. Information pertaining to the times, directions and velocities of the various current phases is readily obtainable from these graphs. For the representation of the hourly velocities and directions by polar coordinates see paragraph 22.

Harmonic Reduction

169. As tidal currents result from the same periodic forces that cause the rise and fall of the tide, they may be represented by similar harmonic terms, current velocities taking the place of tidal heights. In the harmonic analysis* of currents, however, the question of direction must be considered. For a reversing current, the analysis is applied to the movement along the axis of the stream, flood velocities being considered as positive and ebb velocities as negative. For rotary currents the north and east components are analyzed separately. For a short series of observations the reduction is based upon a comparison with tidal constants from a simultaneous series of tide observations or predictions at a suitable reference station, but if the current observations cover a period of 29 days or more the analysis is carried on in the same manner and with the use of the same forms as employed for a tidal series.

170. For a 29-day series of observations, it is recommended that the analysis be made for the M series, the S series, and for N_2, K_1, and O_1. For longer series additional constituents may be included. In the analysis of current velocities, the harmonics of the higher degrees such as M_4 and M_6 may be expected to be of relatively greater magnitude than they are in the tides. From theoretical considerations it may also be shown that the magnitude of the diurnal constituents as compared with the semidiurnal constituents in a simple tidal oscillation is only about one-half as great in the current as in the tide. However, because of the complexity of the tidal and current movement, the actual relation between the various constituents as determined by the analysis is subject to wide variations. The constituent S_1, which is usually negligible in the tides, may be found to be of appreciable magnitude in offshore currents because of the effect of daily periodic land and sea breezes. However, as this constituent has a speed very nearly the same as that of K_1 it can be separated from the latter only by a long series of observations, preferably a year or more.

171. **Harmonic comparison.**—Form 723 (fig. 31) provides for the determination of harmonic constants from a series of current observations by comparison with corresponding constants from a tidal series covering the same period of time. This comparison is to be used if the series of observations is less than 29 days and may be used for longer series if desired. For the purpose of this comparison the hourly predicted heights at the tide station are usually to be preferred to actual observations since meteorological irregularities appearing in observed tides do not necessarily appear in a similar manner in the observed currents. In this work both currents and tides for the simultaneous period are to be summed for constituents M, S, N, K, and O; and the analysis is then carried through Form 194 (Tides: Harmonic Analysis) to obtain the values of R' and ζ'

*A detailed discussion of the harmonic analysis of tides and tidal currents is contained in United States Coast and Geodetic Survey Special Publication No. 98, *Manual of the Harmonic Analysis and Prediction of Tides.*

Form 723
DEPARTMENT OF COMMERCE
COAST AND GEODETIC SURVEY
Ed. Mar. 1935

CURRENTS: HARMONIC COMPARISON

(A) Current Station No. 1, Bolivar Roads, Galveston Bay, Tex. Lat. 29° 20.8' N Long. 94° 46.1'W = L (A) 94.77°

(B) Tide Station Galveston, Tex. (predictions) Lat. 29° 18.7' N Long. 94° 47.5'W = L (B) 94.79°

Series begins Nov. 28, 1936 Length of Series 3 days

Use one decimal for angles and three decimals for other quantities

Component	(1) Accepted H at (B)	(2) From Simultaneous Observations: R′ at (B)	(3) From Simultaneous Observations: R′ at (A)	(4) Ratio (1) ÷ (2)	(5) Corrected H at (A) (3) × (4)	(6) Accepted κ at (B)	(7) From Simultaneous Observations: ζ′ at (B)	(8) From Simultaneous Observations: ζ′ at (A)	(9) Difference (6) − (7)	(10) [L(B)−L(A)]p =[0.02]p	(11) Corrected κ at (A) (8)+(9)+(10)
	Feet	Feet	Knots		Knots	Degrees	Degrees	Degrees	Degrees	Degrees	Degrees
M_2	0.271	0.382	0.859	0.709	0.609	117.7	101.3	94.4	16.4	0.0	110.8
M_4	--------	--------	0.135	do	0.096	--------	--------	197.7	$2M°_2$ 32.8	0.1	230.6
M_6	--------	--------	0.078	do	0.055	--------	--------	231.2	$3M°_2$ 49.2	0.1	280.5
M_8	--------	--------	0.042	do	0.030	--------	--------	67.2	$4M°_2$ 65.6	0.2	133.0
S_2	0.084	0.380	0.862	0.221	0.191	118.7	140.2	132.4	-21.5	0.0	110.9
N_2	0.066	0.365	0.814	0.181	0.147	97.1	73.2	67.1	23.9	0.0	91.0
K_1	0.365	0.809	1.665	0.451	0.751	320.8	332.6	300.5	-11.8	0.0	288.7
O_1	0.343	0.868	1.868	0.395	0.738	311.3	284.4	256.0	26.9	0.0	282.9

Remarks: Direction of flood (positive velocities) 287° (true).

Direction of ebb (negative velocities) 111° (true).

FIGURE 31.—Form 723, Harmonic comparison.

for each constituent. The harmonics M_4, M_6, and M_8 are obtained for the current series, but may be omitted in the tidal series.

172. Enter in Form 723 the accepted H and κ of the principal tidal constituents for the reference station and also the values of R' and ζ' obtained from the analyses of the simultaneous series of tides and currents. The necessary calculations in the form are self-explanatory. The corrected velocity amplitude of each current constituent is obtained by a ratio on the assumption that for each constituent the relation of the corrected amplitude to the uncorrected amplitude is the same for both tide and current. The ratio derived for the constituent M_2 is used also for the higher harmonics of M, this being considered more reliable than ratios determined directly from the much smaller amplitudes of these harmonics. The corrected epoch (κ) for each current constituent is calculated on the assumption that the difference between the corrected and uncorrected epoch is the same for tide and current. For convenience the zetas (ζ) rather than the kappas (κ) from the simultaneous observations are used in the form and a longitude correction, column (10), is introduced to allow for this fact. Differences in column (9) for the higher harmonics of M_2 are derived from the difference for that constituent because of the uncertainty in the determination of epochs of constituents of very small amplitudes.

173. **Half-hourly velocities.**—Short series of current observations are frequently taken at half-hourly intervals. As individual observations are somewhat rough, the utilization of the half-hourly observations will add materially to the accuracy of the results obtained from an analysis. Moreover, the closer spacing of the half-hourly values will give a better development of the higher harmonics of M which are of greater relative importance in the currents than in the tides. Special stencils have been prepared for the summation of these observations. Observations taken on the exact hour are tabulated in Form 362c as usual, while observations on the half-hour are offset to the right on the intermediate lines. As the series of observations under consideration are short, provisions have been made for obtaining only the diurnal constituents K_1 and O_1; the semidiurnal constituents M_2, S_2, and N_2; and the higher harmonics of M.

174. For the diurnal constituents, the special stencils provide for the same distribution, with the inclusion of the half-hourly values, as is obtained with the standard stencils used for the hourly values only. Hourly means for the constituents are obtained and entered in Form 194 and all subsequent computations are the same as those based upon the use of the standard stencils.

175. For the semidiurnal constituents M_2, S_2, and N_2, the semidiurnal period is divided into 24 parts. Special stencils for the constituents M_2 and N_2 provide for the distribution of the observed half-hourly velocities into the 24 groups indicated by this division. No stencil is required for the constituent S_2, the necessary grouping being accomplished by combining sums for afternoon observations with those for the forenoon observations of corresponding hours. Thus, the noon observations will be included with those taken at midnight, and the observations at 12:30 p. m. with those taken at 0:30 a. m.

176. The resulting means obtained for the semidiurnal constituents by the method described above are in reality half-hourly means, but in adapting Form 194 for the analysis, these means may be entered in order in the spaces provided for the hourly means. Then, after doubling all subscripts in the form, the necessary computations may be carried out as indicated. Thus, all computations for the semidiurnal constituents will be made in the spaces originally designed for the diurnal constituents

The computations for all higher harmonics of even subscripts may be carried out in the same form using the spaces originally designed for the harmonics with subscripts one-half as great. In this adaptation, of the form no provision is made for the computation of a harmonic of odd subscript which is here of relatively little importance. Other forms which are used in connection with the analysis will not be affected by the use of the special stencils for the half-hourly velocities.

177. Observations on the half-hour may also be analyzed separately from those on exact hour, using the standard stencils for the summation. In this case the stencils are moved to the right one column and dropped one line, thus covering the hourly values and exposing those occurring on the half-hour. Allowance must be made for the difference of a half-hour in the beginning of the series when computing the (V_0+u)'s in Form 244. This may be conveniently done by assuming a time meridian a half-hour or $7\frac{1}{2}°$ westerly from the actual time meridian used so that the first half-hourly observation will correspond to the 0 hour of the assumed time meridian. The difference of 15 minutes for the middle of the series has a negligible effect in the computations and may be disregarded. In other respects the analysis is carried on in same manner as the analysis for the hourly observations, and the results obtained afford a useful check on the latter.

178. **Current constituent ellipse.**—It has already been shown (par. 22) that an observed rotary current can be represented graphically by a crude ellipse in which the velocity and direction of the current are indicated by the length and direction of the radius vector for different hours of the tidal cycle. From the harmonic constants for the north and east components of any current constituent a smooth ellipse may be constructed to represent that constituent. During the constituent cycle there will be two maximum velocities of equal strength in opposite directions. These will be represented in the ellipse by the two semimajor axes. There will also be two minimum velocities represented by the two semiminor axes of the ellipse. The construction of the current constituent ellipse from the harmonic constants and the computations for the times, velocities, and directions of the current for the maximum and minimum velocities are explained in the following paragraphs.

179. Let H_n and K_n^* represent respectively the amplitude and epoch of the north component, and H_e and K_e the amplitude and epoch of the east component of the particular constituent for which the ellipse is to be constructed. Let T represent time as expressed in degrees of the equilibrium argument for this constituent. It is therefore reckoned from the same origin as the epochs of the constituent. Let V_n and V_e respectively represent velocities for the north and east components, and V and A respectively the velocity and azimuth of the resultant current for any time T. The equations for the north and east component velocities of the constituent may then be written—

$$V_n=H_n \cos (T-K_n) \quad \text{for north component} \tag{1}$$

$$V_e=H_e \cos (T-K_e) \quad \text{for east component} \tag{2}$$

Replacing the symbols for the harmonic constants by their actual values and substituting successive values for T we obtain the corresponding values for the component velocities. Plotting the north component velocities as ordinates with the corresponding east component velocities as abscissas, a series of points will be obtained which when connected will form the current constituent ellipse.

*As a matter of convenience in the formulas that follow, the capital letter (K) is adopted as a symbol for local constituent epochs in place of the Greek letter kappa (κ) which is generally used for this purpose.

180. For obtaining the times or values of T corresponding to the maximum and minimum velocities of the current constituent formulas may be derived as follows. Referring to formulas (1) and (2) for the component velocities, the square of the resultant velocity V for any T may be expressed by the formula

$$V^2=V_n^2+V_e^2=H_n^2 \cos^2 (T-K_n)+H_e^2 \cos^2 (T-K_e) \quad (3)$$

Considering the resultant velocity as positive regardless of direction, its maximum and minimum values will be attained under the same conditions that will render V^2 a maximum or minimum. For the first derivative of V^2 with respect to T we have

$$\begin{aligned} d(V^2)/dT &= -2H_n^2 \cos (T-K_n) \sin (T-K_n) \\ &\quad -2H_e^2 \cos (T-K_e) \sin (T-K_e) \\ &= -H_n^2 \sin 2(T-K_n)-H_e^2 \sin 2(T-K_e) \\ &= -(H_n^2 \cos 2K_n+H_e^2 \cos 2K_e) \sin 2T \\ &\quad +(H_n^2 \sin 2K_n+H_e^2 \sin 2K_e) \cos 2T \quad (4) \end{aligned}$$

Equating the above derivative to zero for maximum and minimum velocities, we have

$$\text{Tan } 2T=\frac{H_n^2 \sin 2K_n+H_e^2 \sin 2K_e}{H_n^2 \cos 2K_n+H_e^2 \cos 2K_e} \quad (5)$$

From tan $2T$ determined by the above formula, four values for T differing from each other by 90° are possible, two of these values being for maximum velocities and the other two for minimum velocities. Two of the values, one for a maximum and the other for a minimum velocity, are obtained when $2T$ is taken less than 360° and the other two when $2T$ is taken between 360° and 720°.

181. The distinction between the values of T corresponding to the maximum and minimum velocities may be later determined when the corresponding velocities have been actually computed, or may be made immediately by reference to the second derivative of V^2 with respect to T. From the first derivative (4) we obtain

$$\begin{aligned} d^2(V^2)/(dT)^2 = &-2(H_n^2 \cos 2K_n+H_e^2 \cos 2K_e) \cos 2T \\ &-2(H_n^2 \sin 2K_n+H_e^2 \sin 2K_e) \sin 2T \quad (6) \end{aligned}$$

Values of T which render the above derivative negative will correspond to the maximum velocities and those which render it positive to the minimum velocities. From (6) it is obvious that if the coefficients of cos $2T$ and sin $2T$ each have the same sign as the function itself, the second derivative will be negative, but if each coefficient has the opposite sign the derivative will be positive. As these coefficients are the same as the terms in the fractional expression for tan $2T$ in formula (5), it follows that for a maximum velocity the signs of the sine and cosine of the angle will be the same respectively as the signs of the numerator and denominator of the fraction represented and for a minimum velocity both signs will be reversed.

182. Formula (5) may be solved graphically as follows: From any point A (fig. 32) draw line AB to represent in length and direction H_n^2 and $2K_n$ respectively; from point B draw BC to represent in length and direction H_e^2 and $2K_e$ respectively. The connecting line from A to C will indicate by its direction the value of $2T$ corresponding to a maximum velocity. The reverse direction from C to A will indicate the value of $2T$ corresponding to a minimum velocity.

183. A formula for the computation of the values of T corresponding to maximum and minimum velocities which is expressed in terms of the ratio of the amplitudes and the difference between the epochs of the north and east components of the current

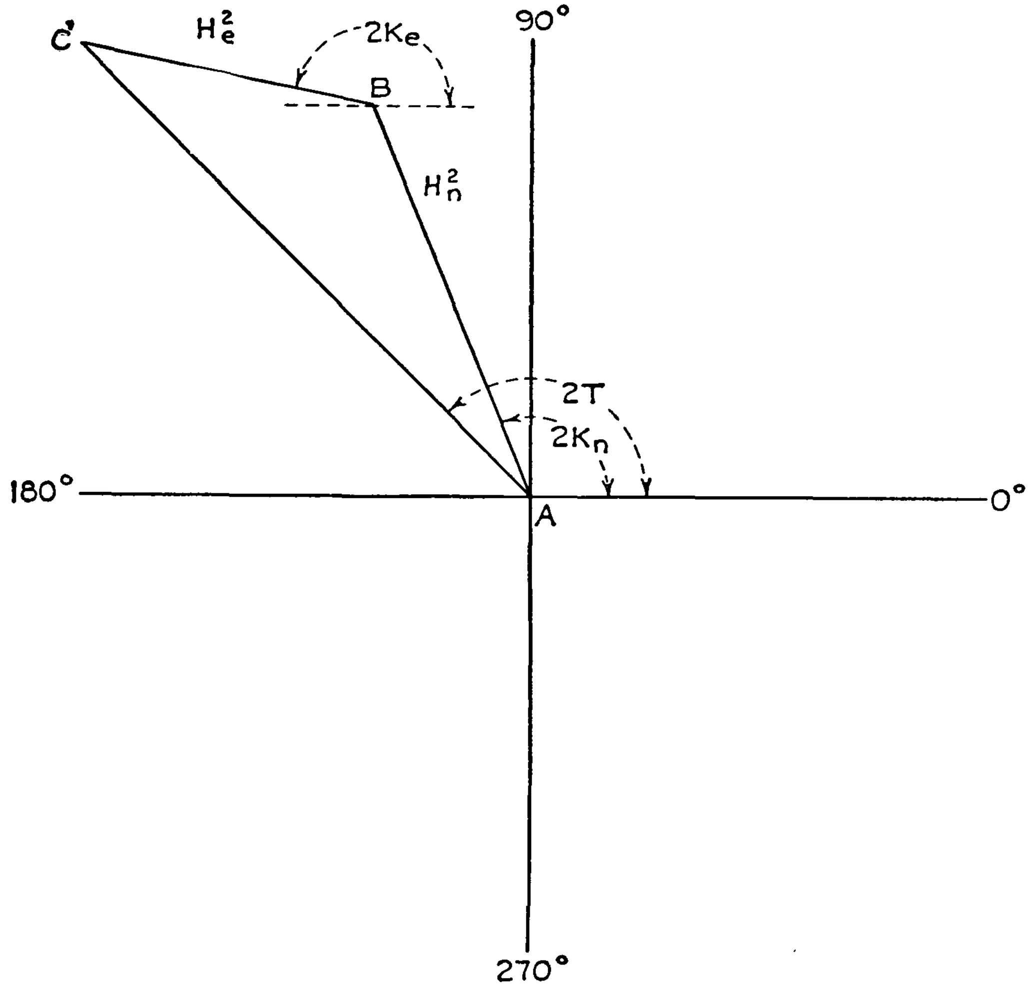

FIGURE 32.—Graphic solution of formula (5).

constituent is especially useful in the preparation of a table for obtaining such values. This formula also may be deduced from the derivative formula (4) after equating the same to zero.

Let R=the ratio H_e/H_n and D=difference K_e-K_n

Then for (4) we have

$$\begin{aligned}&\sin 2(T-K_n)+H_e^2/H_n^2 \sin 2(T-K_n-K_e+K_n)\\&=\sin 2(T-K_n)+R^2 \sin 2(T-K_n-D)\\&=\sin 2(T-K_n)+R^2 \cos 2D \sin 2(T-K_n)-R^2 \sin 2D \cos 2(T-K_n)\\&=(1+R^2 \cos 2D) \sin 2(T-K_n)-R^2 \sin 2D \cos 2(T-K_n)=0 \quad \text{(7)}\end{aligned}$$

$$\tan 2(T-K_n)=\frac{R^2 \sin 2D}{1+R^2 \cos 2D} \quad \text{(8)}$$

For a maximum velocity the quadrant for the angle $2(T-K_n)$ will be determined by the signs of the numerator and denominator of the above fraction, which will be the same respectively as for the sine and cosine of the angle. For a minimum velocity the signs will be reversed.

878447°—50——6

184. By substituting values of T corresponding to maximum and minimum velocities in formulas (1) and (2) the corresponding component velocities V_n and V_e may be obtained. The azimuths and velocities of the resultant current may then be readily obtained by means of the following formulas:

$$\text{Tan } A = V_e/V_n \qquad (9)$$

$$V = (V_n^2 + V_e^2)^{1/2} \qquad (10)$$

185. The two maximum velocities will be of the same strength but in opposite directions and the two minimum velocities will also be equal and opposite. After the azimuth of one of the maximum velocities has been calculated, the other may be taken as 180° different, and the azimuths of the minimum velocities will differ from the maximum velocities by 90°. When the maximum and minimum velocities are plotted they form the major and minor axes of the current constituent ellipse. The eccentricity of the ellipse depends not only upon the velocity ratio of the component amplitudes (H_e/H_n) but also upon the epoch difference $(K_e - K_n)$. When this difference is 0° or 180° the minimum current becomes zero regardless of the velocity ratio, and the ellipse becomes a straight line indicating a reversing current. For any given velocity ratio, the eccentricity of the ellipse becomes a minimum when the epoch difference equals 90° or 270°, in which case the axes of the ellipse extend north-and-south and east-and-west. With

TABLE 8.—*Time and direction of rotary current constituent at maximum velocity*

D		R											D	
		0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0		
°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
0	180	0.0 0.0	0.0 5.7	0.0 11.3	0.0 16.7	0.0 21.8	0.0 26.6	0.0 31.0	0.0 35.0	0.0 38.7	0.0 42.0	0.0 45.0	180	360
10	170	0.0 0.0	0.1 5.6	0.4 11.2	0.8 16.5	1.4 21.6	2.0 26.4	2.6 30.8	3.3 34.8	3.9 38.6	4.5 41.9	5.0 45.0	190	350
20	160	0.0 0.0	0.2 5.4	0.7 10.7	1.5 15.9	2.6 20.9	3.8 25.7	5.1 30.2	6.4 34.4	7.7 38.3	8.9 41.8	10.0 45.0	200	340
30	150	0.0 0.0	0.2 5.0	1.0 9.9	2.1 14.9	3.7 19.8	5.4 24.6	7.4 29.2	9.4 33.6	11.4 37.7	13.3 41.5	15.0 45.0	210	330
40	140	0.0 0.0	0.3 4.4	1.1 8.9	2.5 13.4	4.4 18.1	6.6 22.8	9.2 27.6	12.0 32.3	14.8 36.8	17.5 41.1	20.0 45.0	220	320
50	130	0.0 0.0	0.3 3.7	1.1 7.5	2.6 11.5	4.6 15.7	7.2 20.3	10.4 25.2	13.9 30.2	17.7 35.4	21.4 40.3	25.0 45.0	230	310
60	120	0.0 0.0	0.2 2.9	1.0 5.9	2.3 9.1	4.3 12.7	6.9 16.8	10.4 21.6	14.7 27.0	19.6 32.9	24.8 39.0	30.0 45.0	240	300
70	110	0.0 0.0	0.2 2.0	0.8 4.1	1.8 6.4	3.3 9.0	5.6 12.3	8.9 16.3	13.4 21.6	19.5 28.3	27.0 36.4	35.0 45.0	250	290
80	100	0.0 0.0	0.1 1.0	0.4 2.1	1.0 3.3	1.8 4.7	3.2 6.5	5.3 9.0	8.6 12.7	14.4 18.8	24.6 29.4	40.0 45.0	260	280
90	90	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	------ ------	270	270

Upper values for each double line refer to times of maximum velocities and are positive when D is in the 1st or 3d quadrants, negative when D is in the 2d or 4th quadrants.
Lower values refer to corresponding azimuths of the current and are positive when D is in the 1st or 4th quadrants and negative when D is in the 2d or 3d quadrants.
For further explanations see paragraph 186.

a velocity ratio of unity and an epoch difference of 90° or 270°, the ellipse becomes a circle, indicating that the current constituent flows with a uniform velocity throughout its entire cycle as its direction swings around the circle. The direction of rotation of the constituent current may be determined from the epochs of the north and east components, K_n and K_e respectively, by the following rule:

When the difference between K_n and K_e is less than 180°:

If K_n is less than K_e the rotation is clockwise.

If K_n is greater than K_e the rotation is counterclockwise.

When the difference between K_n and K_e is greater than 180°, the above directions of rotation are reversed.

186. Table 8 for the time and direction of current constituent at maximum velocity and Table 9 for maximum and minimum velocities are based upon formulas (8), (9), and (10). Assuming that R is the ratio H_e/H_n and D the difference $(K_e - K_n)$, the tabular values in Table 8 give directly, with due regard to proper sign as indicated in footnote, the time of occurrence of one of the two maximum velocities of the current cycle, expressed by the angle $(T - K_n)$, and the corresponding azimuth of the current as reckoned clockwise from the north. If this direction is taken as corresponding to a flood current, the value obtained for T will be the epoch (kappa) of the constituent as referred to the major axis of the ellipse. When R is unity and D is equal to 90° or 270°, T is indeterminable since in this case the constituent ellipse becomes a circle, the velocity of the current being uniform without any maxima or minima. The table provides

TABLE 9.—*Maximum and minimum velocities of rotary current constituent*

D		R											D	
		0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0		
°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
0	180	1.000	1.005	1.020	1.044	1.077	1.118	1.166	1.221	1.281	1.345	1.414	180	360
		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
10	170	1.000	1.005	1.019	1.043	1.075	1.115	1.163	1.217	1.276	1.340	1.409	190	350
		0.000	0.017	0.034	0.050	0.065	0.078	0.090	0.100	0.109	0.117	0.123		
20	160	1.000	1.004	1.018	1.039	1.069	1.107	1.152	1.204	1.262	1.325	1.393	200	340
		0.000	0.034	0.067	0.099	0.128	0.154	0.178	0.199	0.217	0.232	0.246		
30	150	1.000	1.004	1.015	1.034	1.060	1.094	1.136	1.184	1.240	1.300	1.366	210	330
		0.000	0.050	0.099	0.145	0.189	0.228	0.264	0.296	0.322	0.346	0.366		
40	140	1.000	1.003	1.012	1.027	1.049	1.078	1.114	1.157	1.208	1.265	1.329	220	320
		0.000	0.064	0.127	0.188	0.245	0.298	0.346	0.389	0.426	0.457	0.484		
50	130	1.000	1.002	1.008	1.019	1.036	1.058	1.087	1.123	1.168	1.221	1.282	230	310
		0.000	0.076	0.152	0.225	0.296	0.362	0.423	0.477	0.525	0.565	0.598		
60	120	1.000	1.001	1.005	1.012	1.022	1.037	1.058	1.085	1.122	1.168	1.225	240	300
		0.000	0.086	0.172	0.257	0.339	0.418	0.491	0.559	0.618	0.667	0.707		
70	110	1.000	1.001	1.002	1.006	1.011	1.018	1.030	1.046	1.071	1.108	1.158	250	290
		0.000	0.094	0.187	0.280	0.372	0.461	0.548	0.629	0.702	0.763	0.811		
80	100	1.000	1.000	1.001	1.001	1.003	1.005	1.008	1.014	1.023	1.043	1.083	260	280
		0.000	0.098	0.197	0.295	0.393	0.490	0.586	0.680	0.770	0.850	0.909		
90	90	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	270	270
		0.000	0.100	0.200	0.300	0.400	0.500	0.600	0.700	0.800	0.900	1.000		

Upper values for each double line refer to maximum velocities and lower values to minimum velocities. All values are positive. For further explanation see paragraph 186.

directly for values of R which do not exceed unity. If H_e is greater than H_n, substitute the reciprocal of R for the upper argument of the table and interchange the values of K_e and K_n in obtaining the difference for argument D. The tabular values for time will then be expressed in terms of the east component phase $(T-K_e)$. The corresponding tabular values for direction are reckoned counter-clockwise from the east and must be subtracted from 90° in order to obtain the correct azimuth as reckoned from the north. In Table 9 the reciprocal of R may be substituted for R when H_e is greater than H_n. All tabular values in this table are positive and express the ratios of the maximum and minimum resultant velocities to the larger one of the two component amplitudes.

187. **Reference of harmonic constants to any axis.**—In a locality where the current, although rotary, has a predominating movement along a particular axis, it may be desirable to refer the harmonic constants to that axis in order that they may be used for prediction purposes. Such an axis would in general be the major axis of the current ellipse for the M_2 constituent, the direction of which may be determined by the method described in the preceding paragraphs. Assuming that the harmonic constants for the north and east components of the several constituents are available they may be referred to any axis desired by means of the formulas derived in accordance with the following explanation.

188. Use the same symbols as before to represent the north and east component velocities of any constituent, and let H_a, K_a, and V_a represent respectively the amplitude, epoch, and velocity of the constituent along an axis with azimuth A. Then resolving the north and east components, as represented by formulas (1) and (2), along this axis and taking the sum, we have

$$\begin{aligned} V_a &= H_n \cos (T-K_n) \cos A + H_e \cos (T-K_e) \sin A \\ &= (H_n \cos A \cos K_n + H_e \sin A \cos K_e) \cos T \\ &\quad + (H_n \cos A \sin K_n + H_e \sin A \sin K_e) \sin T \\ &= H_a \cos (T-K_a) \qquad (11) \end{aligned}$$

in which

$$H_a = [H_n^2 \cos^2 A + H_e^2 \sin^2 A + 2H_nH_e \cos A \sin A \cos (K_e-K_n)]^{1/2} \qquad (12)$$

$$K_a = \tan^{-1} \frac{H_n \cos A \sin K_n + H_e \sin A \sin K_e}{H_n \cos A \cos K_n + H_e \sin A \cos K_e} \qquad (13)$$

The quadrant for K_a is determined by the signs of the numerator and denominator of the above fraction, these being the same respectively as for the sine and cosine of the angle.

189. By means of formulas (12) and (13) the amplitude and epoch for each constituent as referred to the new axis may be computed. The formulas may be solved graphically (fig. 33) by drawing from a point C a line CD to represent in length and direction $(H_n \cos A)$ and (K_n), respectively; from the point D a line DE to represent in length and direction $(H_e \sin A)$ and (K_e), respectively. Then the connecting line from C to E will represent by its length and direction the amplitude (H_a) and the epoch (K_a), respectively.

190. **Hydraulic Current.**—The term "hydraulic current" is applied to a current in a strait that is caused by a difference in the head of water at the two entrances. When this difference in head results from tidal action that causes the water at one end to be alternately higher and lower than at the other end, the movement is periodic and may be treated as a reversing type of tidal current. The currents through the East River which connects New York Harbor with Long Island Sound afford an example of hydraulic currents. When there is tidal action at each entrance to a strait, difference in

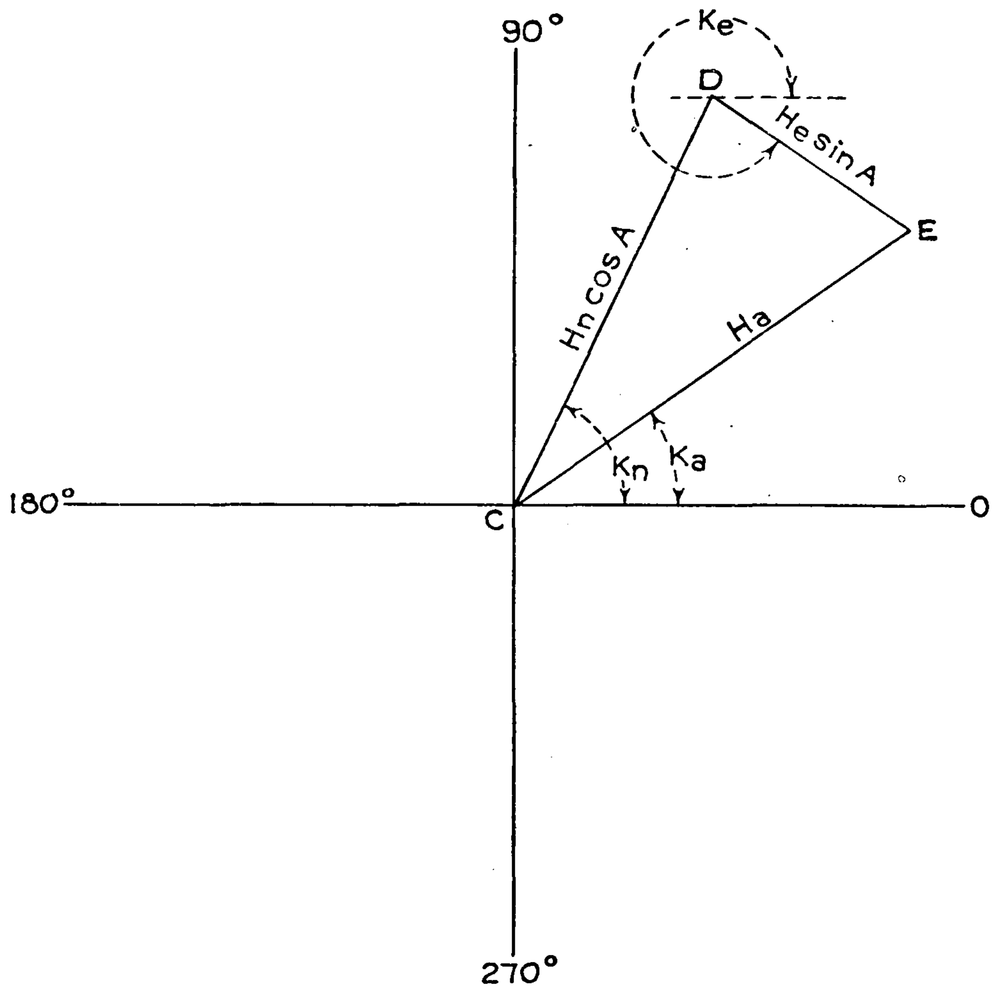

FIGURE 33.—Graphic solution of formulas (12) and (13).

head will result partly from any difference in the range of tide and partly from any difference in the times of the high and low waters. Theoretically, the current velocity will vary as the square root of the difference in head, will be a maximum when this difference is greatest, and will be zero or slack water when the difference is zero. Actually, because of inertia and friction, there will usually be a lag of some minutes in the response of the currents to this difference in head.

191. Predictions of hydraulic currents in a strait, based upon the difference in the tidal head at the two entrances, may be made by means of harmonic constants derived from the tidal constants for the entrances, allowance being made for lag and the fact that the current velocity varies as the square root of the difference in head. Let the two ends of the strait be designated by A and B, with the flow from A toward B considered as flood or positive and the flow in the opposite direction as ebb or negative. With the waterway receiving the tide from two sources, the application of the terms "flood" and "ebb" must be somewhat arbitrary, and care should be taken to clearly indicate the direction assumed for the flood movement.

192. In the following discussion tidal constants pertaining to entrances A and B will be distinguished by subscripts a and b, respectively, and those pertaining to the

difference in head by the subscript d. Since the usual constituent epochs known as "kappas" refer to the local meridian, it will be necessary for the purpose of comparison between places on different meridians to use the Greenwich epochs, which will be designated by the capital letter "G". These should be distinguished from the epochs designated by the British Admiralty by the small letter "g", which involve the time meridian and correspond to the modified kappas (κ') of this office. The relation existing between these epochs may be expressed by the following formula:

$$G=g+aS/15=K+pL \qquad (14)$$

in which L and S are, respectively, local longitude and the time meridian of the place (positive for west and negative for east), and a and p represent, respectively, the speed and subscript of the constituent.

193. For any one constituent let T represent time as expressed in degrees of the constituent reckoned from the phase zero of its Greenwich equilibrium argument. Also let Y_a and Y_b represent the height of the constituent tide for any time T as referred to the mean level at locations A and B, respectively; and let Y_d equal the difference (Y_a-Y_b). Formulas for heights and difference may now be written

$$Y_a=H_a \cos (T-G_a) \text{ for location "}A\text{"} \qquad (15)$$

$$Y_b=H_b \cos (T-G_b) \text{ for location "}B\text{"} \qquad (16)$$

$$\begin{aligned} Y_d &= H_a \cos (T-G_a)-H_b \cos (T-G_b) \\ &= (H_a \cos G_a-H_b \cos G_b) \cos T+(H_a \sin G_a-H_b \sin G_b) \sin T \\ &= H_d \cos (T-G_d) \end{aligned} \qquad (17)$$

in which

$$H_d=[H_a^2+H_b^2-2H_aH_b \cos (G_b-G_a)]^{1/2} \qquad (18)$$

$$G_d=\tan^{-1}\frac{H_a \sin G_a-H_b \sin G_b}{H_a \cos G_a-H_b \cos G_b} \qquad (19)$$

The proper quadrant for G_d is determined by the signs of the numerator and denominator of the above fraction, these being the same, respectively, as for the sine and cosine of the angle. Formulas (18) and (19) may be solved graphically (fig. 34) by drawing from any point C a line CD to represent in length and direction H_a and G_a, respectively; from the point D a line DE to represent in length and direction H_b and $(G_b \pm 180°)$, respectively. The connecting line from C to E will represent by its length the amplitude H_d and by its direction the epoch G_d.

194. By the formulas given above separate computations are made for each of the tidal constituents. The values obtained for H_d and G_d are the corresponding amplitudes and Greenwich epochs in an harmonic expression for the continually changing difference in elevation of the water surface at the two entrances to the strait. When only a single time zone is involved, the small g's or modified kappas (κ') pertaining to that zone may be substituted for the Greenwich epochs (G) in the formulas. For the prediction of the current further modifications are necessary in the amplitudes to reduce to velocity units and in the epochs to allow for the lag in the response of the current to the changing difference in water level at the two entrances to the strait.

195. Since the velocity of an hydraulic current is theoretically proportional to the square root of the difference in head, we may write

$$(\text{Velocity})^2=\text{constant } (C)\times\text{height difference} \qquad (20)$$

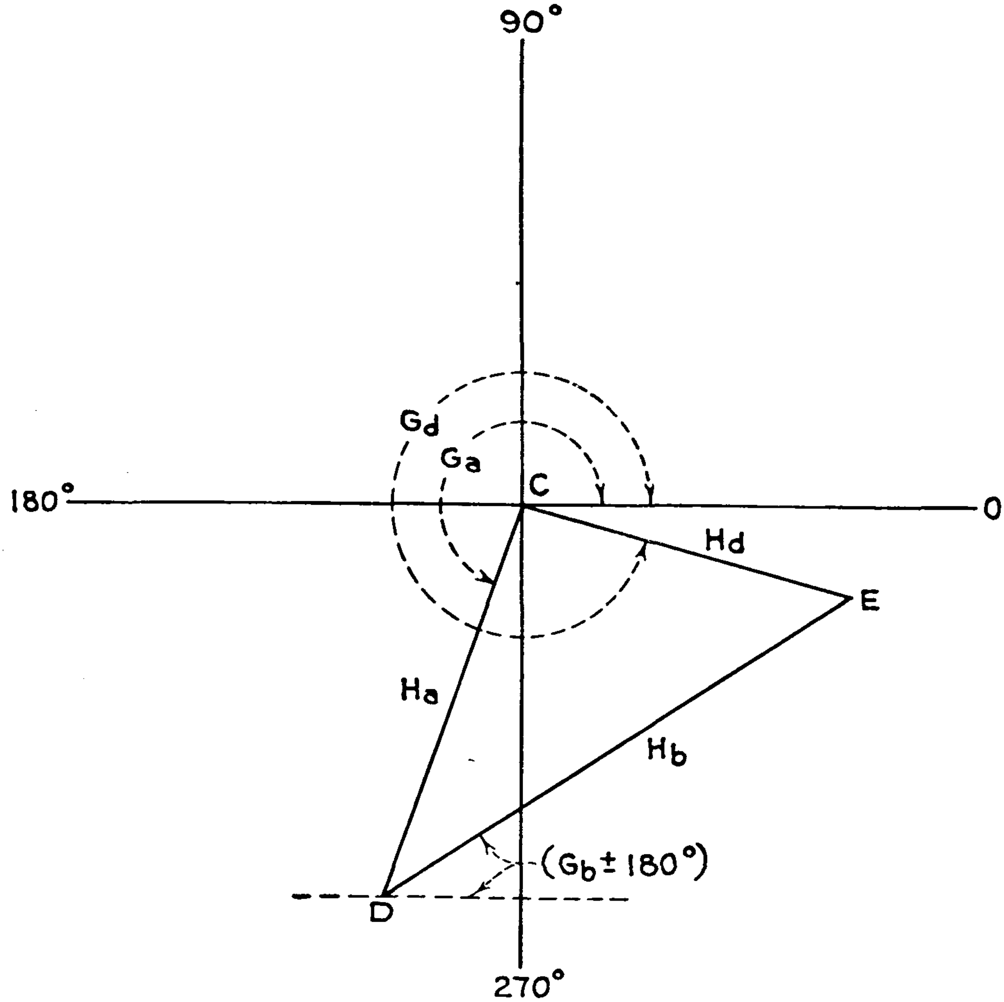

FIGURE 34.—Graphic solution of formulas (18) and (19).

If we now let V equal the average velocity of the current at time of strength as determined from actual observations and assume that the corresponding difference in water level is 1.02 times the difference resulting from the principal constituent M_2, we may obtain an approximate value for the constant (C) by the formula

$$C = V^2/(1.02M_2) \qquad (21)$$

in which M_2 is the amplitude of the constituent M_2 in the harmonic expression for the difference in head. The application of the factor (C) to all the constituent amplitudes in this expression has the effect of changing the height units into units representing the square of the velocity of the resulting current.

196. The lag in the current is usually determined by a comparison of the times of strengths and slacks from actual observations with preliminary predictions of the corresponding phases based upon the harmonic constants derived by the method just described. This lag expressed in hours is multiplied successively by the speed of each constituent and the result applied to the preliminary epoch for that constituent.

197. In order that the magnitude of the constituent amplitudes may be adapted for use with the predicting machine, a scale factor (S) is introduced. This factor, which depends upon the velocity of the current, is selected with the view of obtaining a reasonably large working scale without exceeding the limitations of the predicting machine. The following scale factors are suggested:

Average velocity of current at time of strength:	*Scale factor*
Less than 0.3 knot	20
From 0.3 to 0.5 knot	10
From 0.5 to 1.0 knot	5
From 1.0 to 1.5 knots	3
From 1.5 to 2.0 knots	2
From 2.0 to 3.0 knots	1
From 3.0 to 4.0 knots	0. 5
From 4.0 to 5.0 knots	0. 25
From 5.0 to 10.0 knots	0. 1

In practice, the scale factor is usually combined with the factor (C) and the product applied to each of the constituent amplitudes in the expression for difference in head.

198. Using the harmonic constants, modified in the manner described above, in the predicting machine, the resulting dial readings will represent the square of the current velocity. In order to avoid the necessity of extracting the square root of each individual reading, a square-root scale may be improvised and substituted for the regular height dial on the machine. From a consideration of the construction of this machine, it can be shown that with a scale factor of unity the angular position of a velocity graduation as measured in degrees from the zero point will be $9° \times (\text{velocity})^2$. Thus the 1 knot graduation will be spaced 9° from the zero, the 2 knot graduation at 36°, the 3 knot graduation at 81°, etc. For any scale factor (S), the formula for constructing the square-root scale becomes

$$\text{Angular distance from dial zero} = 9° \times S \times (\text{velocity})^2 \qquad (22)$$

199. To take account of any nontidal current not attributed to difference in head at the two entrances to the strait, a special graduation of the square-root scale is necessary. Let V_0 represent the nontidal current velocity, positive or negative according to whether it sets in the flood or ebb direction, and let V represent the resultant velocity as indicated by any scale graduation, positive or negative according to whether it is flood or ebb. The angular distance of any scale graduation as measured from an initial point, usually marked by an arrow, may then be expressed by the following formula:

$$\text{Angle in degrees} = 9 \times S \times (V - V_0)^2 \qquad (23)$$

The required angle is to be measured to the right or to the left of the initial point according to whether the angle ($V - V_0$) is positive or negative. When setting the predicting machine the velocity pointer must be at the initial point marked by the arrow when the sum of the harmonic terms is zero.

200. In the graphic representation of the summation of the harmonic terms by the predicting machine, the scale of the marigram depends upon the marigram gear ratio as well as upon any scale factor which may have been introduced. With a gear ratio of unity, the scale of the marigram is 0.1 inch per unit of machine setting. In the summation for the hydraulic currents, the marigram read by a natural scale

would indicate the square of the velocity. A special square-root reading scale for taking the velocities direct from the marigram may be prepared as follows:

Let Y=distance of any velocity graduation from zero of scale.

Then

Y (in inches)$=0.1\times$(scale factor)$\times$(gear ratio)$\times$(velocity)^2 -------------- (24)

With the scale factor and gear ratio each unity, 1 knot of velocity would be represented by 0.1 inch on the marigram, 2 knots by 0.4 inch, 3 knots by 0.9 inch, etc. With a scale thus constructed the velocity of the tidal current may be taken directly from the marigram. Any nontidal current which is to be included may afterwards be applied.

Wind Reduction

201. The term "wind current" is applied to a flow of water resulting from the action of the wind. Wind currents usually occur in combination with the periodic tidal current as well as with the more or less permanent nontidal current maintained by the general circulation of the oceanic water or by local conditions such as the fresh water discharge from a river. From theoretical considerations, currents produced by the wind in the open sea in the northern hemisphere will set to the right of the direction towards which the wind is blowing, and in the southern hemisphere to the left of this direction. The actual direction, however, may be largely affected by local conditions such as the underwater topography and the position of the shoreline.

202. For wind reductions long series of observations are necessary in order to average out the effects arising from other causes. Observations covering a year or more taken from lightships anchored well offshore have generally afforded the best available data for the purpose. Preliminary to the reduction the hourly velocities are resolved into north and east components in accordance with the instructions in paragraphs 160–161.

203. The hourly velocity components of the current are grouped according to the direction and velocity of the wind. Form 594a (fig. 35) is used for the purpose. The sixteen wind directions—north, north-northeast, northeast, etc.—are generally used. A separate sheet is provided for each wind direction, and in this sheet separate columns are used for different wind velocities according to certain specified limits. Observations taken when the wind is less than 5 miles per hour are usually excluded. The first group is taken to include all observations when the wind velocity is from 5 to 15 miles per hour with an assumed average velocity of 10 miles per hour. The second group includes wind velocities from 16 to 24 miles per hour inclusive with an assumed average velocity of 20 miles per hour. Similarly, provisions are made for higher average velocities in multiples of 10 miles per hour. For a series of observations covering a year, it will generally be necessary to use several pages of the form to include all observations pertaining to any single wind direction. In this case page sums are taken and brought together on a single summary sheet (fig. 36) upon which component means and corresponding resultant velocities and directions for the several groups are also obtained.

204. In Form 270a the wind directions often are on a different basis from that of the current directions used in determining the component velocities. For example, the wind directions may be compass readings and the current directions magnetic (compass readings corrected for deviation). In Form 594a the values for both wind

and current generally are used as they appear in Form 270a and the results derived on the page-summary sheets are modified when necessary to show the actual relations of current to wind. A procedure for accomplishing this modification and at the same time placing the results on a true-direction basis is outlined below.

205. Close approximations to the true directions and velocities of the currents resulting from winds blowing from the sixteen true directions—north, north-northeast, northeast, etc.—are obtained from the page-summary results as follows. All directions should be expressed in degrees when taking the steps indicated.

(*a*) Determine the true direction of wind corresponding to each of the sixteen wind directions used in the wind reduction.

(*b*) From each true wind direction desired (0° or 360°, 22½°, 45°, etc.) subtract each true wind direction (*a*) which is within 11¼ degrees of it.

(*c*) If only one difference (*b*) is reckoned from the true wind direction desired, apply this difference to the true direction of the resulting current for each wind velocity. In this case the velocities of the currents are taken directly from the page summary sheets.

(*d*) If two differences (*b*) are reckoned from the same true wind direction desired, average the two differences and apply the average difference to the average of the two corresponding current directions. Average also the two current velocities for each wind velocity.

(*e*) In case there is no true wind direction (*a*) within 11¼ degrees of the true wind direction desired, proceed as in (*d*) using the two nearest true wind directions (*a*).

206. Having determined the average velocity and true direction of the current for the several wind velocity groups for each true direction of wind, the wind velocity groups for each wind direction may be combined and average values obtained for the ratio of the current velocity to that of the wind and the amount by which the direction of the wind current deviates from that of the wind. The average current velocity and the ratio of current velocity to wind velocity for each wind velocity group for all the wind directions may also be obtained.

207. In the reduction for wind currents as described above the tidal current is presumably eliminated if the series of observations covers a sufficient length of time. The results, however, will include any permanent current constituting a part of the general circulation of the oceanic waters and also the effects of any permanent local condition. A separation of wind current and permanent current usually is not attempted, as the results of such a separation appear to have little practical value, particularly in view of the fact that the extent to which the permanent current itself is a wind current generally is uncertain. However, if desired, an approximate separation may be accomplished by the following procedure.

(*a*) Determine for each of the 16 wind directions the north and east velocity components of the average current obtained from all the wind velocity groups.

(*b*) Average the 16 north components and the 16 east components obtained in (*a*). These averages are the north and east components respectively of the permanent current.

(*c*) Subtract the components obtained in (*b*) from the corresponding components obtained in (*a*) for each wind direction. The resulting values are approximately the north and east components of the wind currents exclusive of permanent current.

DEPARTMENT OF COMMERCE
COAST AND GEODETIC SURVEY
Form 594 a

CURRENTS: WIND REDUCTION

Station *Chesapeake Lightship* Latitude *36° 58'.7 N.* Longitude *75° 42'.2 W.*

Wind direction (~~true~~/mag.) *North* Observations *Mar. 20, 1935 - Mar. 31, 1936* Velocity constant *3.0* knots.

146611

Wind velocity, *m.p.h.*	*5-15*			*16-24*			*25-35*			*36-44*			*5-15 (cont)*			*5-15 (cont)*			*5-15 (cont.)*		
Current,	Date	North	East	Date	North	East	Date	North	East	Date	North	East	Date	North	East	Date	North	East	Date	North	East
	1935			1935			1935			1935			1935			1935			1935		
1	Mar. 21	2.7	3.1	Apr. 4	2.6	2.6	Mar. 26	2.6	2.9	Oct 6	2.6	2.8	Apr. 22	3.1	3.1	June 5	2.7	2.9	Aug. 8	3.0	3.3
2	22	2.8	3.2		2.6	2.6		2.6	3.2		2.3	2.8		3.1	3.2		2.7	2.8		3.0	3.3
3		2.8	3.2	5	2.9	3.3		2.5	3.3		2.1	2.8		3.2	3.2		2.9	2.7		2.8	3.4
4		2.8	3.2		3.0	3.3		2.4	3.1		1.9	2.7	23	3.0	3.2	9	2.8	2.8		2.5	3.4
5	23	3.1	3.2	8	2.6	3.2		2.4	2.9		2.7	2.8		3.0	3.2		3.0	3.0		2.5	2.6
6	24	3.1	2.6		2.5	3.0		2.5	3.0		2.8	2.8		2.9	3.2	10	2.7	2.9		2.6	2.6
7	29	3.0	3.6	10	2.8	2.8		2.6	2.9		2.7	2.7		2.9	3.2		2.8	2.7	25	2.6	3.1
8		2.8	3.6	11	2.5	2.8	31	2.6	2.5		2.7	2.6		2.8	3.2		2.8	2.7		2.7	3.0
9		2.5	2.9		2.6	2.8		2.3	2.8		2.7	2.7		2.8	2.9	25	2.8	2.9		2.8	3.0
10		2.6	2.9		2.5	2.8		2.3	2.8		2.6	2.8	25	2.9	3.2		2.8	2.9		2.8	3.2
11		2.7	2.7		2.6	2.7		2.4	2.6		2.5	2.8		2.9	3.3	July 26	3.3	2.8		2.8	3.1
12	Apr. 4	2.9	2.8		2.5	2.7		2.2	2.9		2.5	3.0		2.8	3.1	21	2.7	2.8		2.9	3.1
13		2.8	3.0	16	2.5	3.1	Apr. 11	2.5	3.0		2.5	2.9		2.8	2.9	28	2.6	3.0		2.8	2.9
14	5	3.0	3.2		2.6	3.0		2.6	3.0		2.4	2.8		2.8	2.8		2.5	2.8		2.8	2.7
15		2.7	3.2	21	2.6	2.7		2.5	3.2		2.5	2.7		2.8	2.7	30	2.6	2.4		2.9	2.9
16		2.7	3.2		2.6	2.8		2.5	2.8	7	2.4	2.6		2.9	2.6		2.7	2.2	31	2.6	3.1
17		2.9	3.2	May 17	2.8	2.9		2.5	3.1				May 3	2.9	2.6		2.7	2.2		2.6	3.1
18	8	2.6	3.5	18	2.6	3.0	15	2.4	3.2				4	2.5	3.0		2.9	2.3		2.6	3.0
19		2.5	2.8	21	2.4	3.2		2.3	3.1				11	2.6	2.8		2.8	2.3		2.6	3.0
20		2.5	2.6	June 1	2.7	2.6		2.3	3.2				14	3.0	3.3		2.9	2.8		2.6	2.8
21		2.2	2.7		3.0	2.8	16	2.6	2.8				15	2.9	3.3		2.9	2.8		2.6	2.8
22		2.2	2.6		3.0	2.6		2.6	2.8				18	2.8	3.0		2.9	2.8		2.6	2.8
23	10	2.8	2.8		2.8	2.6	May 11	2.7	2.5					2.8	3.0		2.9	2.8		2.5	2.7
24	11	2.4	2.9	9	2.8	2.9	17	2.7	3.0					2.7	3.0	Aug. 4	2.6	2.9		2.5	2.7
25		2.5	3.0		2.9	2.8		2.7	3.0				June 1	2.8	3.5		2.7	2.7		2.6	2.7
26	12	2.8	3.0		3.0	3.0	June 1	3.0	2.7					2.7	3.3		3.0	3.1		2.4	2.8
27		2.7	3.0		2.9	2.9	July 21	2.8	2.6					2.5	3.0		3.0	3.1		2.5	2.8
28	21	3.0	3.0	July 27	2.6	3.0		2.8	2.4					2.4	3.0		2.9	3.1		2.6	3.0
29	22	3.0	3.0		2.5	2.9		3.0	2.4					2.4	3.0	5	2.8	3.0		2.6	2.9
30		3.1	3.1		3.0	2.4		3.0	2.4					2.6	2.5	8	3.0	3.3		2.9	3.2
Sums,		82.2	90.8		81.0	85.8		76.9	86.1		3.99	443		84.3	91.3		84.4	83.5		80.3	89.0
Divisors,		30	30		30	30		30	30		16	16		30	30		30	30		30	30
Means,																					

FIGURE 35.—Form 594a, Wind reduction.

DEPARTMENT OF COMMERCE
COAST AND GEODETIC SURVEY
Form 594 a

CURRENTS: WIND REDUCTION PAGE SUMMARY

Station Chesapeake Lightship Latitude 36° 58.'7 N Longitude 75°42.'2 W

Wind direction (~~true~~/mag.) North Observations Mar. 20, 1935 - Mar. 31, 1936 Velocity constant 3.0 knots.

U. S. GOVERNMENT PRINTING OFFICE 146811

Wind velocity, m.p.h.		5-15			16-24			25-35			36-44											
~~Current,~~		~~Date~~ No.	North	East	~~Date~~ No.	North	East	~~Date~~ No.	North	East	~~Date~~ No.	North	East	~~Date~~	North	East	~~Date~~	North	East	~~Date~~	North	East
Page 1	●	30	82.2	90.8	30	81.0	85.8	30	76.9	86.1	16	39.9	44.3									
"	~~2~~	30	84.3	91.3																		
"	~~3~~	30	84.4	83.5																		
"	~~4~~	30	80.3	89.0																		
2	~~5~~	30	84.4	88.6	30	77.7	85.1	30	79.0	81.2												
"	~~6~~	30	81.1	84.8	30	75.5	83.7	30	70.8	89.4												
"	~~7~~				30	78.8	89.2															
3	~~8~~	30	82.4	88.9	25	63.1	73.2	25	64.1	74.0												
"	~~9~~	30	81.4	87.1																		
"	~~10~~	30	81.6	85.3																		
4	~~11~~	27	73.0	78.4																		
Totals	~~12~~	297			145			115			16											
	~~13~~		815.1			376.1			290.8			39.9										
	~~14~~			867.7			417.0			330.7			44.3									
Means	~~15~~		2.74	2.92		2.59	2.88		2.53	2.88		2.49	2.77									
Resultant vel. and dir.	~~16~~		0.27 Kn.	197°		0.43 Kn.	196°		0.48 Kn.	194°		0.56 Kn.	204°									
	~~17~~																					

FIGURE 36.—Form 594a, Wind reduction (page summary).

Index